Zero-Carbon Investing

Opportunities from China's Carbon-Neutrality Goal

Feb 2021

AUTHORS & ACKNOWLEDGMENTS

Authors

RMI: Ji Chen, Shuyi Li, Ting Li, Ye (Agnes) Li, Jiayin Song, Yanjun Wu, Caroline Zhu

Investment Association of China: Yi Jiang, Yaowei Sun, Jie Zhang, Dongdong Zheng

**Author names in alphabetical order.*

Contacts

Ji Chen, **jchen@rmi.org**

Yanjun Wu, **ywu@rmi.org**

Suggested Citation

Ji Chen, Yi Jiang, Shuyi Li, Ting Li, Ye Li, Jiayin Song, Yaowei Sun, Yanjun Wu, Jie Zhang, Dongdong Zheng, Caroline Zhu, *Zero-Carbon Investing: Opportunities from China's Carbon-Neutrality Goal*, RMI and Investment Association of China, 2021

**All images from iStock unless otherwise noted.*

Acknowledgements

The authors warmly thank all the experts and representatives of companies, academia, and institutions who contributed time and expertise to this research through interviews and support.

Special thanks to the Angela Wright Bennett Foundation, Bloomberg Philanthropies, ClimateWorks Foundation, Quadrature Climate Foundation, Sequoia Climate Fund, and the William and Flora Hewlett Foundation for their support of this report.

**Organizations in alphabetical order.*

ABOUT US

RMI

RMI is an independent nonprofit founded in 1982 that transforms global energy systems through market-driven solutions to align with a 1.5°C future and secure a clean, prosperous, zero-carbon future for all. We work in the world's most critical geographies and engage businesses, policymakers, communities, and NGOs to identify and scale energy system interventions that will cut greenhouse gas emissions at least 50 percent by 2030. RMI has offices in Basalt and Boulder, Colorado; New York City; Oakland, California; Washington, D.C.; and Beijing, People's Republic of China.

The Investment Association of China, IAC (IAC)

The Investment Association of China (IAC) is a national social organization registered as a juridical association at the Ministry of Civil Affairs. It is an authoritative and comprehensive association in the field of investment and construction in China, governed by the National Development and Reform Commission. IAC consists of 16 investment committees with more than 1,000 large and medium-sized investment enterprises as members. This report was coproduced by the IAC's Energy Investment Committee, which is the lead committee of the Zero-Carbon China initiative launched by the IAC in collaboration with more than 50 domestic and foreign organizations in 2020, with the goal of achieving carbon neutrality in contribution to the country's energy transition and green development.

IN SUPPORT OF THE ZERO-CARBON INITIATIVE

"The '2030 carbon peaking' and '2060 carbon-neutrality' goals define the timetable and roadmap for China's green and low-carbon development, which will provide broad space for the development of new, low-carbon technologies, industries, and forms of business. It will create a large number of climate-friendly investment opportunities and support the sustainable development of financial and investment institutions."

– **Gao Li**, director, Department of Climate Change, Ministry of Ecology and Environment

"The implementation of the 'Zero-Carbon China' initiative should convene a group of enterprises who are committed to zero-carbon industry. The Association should identify and support such enterprises."

– **Dinghuan Shi**, former deputy secretary, Ministry of Science and Technology and former counselor of the State Council

"Strong policies and large investments will be needed to achieve the mid-century objective. The priority now is to ensure that actions in the 2020s, and in particular in the 14th Five-Year Plan, achieve rapid progress towards the twin goals."

– **Lord Adair Turner**, chair, Energy Transitions Commission

"Based on the 'carbon peaking' and 'carbon-neutrality' goals, the 'Zero-Carbon China' initiative should focus on representative pilot projects and promote low-carbon transition in energy, building, transport, and industry sectors."

– **Yaowei Sun**, president, the Energy Investment Professional Committee of the Investment Association of China

"The key to achieve carbon neutrality is to advance the energy transition. Energy transition requires not only consensus, but also joint actions."

– **Xingqiu Zeng**, former chief geologist, Sinochem Group

"The new national targets of carbon peaking and carbon neutrality are challenges, but also present opportunities to guide the direction of our national energy transition and investments."

— **Xiangwan Du**, academician and former vice president of the Chinese Academy of Engineering

"To achieve carbon neutrality, we need to start with pilots and gradually expand the scope. We need to gain experience and explore the standards and roadmaps."

– **Junfeng Li**, the first director of the National Center for Climate Change Strategy and International Cooperation

"We should move forward with the implementation to electrify as much as possible of the economy which requires cleaning up the power sector, dramatically increasing efficiency, and further reducing the emissions in the harder-to-abate sectors."

– **Jules Kortenhorst**, CEO, RMI

TABLE OF CONTENTS

FOREWORD

On September 22, 2020, President Xi Jinping announced at the 75th Session of the United Nations General Assembly that "China will enhance its NDC by adopting more powerful policies and measures and strive to achieve CO_2 emissions peaking by 2030, and carbon neutrality by 2060." Carbon neutrality means achieving net-zero carbon dioxide (CO_2) emissions by removing (often through carbon offsets) the same level of emissions that are emitted, or simply eliminating CO_2 emissions altogether. A more ambitious goal than carbon neutrality is to achieve zero carbon emissions, but a national goal of carbon neutrality would already imply that most players within the economic system achieve zero carbon.

Therefore, under the guidance of the Department of Climate Change of the Ministry of Ecology and Environmental Protection, the Investment Association of China (IAC) has taken the lead in launching the Zero-Carbon China Initiative. This initiative aims to explore the action pathway of green development for China to support carbon neutrality by 2060.

The announcement of China's carbon-neutrality target establishes a direction for realizing a zero-carbon China and will greatly support the drive toward ecological civilization and green, sustainable, and high-quality development. It will also be a strong driving force for revolution in the energy sector. In addition, the carbon-neutrality goal will activate the market and encourage more long-term value investors to focus on zero-carbon development and invest in zero-carbon assets, projects, and technologies.

This report is co-authored by the Energy Investment Committee of the Investment Association of China (IAC) and RMI. It identifies seven key investment areas for China's zero-carbon transition: resource recycling, energy efficiency, demand-side electrification, zero-carbon power generation, energy storage, hydrogen, and digitalization. It analyzes the trends and market sizes while envisioning a development pathway for these clean tech solutions. Additionally, policy and investment recommendations are provided for each area according to their development stages and roles in the zero-carbon economy.

1 A Zero-Carbon China in the Global Trend

A Zero-Carbon China in the Global Trend

Zero Carbon: From Global Politics to National Policies

The Paris Agreement reached in 2015 set the goal of limiting global warming to 2°C or even 1.5°C by the end of this century. It further proposed that global carbon emissions should peak as soon as possible, and the specific goal of net-zero carbon emissions should be achieved in the second half of this century.

Driven by the global target system set out in the Paris Agreement, all countries have continuously enhanced their actions on carbon emissions reduction, proposed and updated quantitative targets on emissions reduction and control, and strived to follow global long-term benchmarks. Zero-carbon emissions goals are becoming central themes for more and more countries as they organize their contributions to global climate efforts and carry out actions to address climate change.

Analysis by the World Resources Institute shows that, as of June 2020, 20 countries and regions including Austria, Bhutan, Costa Rica, Denmark, the European Union, Fiji, Finland, France, Hungary, Iceland, Japan, the Marshall Islands, New Zealand, Norway, Portugal, Singapore, Slovenia, Sweden, Switzerland, and the UK have legislated net-zero targets. Through the Climate Ambition Alliance, 120 countries, including all the least-developed countries and some high carbon emitters, have committed to working toward their net-zero goals. More countries' zero-carbon goals are already in the process of being drafted and decided upon.

Zero-Carbon Industries Are Reaching Tipping Points

Clean energy technology is reaching the tipping point for fully capturing the fossil energy market worldwide. Historical experience suggests that an industry will reach its tipping point and capital will begin to pull away from traditional firms when new disruptive technologies reach a market share of around 3%. Historically, horse-carriage demand peaked in the United States when car ownership reached 3% of the market, gas lighting demand peaked in the United Kingdom when electric lighting adoption reached 2% of the market, and fixed-line telephone usage began to decline sharply in the United States when wireless telephone market share exceeded 5%.

RMI presented in its *Seven Challenges for Energy Transformation* report how technology cost curves decline exponentially as production increases. Thanks to a combination of measures including technological innovation, learning effects, and scaled applications, the costs of solar, wind, and lithium-ion batteries have fallen by 90%, 60%, and 85% respectively in the past decade, according to Bloomberg New Energy Finance (BNEF).

A report by the International Energy Agency (IEA) shows that global sales of electric vehicles already accounted for 2.6% of total passenger vehicle sales in 2019 and are likely to exceed 3% in 2020.[1] In 2019, solar power accounted for 2.7% of the world's total power generation, while wind power already accounted for nearly 5% in 2018. Wind and solar power generated 14% and 11% respectively of the global power generation capacity added in 2018, and 22% and 45% of capacity added globally in 2019.[2]

There has always been a cyclical pattern in the oil industry that oil prices are subject to changes caused by economic cycles, international politics, military actions, and other factors. When oil prices fall, investment shrinks, reducing long-term supply, while demand rises, ultimately driving prices up. But this cycle may be slow and low oil prices can last for a long time, with studies showing such cycles range from 6 to 30 years.

However, the dramatic drop in global oil prices under the impact of the COVID-19 outbreak is likely to break the oil price cycle pattern and to overturn the market and industrial base of fossil energy completely. As a result of this pandemic, global oil consumption has fallen sharply this year, sending global oil prices to unprecedented low levels.

Some may argue that the drop in oil prices caused by COVID-19 may be short-lived. However from a long-term perspective, with the rise of new energy industries such as electric vehicles and renewable energy, and their increasing market shares, the trend of continuous decline in global oil consumption may be irreversible. Therefore, the deep drop in oil prices triggered by the epidemic is likely to completely break the industry cycle.

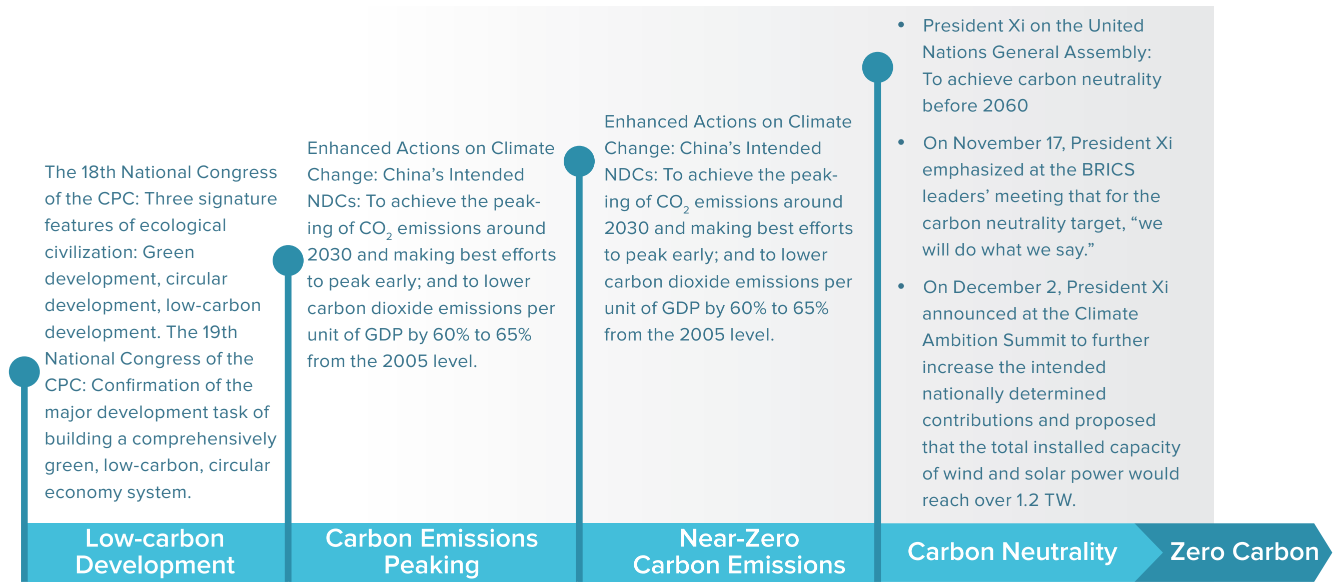
Zero Carbon: A New Direction for Long-Term Value Investment

Addressing climate change has become increasingly important to China over the past two decades. Low-carbon development was identified as one of the three major characteristics of ecological civilization in the 18th National Congress of the Chinese Communist Party. In the nationally determined contribution that was submitted through the Paris Agreement negotiation process, China has declared its aim to peak carbon emissions by around 2030.

Following on this, the Work Plan to Control Greenhouse Gas Emissions of the 13th Five-Year Plan included plans to implement near-zero carbon emissions demonstration projects. And finally, the carbon-neutrality goal was announced earlier in 2020. The Chinese government has gradually improved

Exhibit 1

China's Actions to Address Climate Change



the intensity of climate actions, accelerating China's economic and energy structure transformation toward zero carbon emissions.

The increasingly clearer trajectory of the zero-carbon strategy will help the market create a new field of opportunities for long-term value investment. The essence of long-term value investment is to look for certainties in a longer time span through uncertainties in shorter periods. By setting the policy target for the next 40 years, the 2060 carbon-neutrality goal of the Chinese government creates certainty around the zero-carbon transition for Chinese value investors and anchors new investment targets.

In fact, China's energy sector investment has already accelerated toward clean energy, with a sharp decline of investment in the coal industry since 2014. In recent years, the Chinese government has gradually divested non-coal companies of their coal assets through mergers and reorganizations. State Development & Investment Corp., Ltd. announced in 2019 that it had completely exited the coal businesses and would invest in new energy in the future. State-owned companies in the fields of power generation and oil and gas have also set up companies to grasp the opportunities in new energy industries.

2 Vision and Opportunities for a Zero-Carbon China

Vision and Opportunities for a Zero-Carbon China

A Zero-Carbon Vision under the Carbon-Neutrality Goal

Under the carbon-neutrality goal, China's zero-carbon energy transition means a major shift in energy supply and consumption patterns. Several think tanks, such as the Institute for Climate Change and Sustainable Development (ICCSD) of Tsinghua University; the Institute of Energy, Environment, and Economics of Tsinghua University; Wood Mackenzie; the Energy Transitions Commission (ETC); and RMI, have studied the path China could take to achieve carbon neutrality and zero emissions. The carbon-neutral or zero-carbon scenarios depicted in these studies show distinct features, including decoupling of energy consumption from economic development, continuous improvement of energy utilization efficiency, accelerated evolution of energy demand patterns, continuous optimization and upgrading of energy structure, and rapid iteration of low-carbon energy technologies.

Total energy demand will decline after peaking in the short term, and a higher quality of economic development can be supported by an energy system with lower total energy use and an optimized structure.

According to the zero-carbon scenario studied by the ETC and RMI,[3] China's total end-use energy consumption in 2050 will be around 2.2 billion tons of standard coal equivalent (tce), 27% lower than the 3 billion tce in 2016, with industrial sectors facing the biggest drop of 27%. Total primary energy demand will fall by 45% from 4.5 billion tce today to 2.5 billion tce in 2050. The primary energy mix will change dramatically, with the demand of fossil fuels falling by more than 90% and wind, solar, and biomass becoming the main sources of energy. In terms of the development path, the 1.5°C scenario of China's long-term low-carbon development transformation modeled by Tsinghua ICCSD shows that China's energy consumption will peak around 2025 and carbon emissions will peak before 2025. With the help of carbon capture and forestry carbon sink, net-zero carbon emissions will be generally achieved by 2050, with non-fossil energy accounting for more than 85% of the primary energy.

On the demand side, increased resource recycling, energy efficiency improvements, and the large-scale electrification and use of hydrogen in the building, transport, and industry sectors will reshape energy use and even the entire economy.

In the industry sector, significant improvements in the utilization and recovery rates of key materials and production efficiency have dramatically reduced the demand for energy. Also, technologies such as electrification, hydrogen, bioenergy, and carbon capture and storage would offer the possibility of decarbonizing raw materials and production processes for the heavy-industry sector.

For the steel industry, expanding scrap steel supply in the future could support secondary steel production taking 60% of total output. For the cement industry, improvements in building design and material quality can reduce overall cement demand by nearly 50% compared with the business-as-usual scenario. With the development of physical and chemical recycling technologies, 52% of the plastic demand in China can be met by recycled plastics.

In terms of decarbonization technologies, direct electrification is the most suitable solution for industries with low- and medium-temperature requirements, while hydrogen and bioenergy can be used to meet high-temperature requirements. Hydrogen can also be used as a reducing agent for steel and as a raw material for chemical production. Biomass energy could also be used as an alternative chemical feedstock. Carbon capture and storage will play a role in offsetting industrial process carbon emissions and the remaining fossil-fuel-related carbon emissions.

In the transportation sector, surface transport (road and rail) will be fully electrified. Biofuels, synfuels, hydrogen, or ammonia will drive decarbonization of long-haul aviation and shipping, while short-haul transport will use options such as batteries, hydrogen fuel cells, and hybrids. In light-road transport, electric vehicles (EVs) would soon overtake internal combustion engines economically, while hydrogen fuel cell electric vehicles (FCEVs) could play a significant role in heavy-road transport.

China's vast high-speed rail network and extensive subway systems will partly help control the growth of road traffic and domestic air traffic, and all rail travel could be electrified well before 2050. Because electric engines are inherently more efficient than internal combustion engines, the electrification of these surface transportation sectors will help reduce final energy demand. Alternatives such as biofuels and synfuels may cost more than existing fossil fuels, but technological advances and economies of scale could drive costs down significantly in the long run.

In the building sector, there is still much room for improvement in the level of services in China's buildings, and energy efficiency in the building sector will also increase significantly to ensure cost-effective use of energy. Advanced heat pump technology and insulation materials will be more widely used to provide zero-carbon heating and cooling for homes and offices. Due to the inherent energy efficiency advantages of heat pumps, electrifying heating using heat pumps can significantly reduce final energy demand. Industrial waste heat and biomass that can be transported over long distances will also have roles to play.

On the supply side, by 2050, China's electrification level will be significantly improved and renewables will become the main energy source for the power system. Hydrogen energy will be applied on a large scale, and biomass and carbon capture technology will also play important roles. At the same time, digitalization will greatly improve the overall efficiency of the energy supply and consumption at the system level.

To achieve a zero-carbon economy, China's total electricity generation needs to increase from the current 7,000 terawatt-hours (TWh) to about 15,000 TWh in 2050, 52% of which will be used by direct industrial electrification. By 2050, 70% of China's electricity generation will come from wind and solar sources, with installed capacity reaching 2,500 gigawatts (GW) for solar photovoltaics (PV), 2,400 GW for wind power, 230 GW for nuclear power, and 550 GW for hydropower. Under the scenario of high-share renewables, energy storage technology deployment will scale up. Investment in transmission infrastructure will increase, and measures including demand-side management will also contribute to the flexibility of the power system. As costs continue to fall, battery storage capacity will reach 510 GW by 2050.

Hydrogen, as a clean, efficient, and flexible energy carrier, will be applied on a large scale and play an important role in the decarbonization process of various sectors. Under the 2050 zero-carbon scenario, hydrogen demand would reach 81 million tons per year, more than triple the current level, and would account for 12% of final energy consumption. Hydrogen will be used mainly as an alternative feedstock and energy carrier in heavy industry, and via fuel cell applications in heavy-road transport, aviation, and shipping. With the significant decrease in future costs, hydrogen production from water electrolysis will be the main supply source of zero-carbon hydrogen (70%), and coal gasification and industrial by-products combined with carbon capture technology will also have a role to play as supplemental zero-carbon hydrogen sources.

The potential of bioenergy and carbon capture technology will be fully explored and will be mainly used in the decarbonization process of harder-to-abate industries. Achieving a zero-carbon economy by 2050 would require the production of about 440 million tce of bioenergy per year. Supplying this bioenergy in a sustainable way will be a major challenge. Given its limited bioenergy resource and uncertainty of supply, China would need to prioritize its use on those sectors where alternative decarbonization options are not available, such as aviation.

Exhibit 2

Snapshot of Zero-Carbon China Emissions Reductions

Carbon capture technology is also needed in some industrial processes to help achieve zero carbon in the remaining use of fossil energy. The zero-carbon scenario would still require 1 billion tons of carbon dioxide to be captured per year. The cost of carbon capture varies widely from industry to industry, and the total cost of carbon capture, transport, and storage is expected to average around US$55/ton of CO_2.

In the context of a zero-carbon China, green investments will be directed to wider applications.

Around the world, an increasing number of parties other than national governments have announced zero-carbon and carbon-neutral targets, which creates more and more specific applications for investment. More than 70 cities worldwide have pledged to become “carbon neutral” by 2050 and regions such as California have established ambitious goals to rely entirely on zero-emissions energy sources for their electricity by the year 2045.[4] Also, universities in the United States, the UK, and Canada are racing to set up zero-carbon emissions targets.

Further, more than 1,000 companies have already joined the Science Based Target Initiative, and many have made zero-carbon commitments. Some multinational corporations have expanded their zero-carbon targets to their global operations and the whole supply chain. Among them, Apple has announced the goal of achieving carbon neutrality across its entire business, manufacturing supply chain, and product life cycle by 2030. Additionally, Microsoft plans to become carbon negative by 2030 and AB InBev has committed to secure 100% of the company’s purchased electricity from renewable sources by 2025. An increasing number of provinces/states, cities, industrial parks, and companies stating zero-carbon transition targets would bring wide application cases and leverage significant market opportunities for investments in the future.

In China, driven by the national carbon-neutrality goal and industrial upgrading and high-quality development acceleration strategy, we can expect all localities to carry out energy transitions based on their resources, industries, and technology characteristics. Zero-carbon transport, building, and energy sectors would all be the pillar sectors for the transition. Also, zero-carbon factories, campuses, hospitals, villages, etc. would provide specific applications for green tech commercialization. In fact, since the introduction of near-zero-carbon zones during the 13th Five-Year Plan period, pilot projects have been carried out in Guangdong, Fujian, Zhejiang, Hubei, and many other provinces. Such work has shown that zero-carbon application cases would create a huge market for technologies and projects.

China's Zero-Carbon Transition Could Bring Enormous Market and Economic Value

The transformational trends in energy supply and consumption patterns in China's zero-carbon energy transition will create a huge market for investment. We believe that China's zero-carbon investment market will mainly focus on seven areas, namely: resource recycling, energy efficiency, end-use electrification, zero-carbon power, energy storage, hydrogen, and digitalization. The market size of these seven areas will reach nearly ¥15 trillion (US$2.32 trillion) by 2050.

On one hand, the irreplaceable market position of these seven areas is derived from their outstanding contribution to zero-carbon energy transformation. By 2050, these seven areas will contribute 80% of China's total emissions reduction. On the other hand, related technological advances have helped to drive down costs rapidly, making it inevitable that technologies and applications in these areas will dominate the market.

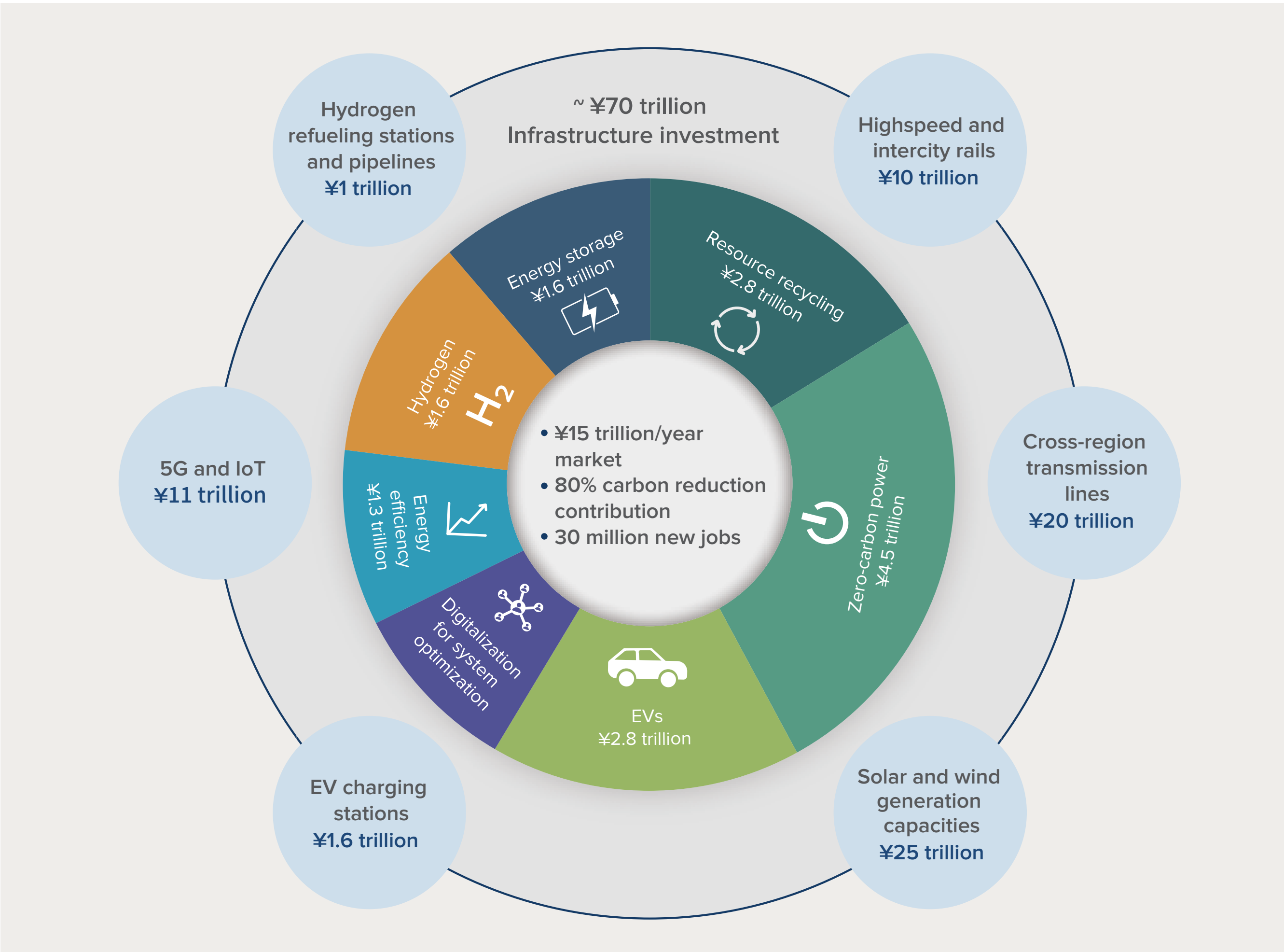
For example, from 2009 to 2018 the global levelized cost of electricity for solar PV has fallen by 81%, while wind and solar power in favorable locations have seen auction prices lower than US$20 per megawatt-hour. Since 2010, battery costs have fallen by an average of 20% per year, and by 2024, average energy storage costs will be below $100 per kilowatt-hour (kWh). Such dramatic cost downturns will make these focus areas ideal for investors. In addition, these seven areas are not independent but complementary, with applications in sectors including industry, transport, buildings, and energy. These applications are often mutually reinforcing, constituting the system solution for a zero-carbon China.

Meanwhile, from 2020 to 2050, there will be about ¥70 trillion (US$10.84 trillion) in infrastructure investment leveraged directly or indirectly. This includes significant PV and wind power capacity on the power generation side, continuously growing interregional transmission capacity, and tens of millions of 5G base stations, Internet-of-Things related infrastructure. Additionally, it will include the accelerated deployment of hydrogen refueling stations and EV charging stations and large-scale extension of the intercity railways. According to the Energy Research Institute of the National Development and Reform Commission, China will invest ¥100 trillion (US$15.5 trillion) in energy-related infrastructure construction alone in the next 30 years to achieve the carbon-neutrality goal.

China's zero-carbon energy transition will also bring major opportunities to develop new technologies and build competitive advantages. In terms of

Exhibit 3

The Seven Investment Areas of China's Zero-Carbon Transition Could Bring Enormous Market and Economic Value



technological development, China now has two of the world's top five wind turbine manufacturers and eight of the top ten solar panel manufacturers, and large-scale electrification will drive the continuous development of wind and solar PV technologies.

China is already in a strong position in manufacturing hydrogen electrolyzers and batteries, and will continue to lead the world as the costs continue to drop due to the economy of scale and learning curve effects.

In addition, China is the world's largest market for EVs, and electrification of the transportation sector will greatly promote technical innovation in batteries, charging facilities, and so on. While many countries are currently making efforts to target economic growth through climate mitigation, early deployment in the zero-carbon transition will win China advantages in the competition between nations.

China's zero-carbon economy will also create numerous new jobs. For example, the International Renewable Energy Agency (IRENA) estimates that the global renewable energy industry (including solar, wind, hydro, bioenergy, solar heating and cooling, heat pumps, geothermal, etc.) has created 11 million jobs in 2018. Four million of these were in China, accounting for 36% of the global total. That number is likely to rise to 24 million globally by 2030 and 29 million by 2050, with about 10 million jobs in China—far more than jobs created by the coal industry today.

RMI estimates that reaching the full potential of the circular economy could create nearly 9.6 million jobs by 2050. Hydrogen alone will account for 12% of China's final energy consumption in 2050, creating 5.9 million jobs. In addition, the EV battery industry, high-quality buildings with high thermal insulation and energy efficiency, and many other industries will create a lot of jobs.

3 Seven Investment Areas for China’s Zero-Carbon Transition

Seven Investment Areas for China's Zero-Carbon Transition

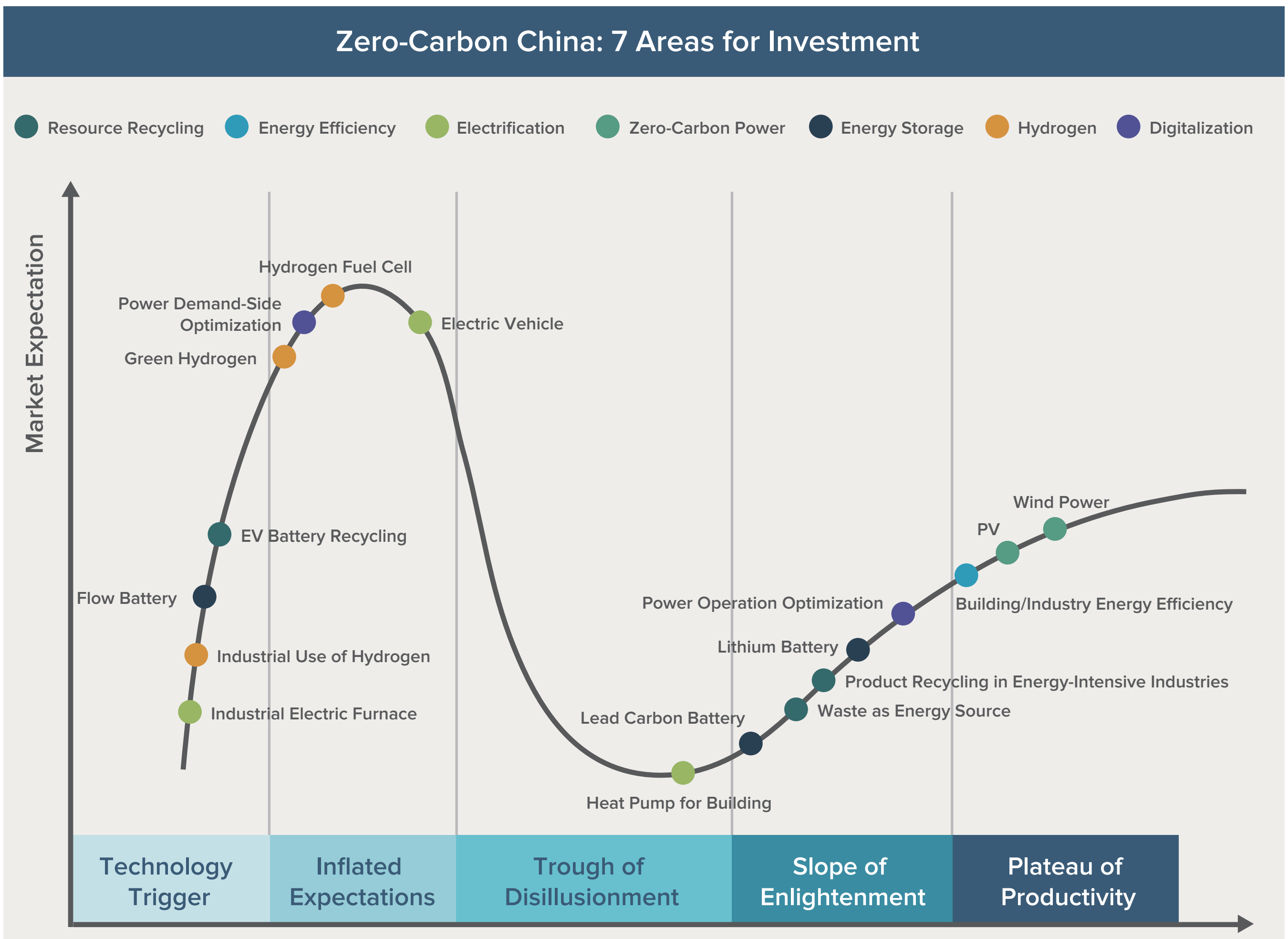
Technological innovation usually will go through five phases during its lifecycle of development toward market maturity: Technology Trigger, Inflated Expectation, Trough of Disillusionment, Slope of Enlightenment, and Plateau of Productivity. Through this lifecycle, core technological advantages are developed, applications are expanded, supporting services are established, and finally the innovation can be adopted by the mainstream.

Technology Trigger: Potential technical breakthrough is about to emerge, with initial proof-of-concept and prototype launched to gain industrial interest. In this stage, no complete product is available and commercial feasibility is yet to be proved.

Peak of Inflated Expectations: Early successful cases begin to emerge and attract high expectations. But failures often happen. Investment bubbles may arise.

Exhibit 4

Industry Development Stages of Seven Investment Areas for China's Zero-Carbon Transition



Trough of Disillusionment: Some technologies or companies may cause bubbles to burst due to insufficient market size, low product efficiency, and financial recovery that is not up to expectations. With the success of superior and elimination of inferior companies and products in this stage, investment will be inclined to find more stable and reliable companies, supporting them to create a new generation of products and penetrate into new markets.

Slope of Enlightenment: Based on early experiences, opportunities, and minefields for technology breakthroughs, applications and business models become clearer. It is also getting clear how those technological innovations bring value to businesses. More companies are investing, but conservative ones are still cautious.

Plateau of Productivity: The actual benefits of the technology have been proven and are recognized. Risk has been greatly reduced. Technology penetration increases rapidly, and more subsequent investments enter the market.

The development of innovative technologies includes two stages of rising market expectations, with different driving forces. The first upturn occurs during the transition from the technology trigger to the inflated expectations, with a positive market reaction from excitement about a new technology or innovation that opens up new opportunities. However, due to the low actual maturity of the technology at this stage, without a test of the market it is likely that the attention will fall back rapidly due to the failure of early projects and arrival of the Trough of Disillusionment phase. The second expectation rise is mainly driven by the increase of technology and innovation maturity, and the maturity of technology ensures the embodiment of actual value.

These zero-carbon technologies are currently at different phases in terms of market expectations and industrial maturity. They therefore face different challenges and opportunities, which require different policy and market enablers to become more bankable.

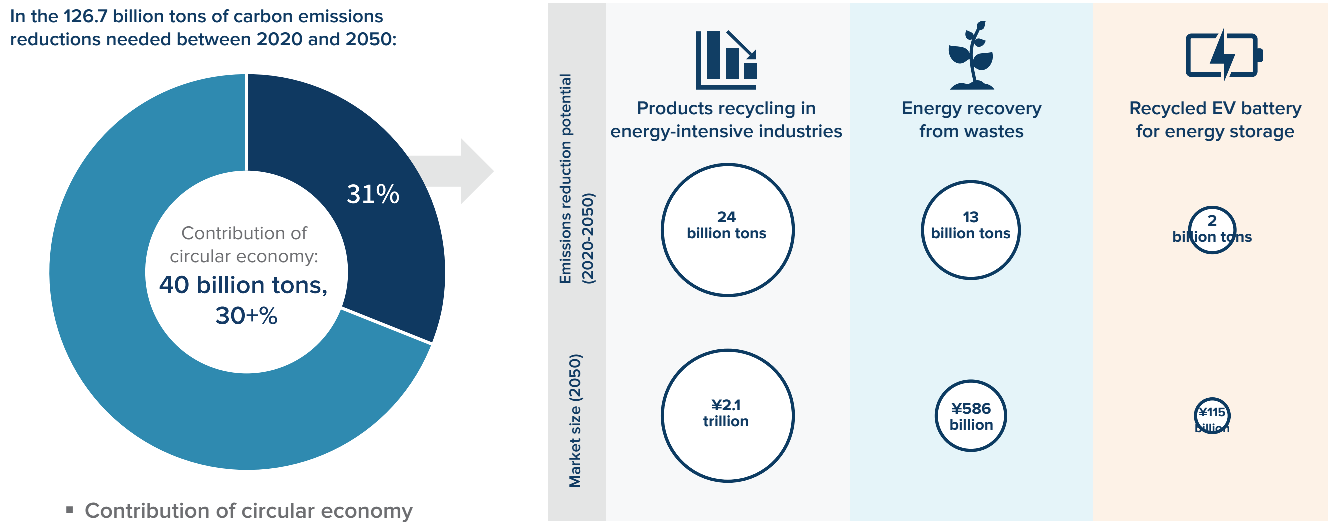
I. Resource Recycling: The Force for Demand Reduction

In China, resource recycling in three key areas will create a ¥2.8 trillion (US$430 billion) market by 2050 and achieve 40 billion tons of carbon emissions reduction between 2020 and 2050, meaning over 30% carbon reduction contribution for the zero-carbon transition.

Resource recycling covers a wide range of segments. Our study comprehensively assessed their contributions to the zero-carbon energy transition and market potentials and identified three key areas to focus on. These areas are **products recycling in energy-intensive industries (steel, cement,**

Exhibit 5

Carbon Emissions Reduction Contribution and Market Size of the Three Key Areas of Resource Recycling



* Under reference scenario (RTS), the trends of technology advances, economic development and population growth stays constant; zero-carbon scenario (ZCS) will generally achieve zero-carbon by 2050. Above emissions reductions refer to the emissions reduction of ZCS based on RTS level.

aluminum, and plastics), waste as an energy source (straw, forestry waste, domestic waste, and animal manure), and recycling of EV batteries for energy storage.

According to RMI's estimates, if China is to achieve zero carbon emissions by 2050, these three areas could achieve nearly 40 billion tons of carbon emissions reductions between 2020 and 2050. This would contribute more than 30% of the total emissions reductions. At the same time, by 2050, these three key areas will also create a huge market worth ¥2.8 trillion (US$430 billion). The three key areas and corresponding emissions reduction potentials and market sizes are shown in Exhibit 5.

One important area is product recycling in energy-intensive industries. **By 2050, the reduction in demand for products in steel, cement, aluminum, and plastic industries may reach the range of 16% to 53%, and the share of recycled products may reach 60% of total production.**

Steel, cement, aluminum, and plastics are important raw materials or primary products, and their industrial process energy consumption and carbon emissions are large. This makes them key areas in the zero-carbon energy transition. These industries also have considerable potential in the circular economy.

There are multiple potential approaches to doing this. The demand for raw materials or primary products can be reduced by (1) reducing waste in design and consumption stages to reduce the demand for raw materials per unit product and (2) reducing the quantity of products required for the provision of unit service through sharing economy business models and extended service life of the product. Additionally, carbon emissions per unit of raw materials or primary products can be reduced mainly by increasing the share of recycled materials produced to replace primary products.

In the 2050 zero-carbon scenario, the reduction in product demand in steel, cement, aluminum, and plastics industries will reach the range of 16% to 53%, with the potential of product recycling being fully unleashed. China's steel production, currently about 1 billion tons a year, is about to peak and begin to decline as the country's infrastructure boom winds down, falling to 475 million tons a year in the 2050 zero-carbon scenario.

At the same time, the share of short-process steel produced using scrap steel as raw material in total steel production will increase from 10% today to 60%, roughly the level of developed countries today. Accordingly, China's annual production of primary steel will fall to 190 million tons in 2050. The recycling potential of cement has yet to be realized, with concrete making up the vast majority of China's nearly 3 billion tons of annual construction and demolition waste.

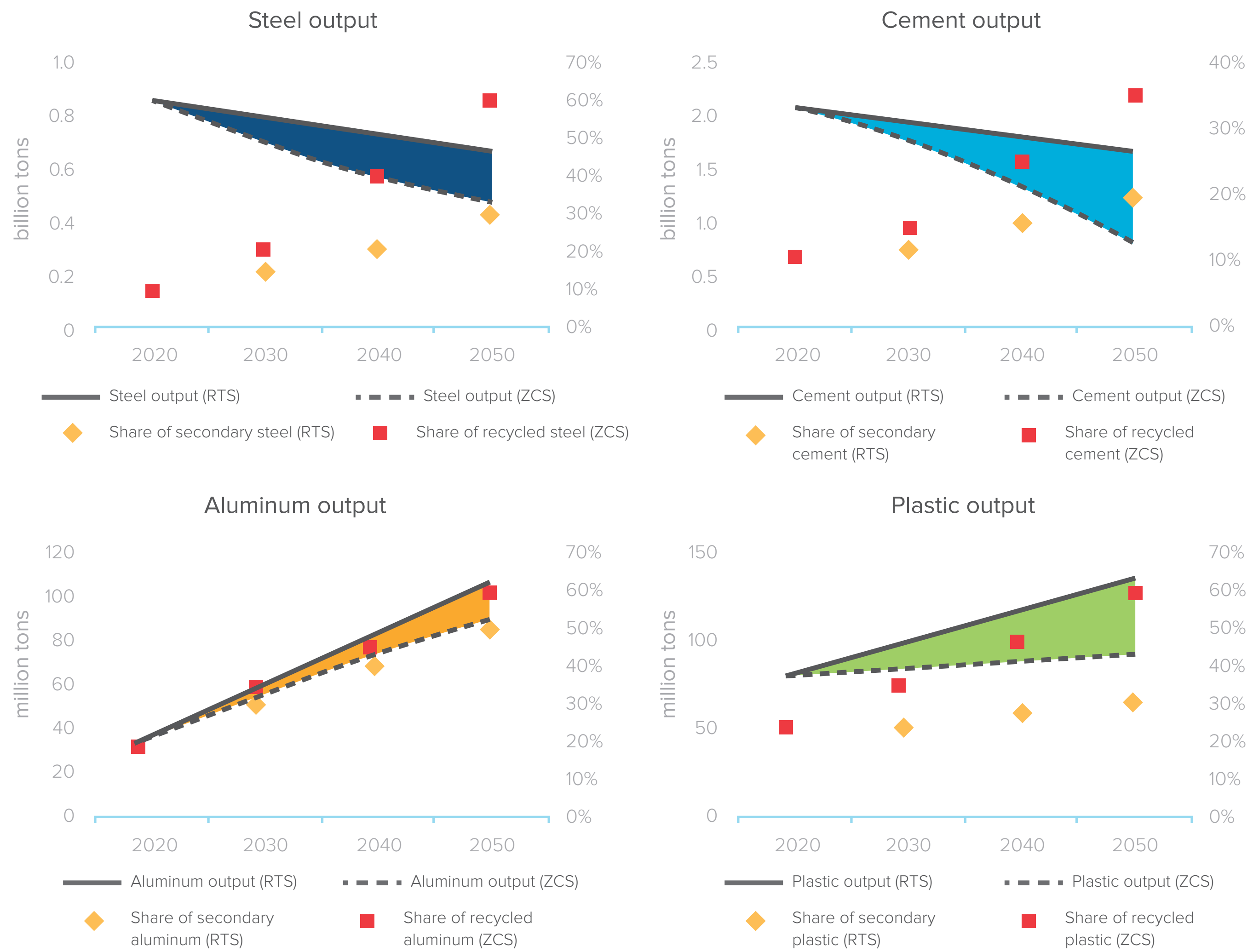
At present, the utilization rate of construction waste in China is less than 5%, compared with over 90% in the EU, and even as high as 95% in South Korea and Japan. The cement production process is irreversible and cement cannot be fully recycled, as metals and plastics can. However, under a zero-carbon scenario, recycling in the form of concrete or, with higher technical requirement for clinker recycling, recycled cement could still account for 35% of total cement production by 2050.

The period of accelerated recycling of scrap aluminum products has also arrived. Although China's demand for aluminum will continue to rise rapidly, the proportion of recycled aluminum will increase from 19% today to 60% in 2050. For plastics, the full release of recycling potential would also reduce the demand for primary materials, with the share of recycled plastics in total plastics production increasing from 23% today to 60% in 2050.

Waste provides substantial potential as an energy source. Crop straw, forestry waste, domestic waste, and animal manure represent at least 370 million tce energy potential per year, with straw accounting for 64% of the total. At present, many companies have

Exhibit 6

Production Quantities and Recycling Potential in the Steel, Cement, Aluminum, and Plastic Industries



Note: In the reference technology scenario (RTS), the trends of technological progress, economic development, and population growth remain unchanged; while in the zero-carbon scenario (ZCS), China achieves zero carbon emissions in 2050.

started working and harvesting in this field, and with further policy guidance and the expansion of market demand, we expect more investors to compete in this field.

Using waste as an energy source not only reduces the consumption of fossil energy, but also creates new market value. According to RMI's analysis, waste as an energy source can reduce carbon emissions by more than 13 billion tons cumulatively between 2020 and 2050. By 2050, the market size of energy recovery from straw and forestry waste, domestic waste, and animal manure will be close to ¥600 billion (US$93 billion).

The methods of using straw as an energy source include biogasification (biogas), pyrolytic gasification, curing molding, carbonization, and creation of cellulosic-based ethanol. The calorimetric value of straw is high with the calorimetric value of 2 tons of straw equivalent to 1 ton of coal. The average sulfur content of straw is only 0.38%, much lower than the 1% of coal. And it's more economical than coal. The residue of straw after full combustion is rich in potassium, magnesium, phosphorus, and calcium, which can all be used as fertilizer to return to the field, further expanding its economic value.

At present, China produces about 140 million tons of forestry waste from activities including logging and timber processing every year. It also produces 100 million tons of forestry waste from tree pruning, which combined is equivalent to 42 million tce assuming an energy recovery rate of 50%. In terms of domestic waste, China produced 228 million tons of cleaned and transported domestic waste in 2018. At present, waste to energy (WtE) is the main treatment method for domestic waste in China. By 2020, China's domestic waste used for WtE will account for 50% of all the harmlessly treated waste nationwide and 60% in the eastern region, with impressive increase in industrial demand that may exceed expectation.

As for animal manure, building of large-scale farm-based biogas projects is the more promising development mode to conduct anaerobic digestion of livestock and poultry manure. This process results in biogas for thermal power generation. The goal is to achieve a comprehensive utilization rate of animal manure of over 75% nationwide by 2020, with manure treatment facilities and equipment installed in 95% of large-scale farms.

However, in the short term, the challenge of waste as an energy source in China lies in the difficulty and high cost of collecting these biomass resources. This is mainly due to the small scale and relatively dispersed biomass sources. In the future, with the advancement of urbanization and the evolution of social and economic structures, the potential land-intensive production and large-scale contracting mode of farm, forestry, and pasture will significantly improve the efficiency of energy recovery from waste resources and greatly reduce the cost.

Another key area for recycling is EV batteries. With the pending market boom, by 2050, it will become one of the main energy storage forms in the power system. RMI predicts a market size of at least ¥114.5 billion (US$17.7 billion) in 2050.

The recovery and utilization of used EV batteries is generally divided into two forms: ladder utilization for energy storage and disassembly for material recycling. Ladder utilization means that due to the reduction of capacity, batteries can no longer play a normal role in EVs, but are not scrapped, and can still be used in other applications such as power system energy storage.

Disassembly utilization is defined as recycling batteries and recovering valuable resources from them, such as cobalt, lithium, and other metals. In the zero-carbon energy transition, the recovery and reuse of used EV batteries can provide considerable energy storage capacity for the power system. If 50% of used batteries are utilized for power system energy storage, the theoretical potential of the used batteries will be close to 590 GWh by 2050. This is equivalent to 37% of the total energy storage capacity required. If this potential is fully exploited, this added energy storage capacity may reduce the demand for coal power plants used for flexible power supply, reducing 800 million tons of carbon emissions cumulatively from 2020 to 2050.

By 2050, the market size of used EV batteries for energy storage in the power system will reach at least ¥114.5 billion (US$17.73 billion). However, despite the huge potential, in practical applications, recycled batteries will have to solve a number of technical problems and compete with other new batteries that can be used for energy storage in power systems.

There are four drivers behind the large market potential of EV battery recycling:

1. Rising demand for energy storage: With the zero-carbon energy transition trend and the improving cost-effectiveness of renewables, a high share of renewable energy in power grids has become an inevitable trend. Therefore, the demand for renewable power and a need for flexibility in power systems will usher in a golden period of development for electrochemical energy storage.

2. A growing supply of retired EV batteries: At present, the first wave of EVs entering the Chinese market have gradually reached the phase-out stage, and the “retirement tide” of power batteries is hitting. This will significantly increase the supply of used power batteries for ladder utilization.

3. Favorable policy environment: The NDRC, the Ministry of Industry and Information Technology, and other departments have paid great attention to power battery recycling, and a series of relevant policies have given strong support to relevant industries. At present, five provinces and cities have established targets for battery recycling.

4. Positive market atmosphere: While the development of the Chinese power battery recycling market is still amateur and as of yet without iconic leading companies, a lot of capital and companies are focusing on this field and ready to deploy. In particular, EV manufacturers are actively deploying vertical integration, such as BYD that established a power battery recycling center, and Beijing Automotive Group that aimed to develop a power battery recycling business by investing in Guangdong Guanghua Sci-Tech Co., Ltd. This trend shows clear market benefits in the future.

With a high level of overall technology and business maturity, resource recycling is entering a fast lane toward the Plateau of Productivity phase. The next five years will be a blowout period for the large-scale and investment value realization in this field.

At present, resource recycling is increasingly recognized as the key to China's zero-carbon transition and an opportunity to promote green development. Generally speaking, compared with other key technology fields in the zero-carbon transition, resource recycling has a higher technical and commercial maturity and is expected to achieve a considerable investment return in the near future. Resource recycling is in the later stage of the Slope of Enlightenment phase and rapidly moving toward

the Plateau of Productivity phase. The next five years will be a blowout period for the scale and investment value realization in this field. Investors should seize the opportunity to take advantage of this "low-hanging fruit."

From the policy point of view, governments of all countries are accelerating the economic growth model shift toward a circular economy that maximizes the utilization of recycled resources. Between when the State Council issued the first circular economy framework document, *Several Opinions on Accelerating Circular Economy*, in 2005 and the official implementation of the Law of Promoting Circular Economy in 2009, China's relevant top-level design is basically complete. Since the 12th Five-Year Plan, the output value of China's resource recycling industry has maintained an average annual growth rate of over 12%. In March 2020, the European Commission published the new EU Circular Economy Action Plan, with 35 legislative proposals to be introduced over the next three years. The circular economy has become a key pillar of the European Green Deal.

Related investment and financing markets are also developing rapidly. Since the beginning of 2020, assets under management of public funds focused or partially focused on the circular economy have increased six-fold from US$300 million to more than US$2 billion. Meanwhile the average performance of these funds has outperformed the Morningstar classification benchmark by 5%, indicating the huge potential of the circular economy to deliver excess returns. At the same time, the number of private equity funds, including venture capital, private equity, and private debt funds, have also risen sharply, reaching 30 in the first half of 2020. This is 10 times the number in 2016.

In the field of bank loans, project finance, and insurance, the European Investment Bank and the five largest European national promotional banks and institutions launched the Joint Initiative on Circular Economy with a total investment of €10 billion (US$12.3 billion), while Intesa Sanpaolo, Morgan Stanley, and AXA also actively announced corresponding resolutions. As investment continues to boom in relevant fields, utilization technologies and solutions of resource recycling will quickly realize their market value and more opportunities will be on the horizon.

Though the investment opportunities are clear, the complexity and diversification of the utilization of recycled resources determines that investors need to accurately grasp the market context for investment and act fast due to the rapid outbreak of the market. Among the three key areas discussed in the previous section, product recycling in energy-intensive industries and waste as an energy source are at a relatively mature stage. These require investors to seize the market trend that combines technology breakthroughs and business models and explore solutions that can scale rapidly. However, recycling of EV batteries for energy storage is in a relatively early stage, with the focus still on technology breakthroughs and the establishment of industry standards.

Suggestions for investment in product recycling in energy-intensive industries and waste as an energy source include the following:

- **Consider the impacts of import and export policies.**

Metal and plastics recycling industries will be affected by the import and export situation, hence relevant import and export policies should serve to improve the recycling system and enhance the competitiveness of recycled products.

The pattern of import and export of metals and plastics has an important influence on prices and competition among recycled products at home and abroad. For example, at present, the scrap steel recycling industry is strongly calling for the liberalization of scrap steel import controls. If this policy is implemented, the cost of scrap steel will be greatly reduced, greatly promoting the development of the scrap steel recycling industry, while forcing the improvement of the domestic scrap recycling system to maintain competitiveness.

Similarly, the current domestic ban on the import of waste plastics is forcing developed countries to step up research and development of plastic recycling technologies. Coupled with the pressure of China's high dependence on petroleum, China's waste plastics recycling industry also needs to accelerate its development to cope with the evolving market environment. All these factors will influence relevant investment decisions.

- **Explore the potential of the demonstration market to play a leading role by setting regional policy goals.**

At present, the recycling system of used products and waste is amateur, with links among subdivisions loosely connected. Regional policy goals with demonstrative significance and leading function will play a greater role in promoting the rise of the local market. Cement, for example, is more expensive to transport, thus the recycling of construction waste tends to be local.

Where there is clear and strong policy support, the market potential can be exploited more easily.

Currently, 35 national construction waste management pilot cities have been established, and some provinces and cities have created higher construction waste recycling targets. For example: Chaoyang District, Beijing, required 2 million tons of construction waste to be "reborn" in three years to achieve a resource recovery rate of above 95%. Xi'an also required at least 80% of the construction waste in the built-up area to be reused by the end of 2022.

In the same way, the generation, collection, and use of waste that can be utilized as energy sources are also localized. The clarity of relevant policy goals will point out the possible early market region for the recycling market and provide references for optimizing the allocation of investment resources.

- **Avoid downcycling.**

To continuously drive technology improvements, it is important to focus on avoiding downcycling of products and materials, while supporting breakthroughs in new fuels and large-scale projects.

The key to technological breakthroughs in steel, cement, aluminum, and plastics recycling is to avoid downcycling. The increase of recycling times of steel and aluminum will lead to the accumulation of impurities and affect the performance of the

recycled products. Yet methods to improve the purity of the recycled metal and ensure the quality of the recycled product is in urgent need of technological breakthroughs.

At present, the recovery of concrete is still limited to low-level applications such as roadbed and river embankment, while in fact, cement has a proportion of unhydrated clinker as high as 30%–40% and has great potential for high-level recovery and reuse. Technology is available in the Netherlands for the efficient recovery of clinker, thus greatly reducing primary cement demand.

Currently, the types of recycled plastic products are limited and cannot be made into high-value-added plastic types. In terms of technology trends, chemical recycling, which can take waste plastics back to the molecular level and reorganize them to broaden product types, will be a major focus in the future.

As for waste as a source of energy, the technologies that can effectively promote the large-scale utilization will focus on two aspects. First, breakthroughs need to be made in new fuel technologies, including the conversion of waste from agriculture, forestry, and animal husbandry into jet fuel, biodiesel, and ethanol. Second, large-scale engineering projects need to be developed, such as biological natural gas projects and large and medium-sized biogas projects. Finally, low nitrogen combustion in large biomass boilers is a key technology.

- **Explore business models with value chain integration potential and exert scale effect.**

The breakthrough of scale lies in the formation of a systematic industry of waste collection, treatment, processing, and marketing, which relies on a highly integrated commercial business model. For example, companies specialized in waste treatment will have better integration effect and cost-competitiveness.

There are two big trends to notice currently. The first is the trend of vertical integration by, for example, some large steel companies. These are integrating scrap recycling businesses and reducing scrap steel costs through vertical integration of upstream and downstream industry chains. In addition, intelligentization also brings opportunities. In view of high labor costs in the recycling industry, the intelligentized internet+ recycling mode has been favored by a lot of capital.

In contrast, although recycling of EV batteries for energy storage has a broad market prospect, the technology and market are still in the Technology Trigger stage. To ensure the sustainable and healthy development of the industry, and to smoothly get through the Trough of Disillusionment stage into the Slope of Enlightenment and Plateau of Productivity stages, technological breakthroughs and market standards should be the two major focus points. Therefore, priorities in this field include the following:

- **Grasp policy dynamics and track industry standardization process.**

Optimization of the used power battery recycling system and its standardization process can also help improve battery consistency. For example, the Industry Standards of the Comprehensive Utilization of Used EV Power Batteries (2019) and the Interim Procedures on the Administration of the Industry Standards of The Comprehensive Utilization of Used EV Power Batteries (2019) released at the national level in January 2020 promoted the establishment of the traceability information system and the database of comprehensive utilization of used batteries. These will improve information transparency for batteries of different types and status. The regulation at the policy level is of great significance for the power battery recycling industry which is still in the Technology Trigger stage.

- **Focus on solving key technical problems such as battery consistency in cascade utilization of batteries and look for systematic solutions.**

Battery consistency (i.e., the consistency of all characteristic parameters of all cells in the battery pack in the whole lifecycle) is the key to smooth operation for cascade utilization of batteries. Due to the differences in the default performances and settings of batteries and other major factors including charging patterns in use, homogeneity of the temperature field, and discrepancy of self-discharge, the capacity distribution of EV batteries is extremely uneven at the time of retirement, ranging from 50% to 80% of the initial capacity. This greatly increases the cost of subsequent operations and safety risks. In order to solve this problem, it is essential to study the attenuation mechanisms of batteries and the evaluation of battery status.

- **Seek integration opportunities at the whole industry chain level to bridge upstream and downstream segments.**

By far, no leading companies with obvious advantages exist in the field of EV battery recycling. To tap the potential of large-scale development, attention needs to be paid to the integration opportunities of different companies in the industrial chain. These include cascade utilization and disassembly utilization companies, battery producers, and battery recycling companies, as well as companies that use recycled batteries and resource materials companies. In addition, it is helpful to integrate with third-party commercial service platforms and technology evaluation systems to explore multi-win cooperation models.

II. Energy Efficiency: The First Fuel to Meet Demand

Energy efficiency is recognized as the "first fuel to meet demand." Its huge potential and ideal cost-effectiveness make it a focus area of energy and climate change-related policies in various countries, and it is one of the most important means to advance the zero-carbon energy transition. According to analysis by the IEA, to achieve the target of limiting global temperature rise to well below 2°C, the contribution of energy efficiency in the medium term (by 2030) must be as high as 48%.[5]

In terms of applications, there is great potential for energy efficiency improvements in the industry, building, and transportation sectors. This section will address key breakthroughs in improving energy efficiency in the industry and building sectors. The potential for energy efficiency improvement in the transportation sector mainly comes from the continued deepening of the trend toward electrification,[i] which will be further discussed in *Electrification: A Blue Ocean for High-Quality Energy Applications* on page 42.

Industrial Energy Efficiency

Industrial energy efficiency is a top priority for overall energy efficiency improvement in China. On the one

[i] Vehicle lightweighting is also an important means to improve energy efficiency of the transport sector, but this report does not discuss this in depth because of its indirect effect. Moreover, since there would be far fewer internal combustion engine vehicles in a zero-carbon scenario, the efficiency gains of the internal combustion engine are not discussed in this report.

hand, the industry sector is the biggest contributor to China's energy efficiency gains. For many years, the decline in China's industrial energy consumption intensity has been higher than the overall decline in energy consumption intensity. From 2011 to 2015, China's energy consumption intensity dropped by 18.4%, while industrial energy intensity dropped by 27%.

On the other hand, the energy consumption per unit product of China's industry sectors, especially energy-intensive industries such as steel, cement, ethylene, and glass, is still 10%–30% lower than the international best cases.[6] There is still great potential to be tapped in China's industrial energy conservation.

For the improvement of industrial energy efficiency, investors can focus on investment opportunities from four aspects: 1) the improvement of energy efficiency of general equipment; 2) the cascade utilization of residual heat and pressure; 3) process and system optimization based on digital and intelligent technologies; and 4) the application of energy-saving technology for specific industrial processes.

The potential for energy efficiency improvement in general equipment comes mainly from advanced technologies and products and the expansion of their scope of applications. Commonly used general equipment includes motors, transformers, compressors, and boilers. In general, the technologies of general equipment are relatively mature now, and further market space comes from energy efficiency improvements brought by the gradual optimization of performance. In the further development of market potential, attention can be paid to the expansion of available applications brought by performance optimization. Investors can focus on the equipment production and sales companies and related projects that meet the above two criteria.

The main scenario of energy cascade utilization, such as the utilization of waste heat and pressure, is the resource exchange and collaborative development of industrial parks. The technologies related to energy cascade utilization, such as the utilization of waste heat and pressure, have been relatively mature, and the investment focus is mainly on the ability to obtain market share and control the cost.

At present, industrial parks are one of the potential markets. Energy with different grades of quality can be used in different industrial processes through systematic planning and design. For example, in Henan Province, Yongcheng Economic and Technological Development Zone is a typical energy-intensive industrial park that achieved a total energy savings of 10,000 terajoules in 12 cascade utilization chains in the park. This was achieved among five enterprises including a coal chemical company, a steel mill, an electrolytic aluminum factory, and two power plants, and greatly reduced air pollutant emissions at the same time.[7] In terms of cost control, the value of potential investment objects can be evaluated based on the heat source cost, pipeline loss, and management level of specific projects.

The development and application of revolutionary digital technologies is a major trend of industrial energy efficiency investment. Such solutions can promote the formation of new industrial production modes with intelligent manufacture as the core through system optimization. For example, in the field of energy management and control in the manufacturing industry, the application of Internet-of-Things technology can provide real-time feedback on the utilization of electric energy and achieve a reduction of approximately 10%–15% of the equipment's power consumption.

The use of artificial intelligence-based machine learning in factory data centers can reduce cooling system energy consumption by 40% and increase overall system energy efficiency by 15%.[8] 3D printing technology can greatly reduce the energy intensity of products by realizing accurate control of material consumption and material recycling, and is widely used in machinery, automobile, and clothing manufacturing. In general, to further tap the potential of industrial energy efficiency through digital solutions, one of the main directions is to reduce the difficulty of data access.

Due to industry differences, the investment in technical optimization of specific industrial processes mainly comes from internal sources in the industry. For example, in the steel industry, there are specific techniques for energy efficiency improvement in coking, sintering, iron making, steelmaking, and steel rolling. The Hanbao Group coking plant achieved 36,000 tce of energy savings every year by using coal moisture control air separation technology, changing the traditional fluidized bed structure, and extending the contact time of coal material with hot air in the equipment in the coking stage.

For another example, in the cement industry, the process technology of cement kiln preheating and in the predecomposition system with large temperature differences across material flows can achieve high-efficiency heat transfer with large temperature differences through material redistribution. The corresponding coal consumption of each ton of product can be reduced by approximately 2.9–4.5 kilograms of standard coal, and the comprehensive power consumption can be reduced by approximately 3.5–5.0 kWh.[9]

Building Energy Efficiency

The main drivers of China's building energy consumption include the accelerated urbanization brought by national economic development and the increase of people's demand for building comfort. China's urbanization rate reached 58% in 2018 and will rise to 75% by 2050.[10] With urbanization, the large number of people entering cities will cause continuously increasing demand for new buildings. This is reflected not only in the growth of per-capita housing area, but also in the sharp increase of commercial building area. RMI projects that China's per-capita commercial building space will catch up with that of developed countries by 2050, with its total building space (residential and commercial) reaching 85 billion square meters.

Heating and cooling are the main sources of energy consumption in China's building sector. At the same time, with higher living standards, people's requirements on building services are also increasing and they are eager for a more comfortable and healthier built environment. Therefore, promoting energy efficiency in buildings is an important way to meet people's demands for a better built environment while moving toward a zero-carbon China.

In this context, there are three main areas that investors can focus on:

1. Building projects with integrated and passive design concepts

2. Energy-efficient building heating and cooling

3. Information technology that empowers systematic solutions for building management

An integrated and passive design meets the need for better buildings, and also reduces the building's energy consumption. Based on the needs of end-users, integrated design takes into account the costs and benefits of various technology combinations and the whole life cycle of the building. Passive design relies on the design of the building itself, through natural ventilation, daylighting, solar radiation, and indoor heating sources to achieve a comfortable indoor thermal, humidity level, and lighting environment. It reduces the dependence on active mechanical heating and cooling systems, thereby reducing energy consumption. Air tightness is an important concern in the evaluation of passive buildings.

The earliest passive house in China was the Hamburg Pavilion in the 2010 Shanghai World Expo. Since then, passive ultra-low-energy green building pilot projects have been carried out, covering practices in different climatic zones. For example, the Passive House Technology Center of the Sino-German Ecological Park built in Qingdao in 2016 has an annual operation energy consumption of 29.7 kWh per square meter. The energy consumption per unit area is only 55% of the average of similar public buildings in the city.

According to the estimate of CFLD Industry Research Institute, the passive house market will reach ¥80.5 billion (US$12.5 billion) by 2025.[11] Investment in the passive house industry can focus on areas including passive doors and windows, shading system materials, thermal insulation system materials, building materials and services (prefabricated building technology, smart home technology, natural lighting technology, etc.), and environmental integrated machines.

Promoting the application of efficient building heating and cooling equipment is another focus of investment in building energy efficiency. In terms of heating, one potentially attractive area for project investors is central heating projects based on combined heat and power generation and industrial waste heat utilization in northern urban areas.

For buildings in northern rural areas without access to a centralized heat supply network and buildings with new heating demands in areas in the Yangtze River Basin with hot summers and cold winters, the current "coal to power" and "coal to gas" policy encourages clean and efficient decentralized heating technologies. Air-source heat pumps are one of the most important development focuses. *Electrification: A Blue Ocean for High-Quality Energy Applications* on page 42 will detail the market segments and product types that investment can focus on.

In terms of cooling, the equipment energy efficiency limit standard is constantly improving. The new energy efficiency standard of Limits of Energy Efficiency and Energy Efficiency Grade of Room Air Conditioners implemented in July 2020 increased the energy efficiency index of variable frequency air conditioners by about 14%. Fixed-frequency air conditioners will gradually withdraw from the market, and the competitive landscape will be reshaped.

The application and development of information technology in building management is another opportunity for investment in building energy efficiency. This includes real-time measurement, monitoring, response, and control of power conversion and distribution, lighting, cooling and heating sources, air conditioning, water supply, and drainage and communication systems in buildings. In recent years, the intelligent building industry has developed rapidly and gradually expanded from first-tier cities to second- and third-tier cities geographically. The suppliers of intelligent system solutions for large buildings are also accumulating experience.

Investing in building energy efficiency requires a holistic approach. This means not only investing in equipment with high ratings in energy efficiency, but also taking into account asset allocation and actual operational efficiency of the equipment in the system. High-quality projects require a sustainable pricing and billing model, stable customer demand, and stable and economical operational management.

Industry Development and Investment Suggestions

Overall, investment in energy efficiency in China has continued to grow over the past decade or so, providing strong support for energy efficiency industry development and China's green and low-carbon development. From 2006 to 2016, China's total investment in energy efficiency reached ¥3.2 trillion (US$500 billion), with a compound annual growth rate of 44.1%. In 2016, the central and local governments spent nearly ¥63 billion (US$9.8 billion) to support energy efficiency, accounting for nearly 20% of the total. At the same time, financial funds also pulled in ¥270 billion (US$41.8 billion) in private investment, of which corporate funds accounted for 26% of the total investment in energy efficiency.[12] Based on our estimate of the market size of energy management, China's energy efficiency-related market could reach ¥1.3 trillion (US$200 billion) by 2050.

Driven by the policy, the energy efficiency industry has developed rapidly and formed a fairly mature market. However, in the new era of gradual transition from policy-led to market-led development, the energy efficiency industry needs new development impetus to systematically solve the problems of strong dependence on administrative means for energy conservation and relatively unequal development of industries, regions, and technologies. On the one hand, supportive policies related to energy efficiency need to be further improved. On the other hand, the further development of the energy efficiency industry also needs the support of innovative financing tools and private capital. In particular, the potential can be further explored from the following aspects:

- **Continuously improve the standards system for energy efficiency, raise the minimum energy efficiency standard requirements, and have standards play a guiding role.**

There are several measures that need to be taken to improve the energy efficiency standards system. These include improving minimum standards that aim to improve overall average market energy efficiency, encouraging competitive and capable entities to achieve higher energy efficiency standards and play a leading role, and setting up dynamic mechanisms to guarantee implementation. Higher and better energy efficiency standards not only supervise and promote the continuous optimization of existing capacity, but also guide and standardize the control of energy efficiency in new capacity.

- **In the short- to mid-term, focus on policy or fiscal incentives for energy efficiency, but take steps to give full play to capital and markets in the long run.**

Policy and financial support play an important role in the early stages of energy efficiency improvements, but only by giving full play to the role of capital and the market can energy efficiency continue to improve and enter a sustainable positive cycle. In areas where energy efficiency is more mature, government subsidies can be withdrawn or gradually reduced to give the market enough room to play its role. At the same time, the focus of policy support should shift to those mechanisms that best stimulate energy efficiency potential from a systematic perspective, rather than focusing solely on improving the energy efficiency of individual technologies or devices. In addition, the function of policies should gradually shift from direct support to a guiding role for markets and capital to help activate the role of markets.

- **Energy service companies should continue to improve their technical and service capabilities to form core competitiveness.**

As the mainstream model of the energy efficiency improvement market, integrated energy service is still at the early stage of development in China, but it is a new business model with broad prospects. However, energy service companies have the potential to upgrade to integrated energy service providers. Especially with the expansion of the market and the improvement of system integration requirements, energy service companies are faced with the condition where superior companies will succeed and eliminate inferior rivals, and winners will further expand their market share. Therefore, for energy service companies, the current priority should be forming core competitiveness in order to seize the huge market opportunities.

- **The financial industry and other relevant entities should actively promote innovation in financing models.**

The development of the energy-saving service industry requires a large amount of capital investment. However, as most of the current energy service companies in China are small and medium-sized enterprises, they may not be able to access many forms of financing and this can cause challenges. Therefore, it is necessary for the financial industry and other relevant entities to deeply engage and actively promote innovation in financing models, as well as adopt more flexible financing models to facilitate the development of the energy-saving service market.

The boundary of the industry continues to expand and any single financing measure can no longer meet the market demand. The development of green bonds and green asset securitization through collaboration between multiple related entities including government, the financial industry, and private capital in the financing model will help customize flexible capital solutions for the energy efficiency industry and enterprises.

III. Electrification: A Blue Ocean for High-Quality Energy Applications

With the large-scale development of zero-carbon energy including wind, solar, and nuclear power, electricity will continue to play an important role in the final energy consumption. Under the zero-carbon scenario, China's total power generation will reach nearly 15 trillion kWh in 2050, accounting for 47% of the country's final energy consumption. Direct electrification of the buildings, transportation, and industry sectors will comprise 82% of the total national power consumption. This represents a huge new market and carbon emissions reduction potential.[13] As the three sectors cover a wide range of areas with different routes and focuses of electrification, we have identified the most critical areas in each sector.

Buildings: Promote Air-Source Heat Pumps in Northern and Southern Areas

Heating is the main challenge of electrification and the application of air-source heat pump technology is key. At present, China's building sector emits 2.13 billion tons of CO_2 annually, accounting for about 20% of the country's total carbon emissions. In *China 2050: A Fully Developed Rich Zero-Carbon Economy*, RMI estimates that, under the zero-carbon scenario, fossil fuels will be phased out in China's building sector by 2050. The report additionally states that electrification will be key to the zero-carbon transformation of the building sector, with the electrification rate of buildings gradually reaching 75% by 2050.

Currently, cooling, lighting, and household appliances have achieved 100% electrification. The challenge of electrifying buildings is heating and cooking. However, with the continuous decarbonization of the power sector, the advantages of heat pump technology over fossil fuels in terms of climate change impacts will be more widely recognized.

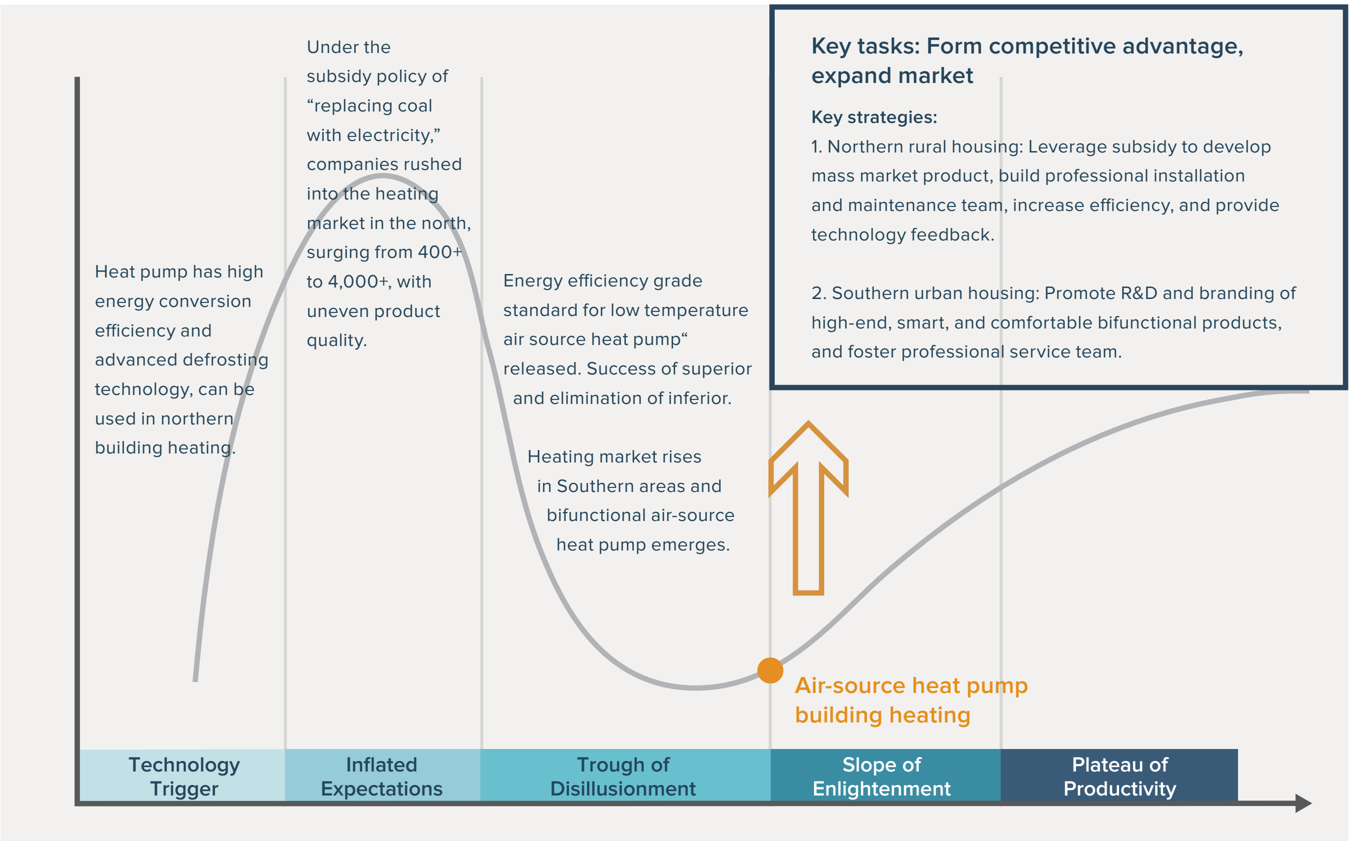
In the zero-carbon scenario, RMI estimates that heat pump technology will account for 60% of building heating and hot water by 2050.[14] Compared with water source heat pumps and ground source heat pumps, the applicability of air-source heat pumps is stronger, as they are not limited by geology, pipelines, or supply, and can be installed anywhere as long as there is air circulation. The application of air-source heat pumps in building heating will become the key to the electrification of the building sector.

Technology Development and Market Status

Currently, the development of air-source heat pumps is in the climbing stage after the Trough of Disillusionment phase and moving toward the Slope of Enlightenment phase. Technology is gradually mature, standards are gradually regulated, competition is benign, and inferior companies are gradually phased out. The key of future development is establishing

Exhibit 7

Development of Air-Source Heat Pumps in Building Heating



product competitive advantage and expanding the market based on consumer need.

Reviewing the history of air-source heat pumps in heating, we will clarify the drivers, obstacles, and risks of its development. We will additionally provide suggestions for the key objectives, core strategies, and required conditions for its future industry development.

Technology Trigger: Air-source heat pumps have high energy conversion efficiency. Technical improvements over the past decade make heat pumps capable of providing heating services in low-temperature environments, and this technology has the technical basis to enter the heating market in the north.

The principle of air-source heat pump heating is to absorb a large amount of low-temperature heat energy in the air, and then convert it into high-temperature heat energy through the compressor. These machines then transfer this heat to water to provide heating service to the room through hot water or hot air circulation. The whole system consumes only a small amount of electric power to drive the compressor and absorb free heat from the air.

Theoretically, at the ambient temperature of -5°C, for every 1°C of electricity consumed, more than 3°C of heat can be generated, providing a coefficient of performance (COP) greater than three. This technology has the advantages of low operating loss, high energy conversion efficiency, and far larger energy savings than traditional electric auxiliary heating.

In China, air-source heat pumps were first used in the hot water supply in southern areas. In recent years, with the progress of defrosting technology, the energy efficiency performance of air-source heat pumps in northern low-temperature environments has been gradually improved. At -20°C, the COP of several air-source heat pumps can reach two, which means that these machines can provide space heating in low-temperature environments. At the same time, air-source heat pumps can be equipped with flexible terminals such as a hot fan, radiator, and floor heating according to user preferences.

Inflated Expectations: Under the policy of replacing coal with electricity, air-source heat pumps entered the heating market in the north through subsidy programs, and the number of suppliers expanded from more than 400 to more than 4,000.

In terms of geography, heating is a must-have in the northern areas, which is the existing market. In the northern areas, as the government has focused on preventing and controlling air pollution in the 2+26 cities in Beijing-Tianjin-Hebei region since 2016 and implemented the clean heating plan, replacing coal with electricity has become a major trend in the heating sector. Especially in rural areas, due to low building density, high investment in central heating network construction, and low operating efficiency, decentralized air-source heat pump heating has become the most practical and feasible means to replace coal heating.

Air-source heat pumps are not only a clean way to provide heating, but also have the advantage of low operating costs due to high energy efficiency. For example, in rural Shandong province, the operating cost of an air-source heat pump for heating for a house of 80 to 90 square meters is about ¥1,000 (US$155) for one heating season. This is without an operating electricity subsidy, as Shandong does not have one. The operating cost of a coal-fired heating system is about ¥1,600 to ¥2,400 (US$248 to US$372).

However, due to the high initial purchase cost and installation cost (higher than ¥20,000 [US$3,100]), the application of air-source heat pumps in northern areas is mainly driven by the government's purchase subsidy. The subsidy rate varies from region to region but is usually above 80%. Early active policies and obvious investment hotspots have already attracted a large number of companies to deploy in this sector, and the number of companies has expanded from 400 to more than 4,000.

Trough of Disillusionment: The influx of a large number of companies in a short period of time has caused market chaos. In 2018, the launch of industry standards drove the gradual phaseout of inferior air-source heat pump companies. However, the rise of heat pump products with both heating and cooling functions has potential application in the southern market.

Encouraged by the policy of Replacing Coal with Electricity, a large number of companies poured into the market in a short period, resulting in the chaos of market order. Uneven product quality, insufficient branding, and lack of professional after-sales service resulted in the chaos of the market, and price competition has brought harm to companies that stick to product quality.

Since 2018, with the innovation of industrial technology and the release of the Energy Efficiency Grade Standard for Low Temperature Air-source heat pumps by the Ministry of Industry and Information Technology, the air-source heat pump industry has seen survival of the fittest. At the same time, the rise of products with dual functions that can provide heating in winter and cooling in summer has attracted wide attention in the market. However, as heating in southern areas is an incremental market, and with the market competition of traditional heating and cooling, air conditioning, and emerging gas-fired water heaters, at present air-source heat pumps still lack user recognition.

Toward the Slope of Enlightenment and the Plateau of Productivity: The key task to drive the development of the air-source heat pump is to find consumer needs, establish product competitive advantages, and expand the market. In this process, northern rural houses and southern urban residential buildings represent two different key markets. There are different strategies and roles for each of these in the development of the industry.

Industry Development and Investment Opportunities

Residential heating in northern rural areas: Growing the heat pump market in these areas requires developing popular products with the support of subsidies, exploring and establishing professional installation and maintenance teams, improving efficiency, and providing feedback for the updating of air-source heat pump-related technologies.

The growth of air-source heat pumps in the northern rural housing market will still be mainly dependent on policy subsidies, and the main problem for its development is the high cost of equipment purchase and installation. The upfront investment (including equipment and installation) of air-source heat pump heating equipment is more than ¥20,000 (US$3,100), of which about ¥2,000 (US$310) is currently paid by rural users. As mentioned earlier, while operating costs are more economical than coal-fired heating, the high upfront investment makes policy support particularly critical.

In the future, one of the breakthroughs for the cost reduction of the industry will be the efficiency improvement and cost reduction of the installation and maintenance. At present, the installation speed is about one unit per day and the service teams are mostly part-time staff or agents of air conditioner manufacturers, while the suppliers of air-source heat pumps pay little attention to the installation and aftersales. In order to reduce cost of air-source heat pumps in the northern residential market, it is essential to gradually simplify the installation process and train professional installation and maintenance teams.

In the short term, policy support will still be essential to popularize air-source heat pumps in the northern rural housing market. However, the exploration in installation technology, efficiency, and service will provide feedback for the full-service package of product maintenance and gradually drive the development of air-source heat pump technology toward maturity.

Residential heating in southern urban areas: In order to grow the market in southern urban areas, it will be necessary to promote the development and branding of comfortable, premium, intelligent, and dual-functional products, as well as cultivating professional service teams.

In Southern China, the need for building heating has been growing. Comfort is the key competitive advantage of air-source heat pump products. And this matches the primary need of consumers in their purchase.

In the context of rapid macroeconomic growth and upgrading consumption, users in the wealthy southern regions of China (the middle and lower reaches of the Yangtze River with hot summers and cold winters) have been constantly expecting a higher quality of life, and their requirements for a comfortable indoor environment have been constantly evolving.

At present, the energy consumption of heating in winter, air conditioning in summer, and domestic hot water is not high in these regions, and energy consumption per household is at a low level. However, the growth rate is very fast, and the average annual growth rate in heating demand is more than 50%.[15] As early as 2013, the results of an online survey conducted by the People's Daily, involving about 20,000 participants, showed that 83% of residents supported heating in the southern areas.

Most of the delivery of heating services in Southern China is decentralized with heat sources including air-source heat pumps, direct electric heating, and other heating methods for building space. Additionally, there are various local heating methods such as charcoal basins, electric blankets, and electric hand stoves.

In terms of consumer needs, the survey of consumers in several southern cities, conducted by the Heat Pump Special Committee of China Energy Conservation Association, shows that comfort is the most important factor for users when they choose to buy heating equipment. This was followed by ease of use, convenient maintenance, and brand.

On this point, compared with the most widely used cooling and heating air-conditioners, dual-functional air-source heat pumps with floor heating as the terminal heat dissipation product have a great advantage. Ground radiation heating dissipates heat from the bottom to the top of a space to provide users more comfort with “a cool head and warm feet.” At the same time, high reliability, low operating energy consumption, and long service life (12–15 years) are

Exhibit 8

The Competitive Advantages of Air-Source Heat Pumps

Attribute	Regular AC	Gas-fired water heater	Dual-functional air-source heat pump
Installation (flexibility and cost)	😀	☹️	☹️
Operating cost and energy consumption	🙂	☹️	😀
Service stability	☹️	😀	😀
Multi-functional	😀	☹️	😀
Comfort	☹️	😀	😀

Notes: Use cost of the gas-fired water heater is particularly high. For the middle and lower reaches of the Yangtze River, where the gas price is relatively high, the cost of a heating season will exceed ¥10,000 (US$1,550).

also obvious advantages of air-source heat pump products compared with their competitors including air conditioners and gas-fired water heaters.

Suppliers should first enter the premium market and promote the research and development and branding of dual-functional products. They should focus on providing a comfortable living environment as the core and create a smart home heating experience with great products and service.

The advantages of dual-functional air-source heat pumps are obvious, but the high purchase and installation cost is indeed a major obstacle to its penetration growth. Also, as a new category of home appliances, their after-sales repair and maintenance services are still undeveloped and belong to the extension services of general heating and cooling air conditioners. Therefore, to further stimulate the potential of the air-source heat pump market, it is important for suppliers to enter the premium market and delight consumers with dual-functional products. The way in should include research and development, brand building, and creating smart heating products with comprehensively upgraded products, service, and experience. According to the development of air-source water heaters and the smart home concept that has gradually emerged into the mainstream, popular heating products need to follow these principles:

1. Make products that are small and simplified in outlook.

2. Provide functions that conform to health and comfort.

3. Provide professional repair and maintenance service.

4. Build a smart system that enables users to remotely control heating and cooling through mobile apps and stores data to achieve precise aftersales maintenance.

There are likely to be two segments in the premium market with different key tasks. The first is the distributed but centralized business-to-business model, which is composed of the chain of suppliers, heating companies, and developers of new residential buildings. The first key to the successful utilization of heat pumps is the digitalization and intelligentization of the system, which can adjust and control the heating of the building in real time through big data and internet to ensure operation efficiency and comfort of heating. The second is the completely distributed business to consumer model, in which the main users are house residents. In this business model, as the manufacturer is directly facing individual users, user experience will be particularly important.

Mature products and services in the premium market will enable the establishment of a complete value chain. Also, it will provide feedback for technology development and cost reduction and ultimately promote air-source heat pumps into the mainstream market. With an improving standard of living, increasing demand for heating, an increasing level of service, and falling costs of air-source heat pumps in the high-end market, dual-functional air-source heat pumps may achieve similar market development patterns as Tesla. This involves a move from the premium market to the middle and mass market with profit from each level used as the fund for the development in the next level, to eventually form a mature market with differentiated products in all market segments.

Meanwhile, the concept of passive housing has been introduced to China from Europe in recent years, and the innovation of building materials will contribute to the enhancement of building insulation performance. This will further provide market space for smaller air-source heat pump products.

Different strategies for air-source heat pumps in the northern and southern markets require different policy and market enablers.

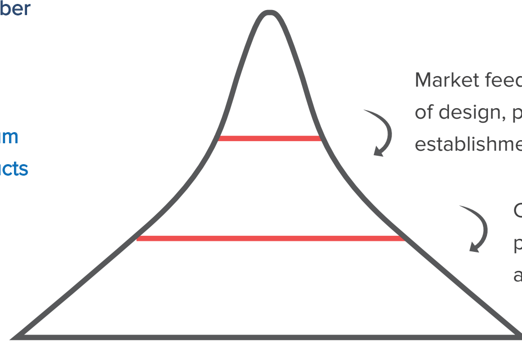
The development of the residential heating market in northern rural areas will still rely mainly on policy support. At this stage, the energy efficiency standards have been released, and the strongest manufacturers are emerging from a period of survival of the fittest. In the next step, it will be important to improve installation technology and efficiency to reduce costs.

Exhibit 9
Potential Market Expansion Route for Air-Source Heat Pumps in Southern China

Step 1: Provide high-end customers with small number of bifunctional air-source heat pump products with expensive price, high quality, and premium service

Step 2: Provide middle-class customers with medium number of bifunctional air-source heat pump products with moderate price

Step 3: Provide mass market with large number of bifunctional air-source heat pump products with affordable price, transforming winter heating devices from unnecessities to necessities



On the policy side, it may be effective to separate the processes of equipment purchase from installation and maintenance, establish standards for installation and maintenance, and implement incentives in the form of awards instead of subsidies.

The development of the residential heating market in southern urban areas will be mainly driven by market forces. Investors can focus on the dual-functional comfortable and smart home heating products, including business-to-business building heating equipment that focuses on digital and smart functions, and business-to-consumer (for houses) home heating products. These should focus on providing premium experiences and developing brand awareness through joint efforts, to push the development of companies and the market toward maturity.

Transportation: Growing EV Penetration through Technology, Business Models, and User Experience

Growing electric vehicle penetration is key to achieving China's transportation electrification and zero-carbon transformation. Accompanying its continuous economic development, China has invested heavily in transportation infrastructure over the past 40 years. A major national highway network has been completed, and the per-capita consumption of transport services will continue to increase.

Analysis by RMI shows that the total volume of passenger transportation in China will rise from 9 trillion passenger-kilometers (km) to 28 trillion passenger-km between 2018 and 2050, an increase of more than 200%.[16] By 2050, road transport will account for about 50% of total passenger transport kilometers. By then, every 1,000 Chinese residents will have about 460 automobiles.[17]

The most important paths to the electrification of future road transportation include battery EVs and hydrogen fuel cell vehicles. These options are more efficient than internal combustion engine (ICE) vehicles and can reduce final energy consumption in the face of a significant increase in passenger transport demand. For the potential development paths of the two, EVs are more likely to be suitable for short-distance passenger transportation, and hydrogen fuel cell vehicles are more likely to be suitable for long-distance heavy-haul transportation. However, it is also possible for large energy companies to restructure the hydrogen fuel vehicle industry chain to compete with battery EVs. This section will focus on how to steadily grow penetration of battery EVs through technological advances and business model innovations.

The development of China's EV industry is currently in the Inflated Expectations phase, with different market segments, including the parallel development of high-end and mass-market models, as well as different charging models in different scenarios. Over the past decade, with the support of policy subsidies and the cultivation of car companies, China has become a global leader in the promotion of EVs, with more than 3 million EVs, 38,000 charging stations, and 1.3 million individual chargers.[18]

In terms of market competition, car companies have gradually formed brand segments with different pricing tiers, functions, and experiences. These include Tesla, Celeste, Ideal, and Xiaopeng models above ¥200,000 (US$31,000), which have fashionable appearance, high quality service, and various intelligent functions; as well as Chery Little Ant and Wuling MINI EV models under ¥100,000 (US$15,500) in the New Energy Vehicle Rural Program, which meet the mobility needs of the elderly in the low-end market and the daily travel of young consumers in third-tier small cities.

As for charging infrastructure, the charging mode is mainly AC slow-charging, supplemented by DC fast-charging, which can meet the different charging needs of users depending on the end-use case. The average daily mileage of private and public vehicles is short, and they spend most of their time in parking lots, mainly in the form of AC slow charging. Because buses, cabs, and other operating vehicles have a longer average daily mileage and higher charging efficiency requirements, DC fast charging is mainly used in public charging stations. Meanwhile, the brands of operating vehicles are concentrated, battery specifications are relatively consistent, the degree of standardization is high, and the operating scenarios are fixed.

In the future, the goal of EV development is to grow penetration. This requires solving users' mileage and charging anxiety, as well as overtaking ICE vehicles by relying on the competitive advantages of intelligent, network-connected, shared and humanized electric vehicles. Overall, the EV market is expected to expand from the high-end and low-end markets to the middle, with high-end brands (e.g., Tesla) enriching their product portfolios to provide models for midmarket users, and low-end brands (e.g., Chery) offering a portfolio of products at different price points in rural and low-tier cities.

The emergence of new automakers and the transformation of traditional automakers have brought new ideas and vitality to the entire auto industry, and the outlook for EVs is promising. The industry development and investment opportunities are in the upgrade of battery technology, user experience design, and charging models.

Opportunity 1: Upgrade battery technology and energy density.

According to statistics from the *Recommended Catalogue of the Ministry of Industry and Information Technology*, the average mileage of battery passenger EVs in the 7th batch of the recommended catalogue in China in 2020 has reached 391.4 km, 85% higher than the level in 2017. The average energy density of the battery system has been continuously increased to 152.6 watt-hours per kilogram (Wh/kg), and the share of installed ternary system power battery has been continuously increased from 46.1% in 2015 to 92.3% in the first half of 2020.[19] Ternary lithium-ion batteries have high voltage and the energy density generally can reach 240 Wh/kg.

According to the current mileage requirements for EV batteries, NCM811 lithium-ion chemistry with high nickel content is the key breakthrough direction. With the increase of nickel content, the specific capacity of ternary anode material gradually increases, and the energy density of the battery cell increases accordingly. The energy density of Tesla's 21700NCA ternary lithium-ion battery cell is as high as 260 Wh/kg, which is the highest among the currently mass produced EVs. The nickel-cobalt-aluminum ratio is 8:1.5:0.5, which belongs to the "high-nickel battery."

But for ternary lithium batteries, 300 Wh/kg will be an insurmountable gap. Therefore, solid-state batteries that replace the diaphragm and electrolyte with a solid-state electrolyte will be the next breakthrough to focus on. Solid-state batteries use lithium metal as the cathode, significantly reducing the amount of cathode material used compared to graphite. The energy density of solid-state batteries can easily surpass 400 Wh/kg, making it possible for EVs to exceed 1,000 km of range.

At the same time, as a leader and innovator in the EV industry, Tesla is committed to driving the technological revolution with its own battery design, and its newly launched technology in September may lead the new wave of power battery technology. The use of large battery cells to reduce costs, improve integration efficiency, and improve energy density deserves continuous attention.

Opportunity 2: Leverage smart, network-connected, shared, and humanistic design to build electric cars as a large intelligent terminal with the shape of a vehicle.

Electric vehicles are an ideal carrier for intelligent and networked driving. First of all, EVs have a large battery capacity and high level of electrification, which is a natural advantage for powering various components and equipment for intelligent driving. Secondly, electric vehicles are better able to implement the in-line control technology required for automated driving, while the chassis, braking, steering, etc. of traditional fuel-efficient vehicles are mostly controlled mechanically. At the same time, the short response time of EVs can provide better control accuracy than traditional machinery, enabling real-time response.

Electric vehicles also have the potential to provide powerful support for optimizing the driving experience and providing personalized services based on the user's driving record and analyzing big data. According to a Deloitte report, 70% of respondents expect innovative technology to be maximized in new energy vehicles.[20] Electric vehicles are not only a means of transportation for users, but also a large smart terminal that integrates technology, fashion, and leisure.

According to industry insiders, the lack of consumer-designed products and services is the root cause of the difficulty in improving the quality of electric passenger cars for individual users. But in the future, the mode of car ownership and consumption will change. Intelligent, networked, shared, and humanized are the important principles to follow in the design of the electric car experience. Specific services include intelligent safety, online-to-offline car-related services, emotional interaction, behavior memory, personalized service recommendations, and more.[21]

With the further development of the Internet, investment in terminals will be more important, as will investment in end-user services, which have vast room for innovation and profitability. New carmakers such as NIO are also exploring the user community economy model, introducing social networking into the EV market and stimulating user spending throughout the EV lifecycle. These upgrades in the design of the end-user experience will drive EVs to become large smart terminals and personalized spaces where users can express themselves and enjoy technology, trends, and leisure experiences. The purchase of EVs will be associated with the embrace of new lifestyles.

Opportunity 3: Expand new charging models based on different user scenarios.

While breakthroughs in battery technology have significantly increased the theoretical range for potential mainstream EV users, ranges of up to 1,000 km are actually only used for long-distance trips, which occur less frequently. At the same time, government subsidies are gradually shifting from the acquisition side to the operation side and infrastructure construction. In November 2018, four ministries issued the "Notice on the Action Plan to Improve the Charging Capacity of New Energy Vehicles," which implements guidance for local subsidies to shift from the purchase side to the operation side.

Therefore, playing around with the charging technology and business model of EVs and improving charging performance, service, and experience have become important breakthroughs. In addition to the most common slow charging (6–8 hours) and fast charging (0.5–1 hour), in recent years, super-fast charging (15 minutes) represented by Tesla and the battery swap mode (5 minutes) represented by NIO have become new charging models for electric vehicles.

Different charging (swapping) modes are suitable for different scenarios and users. It can be predicted that in the future, EV charging will form multiple market segments based on slow charging supplemented by fast charging, super-fast charging, and swapping. At the same time, charging stations will connect vehicles with grids, realizing interoperability of vehicle networks. This will not only improve charging efficiency, but also allow electric vehicles themselves to become energy storage units. In addition, driven by the development of the sharing economy and community economy in other industries, the innovation of shared charging stations inside communities will probably be an opportunity for the development of charging business models.

Industry: Cutting-edge electric heating technologies drive the transformation of process heating

Globally, about 10% of greenhouse gas emissions come from providing heat to industrial processes, more than the combined emissions of the road transport and aviation sectors.[22] In most industrial processes, supply of high-quality thermal energy is one of the most important inputs. For example, in the cement, steel, and chemical industries, the main production processes are based on the smelting of ore, the breaking of chemical bonds, and the increase in the internal energy of the product. All of these require high-quality thermal energy.

At present, the supply of heat mainly depends on the burning of fossil fuels, which makes industrial heating one of the largest sources of greenhouse gas emissions in the industry sector, representing 40% of the total global industrial emissions.[23] Therefore, emissions reduction in industrial heating is crucial for decarbonizing the industry sector and realizing the whole zero-carbon vision. Electrification of industrial heating is one of the most important technological means to achieve that.

The use of fossil fuel combustion for industrial heating has been able to provide a high-temperature, continuous, and stable thermal energy supply. Therefore, any low-carbon transformation in process heating should meet the basic requirements of the current stage. These include:

1. Temperature: Requirements vary from industry to industry, ranging from 200 to nearly 2,000 degrees Celsius.

2. Heat Influx: Industrial heating usually requires a sufficiently large and stable heat flux to maintain production.

3. Reliability: Most heavy industry sectors use large equipment for production, which has high fixed costs and high capacity factors (typically between 60% and 95%). Therefore, the heat supply requires systematic planning to ensure sufficiency and stability.[24]

Different electrical heating technologies have long been available for industrial processes. They have three major common advantages. First, electric heating systems can precisely control the temperature and heat transfer of the heating process by adjusting relevant parameters such as voltage and current, thus reducing energy consumption and ensuring automation of production. Second, electric heating systems have the immediacy of fast startup and stop, which makes the production operation highly flexible. Third, electric heating systems have lower maintenance costs, as there is no need to store fuels and create a combustion environment.

Indirect heating technologies such as microwave heating can also avoid the possibility of contact between the fuel and the reactants when using fossil fuels, thus further controlling the reaction environment from contamination. In the field of industrial electric heating, the main technical means are as follows:

- Resistance heating: The principle is that current flowing through a section of conductor with resistance produces heat. It's suitable for low-cost, low-power, and short-time heating applications.

- Infrared heating: Infrared heating can be categorized as the scope of thermal radiation. After the radiation source is heated, the internal energy is converted into radiant energy and transmitted to the heated object through an infrared ray. Normally, the electro-thermal conversion efficiency of infrared heating is more than 90%, which is generally suitable for the applications of surface heating, such as paint drying, food rapid dehydration, etc.

- Microwave heating: Microwave is a specific range of electromagnetic waves, causing the internal molecules of substances that can absorb microwaves to vibrate, so as to achieve the heating effect. Microwaves cannot heat metals because metals reflect them. Microwave heating is uniform, fast, clean and pollution free, and is widely applied in the food industry.

- Electromagnetic induction heating: Alternating an electric field produces an alternating magnetic field. When the heated object cuts the magnetic field, an internal vortex is generated and heat is produced. The application of electromagnetic induction heating requires an electromagnetic heater, induction coil, and the heated object to form a complete induction heating system. The advantages of this method are fast heating, energy savings, and a high degree of intelligence. It is applied in plastic and food industries.

- Arc-furnace heating: Arc furnaces use arc discharge to transfer heat to the heated material.

Industrial electric arc furnaces, which can heat up to 1,800 degrees Celsius, are commonly used in the steel industry.

Industry Development and Investment Opportunities

The development of industrial electric heating technology is still at an early stage and needs relevant policy support for equipment upsizing and production process transformation. In China relevant information is scarce. The application of electric heating will lead to a huge increase in power demand in the industry sector and will require the construction of infrastructure and the retrofit of factory equipment. Therefore, in the short term, it is particularly important to pay attention to policy signals related to the transformation of energy conservation. Electric heating will be a potential way to achieve industrial energy savings and emissions reductions if mandatory policy requirements are adopted for the energy-saving retrofit in key industrial sectors.

The market potential of electrical heating will be high in new industry and high-end manufacturing, including new materials like lithium batteries and graphene. These new industries have different industrial production processes than traditional commodities. These differences, and the demand for new capacity, open up markets for electric heating technology.

IV. Zero-Carbon Power: The Cornerstone of a Zero-Carbon Energy System

The electricity sector accounts for about 40% of total carbon dioxide emissions society-wide, mostly due to the combustion of fossil fuels in thermal power plants. Therefore, decarbonization of power generation is of great importance for the emissions reduction of the entire economy. With the gradual growth in the electrification of various end-use applications, a greater supply of electricity will be needed in the future, making the further development of an efficient and low-carbon power system key to achieving the goal of zero carbon.

This will require the large-scale deployment of clean power sources that are cost-effective, safe, and sustainable. According to an analysis by the Energy Transitions Commission, nearly 65% of China's total power generation will come from wind and solar by 2050, 10% from nuclear, 14% from hydropower, 10% from biomass, and 4% from natural gas plants retrofitted with carbon capture, usage, and storage.[25] **Under the zero-carbon scenario, we estimate that by 2050 the total emissions reduction of the power system will reach 33 billion tons compared with a business-as-usual scenario, and the annual market size will reach ¥4.5 trillion (US$700 billion).**

1. Status and future trend of the industry

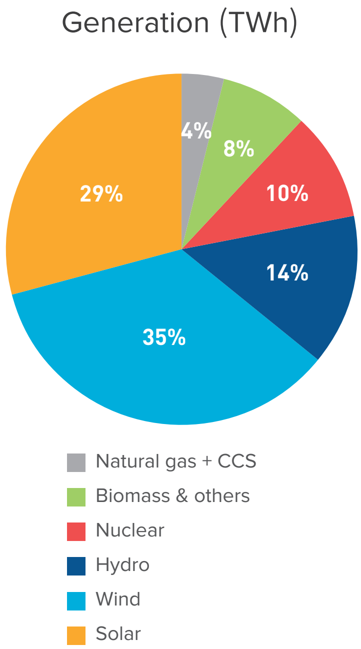
The power industry is undergoing a low-carbon transformation. From 2005 to 2019, the carbon intensity of the power system was reduced by 33% through the rapid penetration of wind and solar, the steady growth of nuclear energy, the orderly development of hydropower, and the expansion of other low-carbon generation technologies, as well as efficiency improvements in coal-fired power units.[ii, 26]

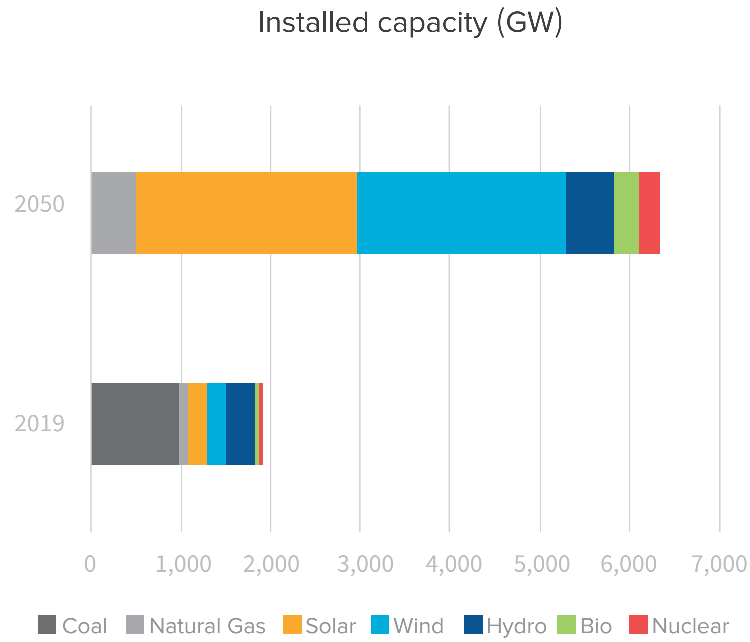
Today, zero-carbon power generation technology, which is on track to take the majority share of the future installation portfolio, has become increasingly mature and already formed a complete value chain. The manufacturing of most equipment has been localized with a competitive landscape led by local leading players. The market competition for project development is more intense, especially for wind and solar plants, with players including state-owned companies, private companies, and foreign companies. The operation and maintenance industry has also seen the emergence of a variety of service providers from traditional energy companies to innovative new technology companies. This has laid a solid foundation for the long-term low-carbon transformation of the power industry.

[ii] Carbon intensity reduction was calculated based on data collected from the China Electricity Council.

Exhibit 10

China's Power Generation and Installed Capacity under a 2050 Zero-Carbon Scenario



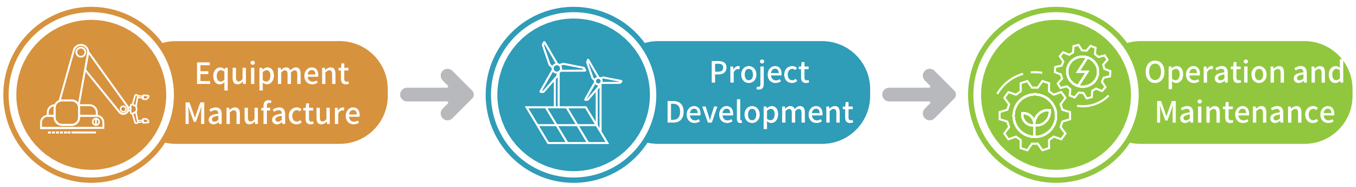


Source: Energy Transitions Commission and RMI

The cost-effectiveness of wind and solar generation is improving continuously. Subsidization through feed-in tariffs has driven the rapid growth of wind and solar installations. During the 13th Five-Year Plan, the total capacity of wind and solar expanded from 172 GW in 2015 to 414 GW in 2019.[27] From 2010 to 2019, the cost of solar and wind power in China decreased by 82% and 36% respectively.[28]

This was achieved by lowering the investment cost of PV modules and wind turbines through technological improvement and economies of scale, enhancing generation efficiency, and increasing maturity of the industry supply chain. As the costs of wind and solar continue to fall sharply, the government has gradually reduced subsidies and introduced a series of policies to accelerate the integration of renewable power at grid parity.

Exhibit 11
The Value Chain of Electricity Generation



Subsidies will soon be phased out for onshore wind and utility-scale solar projects. Starting in 2022, all new onshore wind projects will no longer receive subsidies. Although there is no clear end date for solar subsidies, the market forecast there will be no or very little subsidy in 2021. This is based on the most recent auction results in 2020 which showed that the average subsidy is around ¥0.03 (US$0.005) per kWh (required to be connected to the grid by the end of 2020).[29]

According to BNEF, wind and solar are already at parity in some provinces in China and are expected to be cheaper than coal across the entire country soon, becoming the cheapest sources of power generation (Exhibit 12).[30] Moreover, wind and solar face little natural constraints and have huge development potentials. Looking back at the development history, these two technologies have not yet encountered technical bottlenecks, which supports the ongoing trend of continued, rapid cost declines.

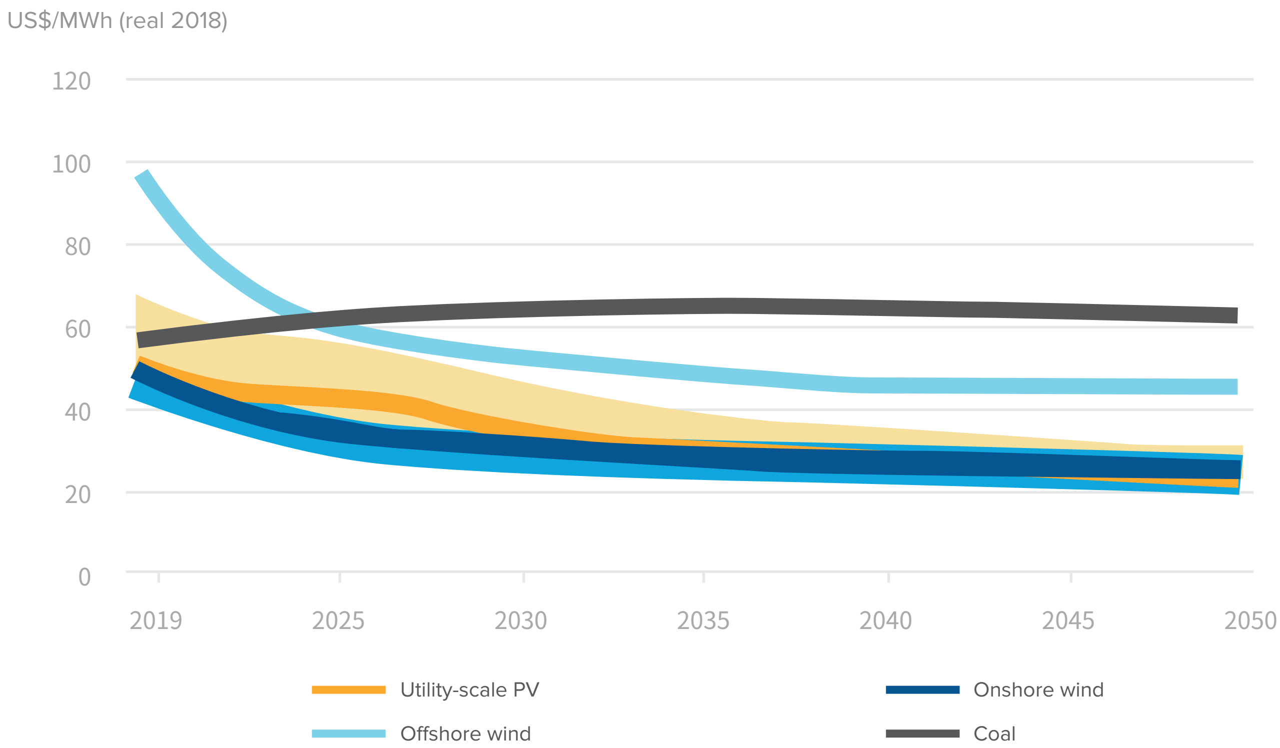
The development of nuclear is of strategic significance but will be challenged by economics.

China's resources vary greatly among different regions. Wind, solar, and hydro resources are concentrated in Western and Northern China, while the renewable energy resources in Eastern China are relatively poor (except for offshore wind). Nuclear, therefore, will continue to be an important generation source for the power system in the east.

Unlike other power sources, safety is always the top priority for nuclear. In the past, it has been strengthened by defensive measures such as improving the design, construction, and operation of the nuclear reactor core and implementing various security systems. However, enhanced safety measures would greatly increase the project cost and decrease commercial sustainability, prohibiting large-scale development of nuclear.

Currently, most of the nuclear power plants in China utilize the Generation II pressurized water reactor design. With the commissioning of the Sanmen Nuclear Power Plant and the Tianwan Nuclear Power Plant, Generation III nuclear technology has entered

Exhibit 12
Average Power Generation Cost (LCOE) Trend in China



Source: BNEF

an accelerating stage. However, according to the commissioning data of the Sanmen Plant, the cost is significantly higher than that of the Generation II nuclear power plants.[31]

The cost of Generation III nuclear is expected to reduce by accumulating project experience and localizing manufacturing. We expect it to achieve a comparable level with the current cost of Generation II technology in the long run. The emergence of the Generation IV nuclear reactor technology aims at reducing the probability of the core melting and restoring operation quickly, while putting forward requirements of shortening construction cycles and reducing generation cost.

In general it is considered to be a better solution to the long-term safety challenges. Although the new advanced reactors have been tested in national laboratories for decades, they are still in the early stages, with the goal of commercialization by 2030 and large-scale use by 2040. There are still high uncertainties in the economics of advanced reactors in the future.

The scale of new hydropower projects will be limited by the natural environment. Hydropower is currently one of the most economical power sources in China and plays a vital role in the low-carbon transition of the economy. From 2010 to 2019, the installed hydro capacity increased from 213 GW to 328 GW.[32]

We expect that with the continuous development of low-cost hydropower projects, the difficulty of future hydropower development will increase, and the economics will be inferior to that of projects already in operation. Due to the impact of natural conditions and the consideration of ecological protection, the development of small- and medium-sized hydropower projects will be strictly controlled in the future.

The development of large projects will be coordinated as major national projects (such as the Baihetan Project to be put into operation), and the overall growth will gradually slow down. The development of hydropower projects is relatively concentrated and seven major energy groups (Three Gorges, Huadian, Datang, SPIC, Huaneng, Guodian, and SDIC) account for 54% of the total national installed capacity. [33] With the accumulated project development experience over the years, industry leaders will maintain their leading roles in future project development.

China's biomass supply mainly comes from crop straw and other agricultural waste, wood waste, energy crops, and municipal waste, of which crop straw and other agricultural waste account for more than 50%. Currently, the utilization rate of agricultural and forestry waste in China is very low. One problem is that the low density and large volume of agricultural and forestry waste has made the collection process challenging. Another is that there is a lack of large-scale systematic collection mechanisms and complementary logistics systems due to scattered planting practices.

Furthermore, energy crops will face a high level of uncertainties as the land use for energy crops will compete with the use for food production. Due to the limited available biomass resources in China, in the future, biomass resources will be prioritized to support decarbonization in areas such as aviation. The use of biomass will be limited in the power sector, with a main role as a flexibility resource for a high renewable penetration power system.

Hydrogen can be produced by water electrolysis with otherwise curtailed electricity and can be burned in a gas turbine or converted by a fuel cell to produce electric power. Power generation from hydrogen is still at a very early stage, and there are few pilot projects under development to upgrade traditional natural gas plants to burn a mixture of hydrogen and natural gas. The main application scenarios for hydrogen power generation in the future will be providing seasonal balance rather than large-scale power generation. With the rapid cost decrease of electrolyzers, hydrogen could become a low-cost solution for seasonal energy storage.

The future development of the power industry will be dominated by wind and solar, supplemented by hydropower and nuclear power. Other flexible power generation resources will play a supporting role to realize a power system with high renewable penetration. Driven by the declining cost of wind and solar, the cost of power generation in the industry will show a downward trend.

2. Focus of Investment

Because electricity is a fungible product with high homogeneity, economics plays a decisive factor in the market potential of any power supply. For all types of power generation technologies and their corresponding supply chains, further cost reduction will be the core of development.

The cost of power generation consists of investment costs and operation and maintenance (O&M) costs. Investment costs can be divided into technology costs that include equipment procurement and project construction, and soft costs that consist of land cost, grid connection costs, and financing.

The O&M of power plants mainly involves taking preventive and periodic maintenance and regular equipment checks to guarantee the safe, stable, and efficient operation of the whole generation system, as well as the return of investment. Currently, labor is the biggest portion of O&M costs, thus improving efficiency and minimizing labor are the top leverage points. This includes improving generation forecast accuracy and optimizing system operation. The O&M of the project is transforming toward digitalization, automation, and intelligentization. The O&M part will be introduced in detail in the digitalization section, while this section will focus on the future trend of cost reduction from the perspective of reducing investment costs.

Solar

- **Hardware Costs**

In a large-scale solar PV system, modules account for half of the initial investment cost, and the reduction of equipment cost has a great impact on the cost of power generation. As a result, efficiency improvements result in continuous reduction of equipment costs. Increased efficiency can increase the amount of electricity generated per unit of area. Hence it not only reduces the investment cost of the equipment, but also reduces the need for land and system hardware including racking/tracking/mounting systems, cables, electrical connectors, and other components.

The following steps can be taken to reduce technology costs in PV systems:

- Further improve efficiency through optimization and upgrading of system design. Bifacial modules can generate electricity using reflected light from the ground, achieving efficiency improvements of 5%–20% over monofacial modules (depending on the reflectivity of the ground).[34] The back panel of the bifacial PV module is made of transparent glass. Due to the extremely low permeability of glass and its low sensitivity to humidity, it can avoid damage and the loss of power output caused by water vapor entering the module. This type of module is more adaptable for deployment in harsh environments, such as areas with more acid rain, salt fog, and high temperatures. According to the International Technology Roadmap for Photovoltaics, the market penetration of bifacial modules could reach 40% in the next 10 years.[35]

- Unlock higher efficiency potential through new material sciences. The efficiency

of various technology routes has been continuously improving over the years. From the early multicrystalline silicon to the current mainstream monocrystalline with passivated emitter and rear cell (PERC), the efficiency has increased from 14%–15% to higher than 20%, and the module cost has decreased by more than 90%. In 2019, PERC's market share exceeded 65%.[36] Silicon-based PV technology has been widely deployed and its value chain has reached a high level of maturity with the rapid expansion of production capacity. Nonsilicon-based new materials face a high industry barrier to replace the current technology pathway on a large scale. This is especially true as the levelized cost of energy of silicon-based PV systems continues to decrease (to US$10/MWh or even lower), removing any incentive to switch the technology.

When the current technology hits the ceiling, new technology pathways will unleash greater business opportunities. N-type crystalline silicon modules may be one of the directions of future PV technology by leveraging the technical experience accumulated in the field of crystalline silicon cells for many years. In addition, some new materials that can combine with the current mainstream technologies and create synergy have also attracted great attention. For example, perovskites can be used as a film stack to absorb another part of the spectrum to generate more electricity and improve the overall power generation efficiency.

- **Soft Costs**

For solar projects, technology breakthroughs can drive down the technology cost. But at present, the soft costs faced by power generation companies are becoming a more evident problem that cannot be ignored. **We expect soft cost reductions, such as via reducing land cost and lowering the difficulty of grid connection, to be achieved through business model innovation.**

Multi-dimensional land use: In the more economically developed load centers in Southeastern China, land scarcity will restrict the development of utility-scale projects. An increasing number of utility-scale solar plants are developed in the form of complementary solar-plus-agricultural and solar-plus-fishery projects. These create new economic value while supporting agricultural production and fisheries. Various other new solar application environments have also been explored:

- Floating solar: PV modules installed on a structure that floats on a body of water do not occupy land resources and can improve power generation efficiency through the cooling effect of water. At the same time, floating PV panels can reduce evaporation, inhibit algae growth, and improve water quality.

- Building integrated PV (BIPV): PV modules can be used to form various surfaces on buildings, such as walls and roofs. The electricity generated can be consumed by the buildings, and it also provides a certain degree of insulation to improve the energy efficiency of the buildings.

Distributed resources become mainstream: With the growth of installed capacity, the most suitable areas for development and grid connection are often developed first. At the same time, as renewable energy penetrations increase, it becomes more difficult for the grid to integrate additional renewables, which increases the grid-connection cost of new projects. The development of distributed PV boomed in the past few years due to its low land cost, favorable economics, and proximity to load centers that reduces the difficulty of grid connection. Distributed PV will be a major trend in the future. Furthermore, as BIPV matures, it may unlock the greater distributed solar market.

In the context of power market reform, the emergence of innovative business models brings new opportunities to reduce soft costs.

- Since the electricity market is highly regulated, renewable energy companies are used to a simple sales relationship with utility companies in the past by directly selling all the electricity generated to the utilities. In the future, with the continuous penetration of wind and solar and the deepening of power market reform, the traditional relationship between power generators and grid companies will change. As the percentage of electricity sold directly to retailers and end-users increases, the role of the utilities is partially shifting from the original sales agent to a third-party network operator, and the market share of electricity sold by grid companies is shrinking.

  In the future, renewable energy projects will need to explore new business models, form direct partnerships with end-users, and sign long-term power purchase agreements. This will mitigate price risks introduced by the spot market, while potentially solving grid connection difficulties to lower soft costs.

- With the rapid growth of distributed power resources, traditional power consumers are gradually becoming "prosumers," which can sell excess power back to the grid. In the future, as the percentage of this type of prosumers increases, peer-to-peer transactions will become possible and small-size virtual power plants will also be formed through aggregation to participate in the power market.

Wind

While the rate of decline in onshore wind investment costs has been impressive over the past decade, it has slowed over the past two to three years. Offshore wind power has a relatively short history of development; hence it still has high potential for significant cost reductions. In the future, in addition to improved economies of scale and more competitive supply chains, further technology innovations will continue to reduce the cost of wind power.

- **Hardware Costs**
  - **The increasing diameter of turbine blades and larger unit capacities improve the efficiency of power generation.** With the increase of the blade size, the swept area is enlarged, hence larger and more stable wind energy can be captured. The average capacity of onshore turbines increased from 1.9 megawatts (MW) in 2010 to 2.6 MW in 2019, with global average capacity factors increasing from 27% to 34%.[37] The International Renewable Energy Agency predicts that as the volume of wind turbines deployed increases, the global average capacity factor for onshore wind will further rise to 30%–55% by 2030 and 32%–58% by 2050.[38]

Since two-thirds of China's wind energy comes from low-speed sources, improving wind turbine efficiency will accelerate the cost reduction of power generation. Under the same project size, a larger unit capacity will reduce the number of wind turbines needed, reducing installation and operation costs and the requirement for land acquisition.

The increase of turbine capacity will have an even more significant impact on the economics of offshore wind power. The current maximum capacity of offshore wind power is about 9.5 MW, which can be expanded to 15–20 MW in the future, while the average capacity factor can be increased from 43% in 2018 to 36%–58% by 2030 and 43%–60% by 2050.[39] However, as the blade size expands, the wind tower grows taller, imposing greater challenges for construction and transportation of turbines. Therefore an optimum unit capacity needs to be identified.

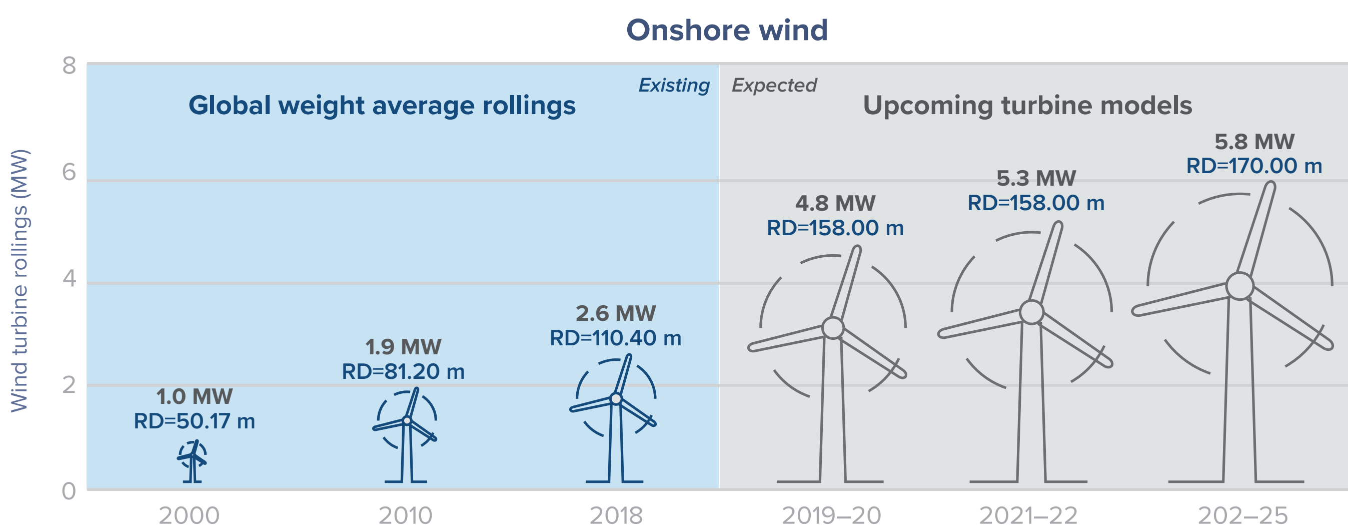
- **Materials science improves the performance of turbines.** High performance materials can also improve the power generation efficiency of turbines. For example, lightweighting of the blades, such as the use of carbon fiber composites, helps reduce the load-bearing requirements on other components, reducing the overall wind turbine cost. At the same time, lightweight turbines capture more wind energy at the same wind speed, improving conversion efficiency. Improving blade aerodynamics and materials can make the turbine more resilient to adapt to more extreme weather, especially in desert, offshore, and polar regions; prolong the useful lifetime of the equipment; and reduce operation and maintenance costs.

- **Modular design reduces manufacturing costs.** A highly customized wind turbine design is not conducive to achieving economies of scale and rapid cost reduction. Modular design can shorten the long cycle from design development, production, and launch, and can be optimized to meet the diverse needs of various projects. Modular design is also expected to solve the transportation and lifting challenges associated with large wind turbines.

- **Integrate the application of oceanography and geology into offshore wind power projects.** Foundations account for a big part of the cost of offshore wind power. In recent years, with the development of offshore wind power moving from shallow water to deep sea areas, project costs increased. By improving the understanding of geological structure, site selection, and marine knowledge, the design and development of wind power projects can be further optimized. In recent years, more

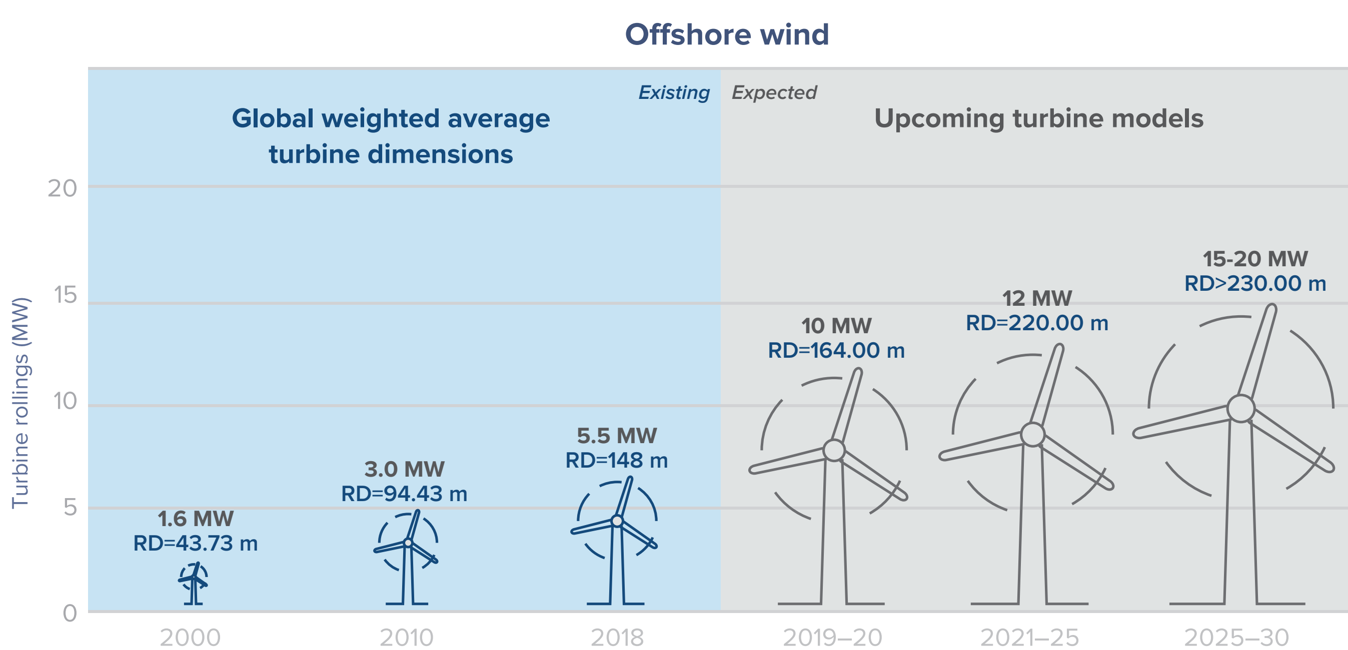
Exhibit 13

Trend of Wind Turbine Capacity



*denotes turbine developments happening from now and latest models available in the specific year.

Source: IRENA, 2019c; Wind Power Monthly, 2019, 2018.



Source: GE Renewable Energy, 2018; IRENA, 2019c, 2016b, MHI Vestas, 2018.

Source: IRENA

Exhibit 14
Estimated Floating Wind Potential in China

Depth (m)	Offshore area (km^2)	Wind power (W/m^2)	Floating wind potential (GW)
0–20	310,815	110	496
20–50	363,322	214	1,127
50–100	377,240	409	2,237

Note: The results take into consideration maritime boundaries and Exclusive Economic Zones (200NM) for China. The potential for offshore wind is estimated based on wind turbines with an average of 136 m diameter and 0.4 of efficiency (Fraunhofer IEE, n.d).

Source: IRENA

and more oil and gas companies have joined the development of offshore wind power: these companies can make full use of years of offshore drilling experience to advance the efficient development of offshore wind power.

- **Floating technology advances the use of wind power in the deep ocean.** At present, the existing offshore wind turbines in China mainly use fixed foundations, which are mostly installed in shallow sea areas, and the water depth is no more than 30 meters. Since more than 85% of wind resources are in areas with water depth over 20 meters, and the development of offshore projects needs to avoid shipping routes, offshore wind power is bound to move to the deep sea (Exhibit 14).[40] As the development of offshore wind goes into the deep sea, the water depth increases, the difficulty of installing stationary turbines increases greatly, and construction and installation costs also increase sharply.

  Floating technology is expected to enable greater use of offshore wind potential, making deep-sea projects possible. However, the development of floating wind is still immature, with limited track records globally, and still needs to be validated by the market.

- **Soft Costs**

Similar to the challenges faced by solar projects, soft costs are also a barrier that cannot be ignored for wind power projects. Unlike solar projects, the output of wind projects, especially for onshore projects, is usually higher at night and more negatively correlated with the demand load. This increases the difficulty of grid consumption and delays in interconnection approval related to these challenges can drive up soft costs.

Due to the potential risk of turbine tower collapse and the issue of noise, China’s installed wind power is still dominated by utility-scale projects. Meanwhile the development of distributed wind power is facing great obstacles, and its development scale is limited in the short term. Integrated wind and solar power development or combined development of multiple power sources can be a useful means to reduce output fluctuation of wind projects, lowering grid-connection difficulty. As mentioned in the solar PV section, emerging business models will also be applicable to the wind power industry to help solve the challenge of grid connection.

3. Recommendations

As the zero-carbon power industry matures and becomes far less dependent on subsidies, the business model is gradually shifting to a market-driven one. By setting long-term installation targets, macro planning can send clear policy signals for industry development and promote the orderly and sustainable development of the industry.

Policy

- **Establish a timeline for subsidy phaseout.** Subsidies for onshore wind and solar have been/will be gradually eliminated. However, compared with other zero-carbon technologies, offshore wind technology is still in the rising stage of development with higher technology risks and its economics still need to be greatly improved. Floating wind, in particular, will still rely heavily on subsidies in the short term.

  Referencing the phaseout history of wind and solar subsidies, subsidy signals have a significant impact on the market. The unexpected introduction of the “531” policy for solar in mid-2018 caused a huge shock to the industry and slowed the growth of installed solar capacity that year. The government needs to introduce a clear timeline for the withdrawal of offshore wind subsidies to help developers form a long-term policy vision, formulate corresponding strategic plans, accelerate cost reduction, and lock in the long-term economics of the projects.

- **Coordinate grid planning with renewable energy development.** Due to the economies of scale achieved via large-scale project development, technology costs are expected to fall further. Soft costs will account for an increasing percentage of the total generation cost and may become a challenge for renewable energy. Constrained by local grid integration capability, the actual grid connection process remains a key barrier for renewable energy project development. Grid planning should be aligned with long-term quantitative targets to ensure that local systems can support the growth of renewable energy. This, in turn, can simplify the process of new project development, drive down the cost of grid connection, and accelerate renewable energy deployment. Meanwhile, other incentive and land policies and green financing can also help reduce soft costs.

- **Improve the electricity market to provide price signals.** A well-functioning power market will optimize system operation with the most economical dispatch. In the absence of a spot market, renewable energy is currently procured at government-set prices and guaranteed operation hours. In provinces with high renewable energy penetration, renewable energy generation beyond the guaranteed operation hours is at risk of curtailment, and renewable energy operators have to pay thermal power operators to ensure generation rights. This mechanism exposes renewable energy projects to greater price uncertainty and economic risks.

- **Beware of industry transition risks.** In the past, China was highly dependent on coal power, which facilitated the creation of an advanced manufacturing supply chain. With the boom of the zero-carbon power industry, the market share of coal power will gradually shrink. While ensuring the orderly phaseout of coal-fired power plants, it is necessary to take into account the transition pressure faced by the coal sector and related manufacturing industry. Therefore, it is important to help companies leverage current advantages and transition businesses toward renewable energy.

Market

- **Be prepared for new risks and opportunities brought by power market reform.** As a spot market develops, the biggest price risk for power generation projects in the future will come from the constantly fluctuating power market price. This leads to uncertainties in the economic performance of projects. Investors need to improve their capacity building in the power market, form a vision of future price trends, and make project investment decisions. At the same time, the emergence of price signals will improve the degree of marketization of the power system. Through price dynamics, investors will be able to better assess the supply-demand relationship and explore new business opportunities such as participating in peer-to-peer transactions.

- **Upgrade grid infrastructure to support the low-carbon transformation of the power system.** The development of ultra-high voltage power transmission makes it possible to optimize renewable energy resources over long distances.

The continuous improvement and upgrading of transmission facilities has supported the development of a larger volume of wind and solar projects. In the future, along with the integration of growing distributed energy resources (DERs), grid networks will transform from the traditional unidirectional transmission to bidirectional distribution, not only requiring the hardware upgrade of the distribution networks but also disrupting the status-quo of grid operation, with the distribution level dispatch playing an increasingly important role to optimize local DERs, such as distributed solar and wind and energy storage.

- **An increasingly well-established industry value chain ensures that project development will proceed in an orderly fashion.** Although in the future large-scale capital will be deployed to support renewable energy project development, the industry still needs to continue to focus on equipment and technology innovation to ensure that China retains a leading position in advanced manufacturing. In this field, research and development efforts to address technology bottlenecks should be prioritized. This can ensure the whole supply chain is evolving in a coordinated fashion and avoid the situation that one link slows down the development of the entire industry.

V. Energy Storage: Guardian of High-Penetration Renewable Energy Systems

In 2050, China's battery energy storage capacity will reach 510 GW and the market size will reach ¥1.6 trillion (US$250 billion). This technology will contribute one-third of the carbon emissions reductions from the power system between 2020 and 2050.

Energy storage technology includes physical energy storage and chemical energy storage. Thanks to the technical characteristics of high power density and high energy density, electrochemical/battery energy storage has the most extensive application scenarios. Compared with other means of energy storage, battery energy storage has the advantages of good device mobility, fast response speed, high energy density, and high cycle efficiency, and is the current key area of energy storage research at home and abroad.

With the rigid demand of the development of renewable energy, battery energy storage is being rapidly deployed. Coupled with the limitations of pumped storage resources, site location, and the accelerated emergence of the cost-competitiveness of battery energy storage, a sharp rise of the market is expected in the future. By the end of 2019, China's cumulative installed capacity of battery energy storage was 1.7 GW, 59.4% higher than the previous year, and is expected to continue to increase at an annual rate of higher than 50%.[41] RMI estimates that battery energy storage will become the most important means of power storage in China with an installed capacity reaching 510 GW by 2050, far exceeding the pumped storage capacity of 140 GW.

With the introduction of policies by various governments to support the energy storage industry, the scale of investment in the energy storage market will continue to increase. Additionally, the deployment of the industrial chain will be optimized, the business model will be diversified, and the application scenarios will be extended at an accelerating pace.

In China, the introduction of a series of policies has accelerated the development of the energy storage industry, and the market size of the industry is about to reach a tipping point. Assuming the energy storage cost as ¥1,500/kWh (US$230/kWh) before 2030 and ¥1,000/kWh (US$155/kWh) after 2030, the market size of electrochemical energy storage in China will reach ¥1.6 trillion (US$250 billion) by 2050, and the total market space between 2020 and 2050 will reach ¥15 trillion (US$2.3 trillion). Based on the emissions reduction potential of electrochemical energy storage to replace flexible coal power units in the electric power system, this part of energy storage will contribute one-third of the total carbon dioxide emissions reductions of China's power system from 2020 to 2050, reaching more than 10.6 billion tons.

We believe that the development of the energy storage market under the trend of zero-carbon energy transition will show two major trends, and correspondingly, the energy storage technology with the most potential for development and scale will also have certain characteristics. By understanding the trend of zero-carbon energy transition and analyzing the characteristics of various energy storage technologies, energy storage technologies and applications with broad application prospects can be selected as the key directions of investment in energy storage and the zero-carbon energy transition. These are expected to develop rapidly in the near- and medium-term and generate relatively large investment returns.

Trend 1: Distributed energy storage will be gradually applied in scale under the trend of Internet of Energy (IoE).

Distributed energy systems will widely exist in IoE, especially in the industrial and commercial application scenarios. Meanwhile, in the context of large-scale development of new infrastructure and 5G technologies, standby power supply is also an application scenario with a huge market potential.

Under this trend, special attention should be paid to technologies with good operational safety, high freedom of site selection, and cost-competitiveness.

In addition, the scale effect brought by the development of the EV industry will greatly promote the comprehensive application of energy storage and activate demand-side management potential. Options with high energy density, good safety, low costs, and long lives will become the focus of technological development and investment. In these consumer and distributed use cases, cost-competitiveness is a core factor in market expansion.

Trend 2: The integration of a high share of renewables in zero-carbon power systems is creating demand for large-scale energy storage.

In the zero-carbon scenario analyzed by RMI and the ETC, nearly 70% of power generation in China's power system will come from wind and solar by 2050. Due to the variability of these resources, a high share of wind and solar will create a large-scale energy storage market to meet the requirements of balancing power supply and demand in the system.

In this scenario, the function of the energy storage system is to improve the ability of solar and wind generation to follow the output schedule, improve the grid integration of renewables, and promote nearby consumption of renewable power. Under this requirement, technologies with large storage capacity, long continuous discharge time, high system efficiency, and good cycling performance will stand out. Flow batteries are currently the technology drawing the most attention for large-scale energy storage.

In general, China is still in the initial stage of energy storage industrialization, and it is more likely to see the coexistence of various energy storage technologies in the future. Due to their different characteristics, different technologies show their advantages in different application fields. The mainstream energy storage technology in the future will be based on market selection. At present, there is no one technology that can fully meet the five key technical indexes of energy storage, namely cycle life, scalability, safety, economy, and high energy density. In general, the three most promising energy storage technologies are lithium-ion (Li-ion) batteries, lead-carbon batteries, and flow batteries.

Li-ion is currently the mainstream battery technology thanks to the cost advantage brought by the scaling of the EV industry. RMI predicts that the next breakthroughs of cost reduction and efficiency improvements will be achieved through the upgrade of electrode materials and the optimization of electrolytes.

From the perspective of the development path of the industry, in the short term, EV batteries are still the most important market for lithium-ion batteries, and lithium-ion batteries will also depend on this market to rapidly scale. With the continuous reduction of lithium-ion battery costs and rapid development of the industry, it is expected that lithium-ion batteries will continue to be the main energy storage technology in the future. If further breakthroughs are made in key performance parameters such as safety and cycle life, Li-ion batteries may become a powerful competitor to flow batteries in the large-scale energy storage market. At present, domestic large-scale energy storage demonstration projects such as the wind and solar storage project in Zhangbei and CSG Baoqing power storage station typically utilize lithium-ion battery technology.

With good charge and discharge performance, fast response speed, and high energy density, lithium-ion batteries have technical and cost advantages in many application fields. By the end of 2019, the cumulative installed capacity of lithium-ion batteries in China reached 1,378.3 MW, accounting for more than 80% of the total electrochemical energy storage in operation in the nation. Lithium-ion batteries have clearly achieved a certain market scale in the field of energy storage and are in the Slope of Enlightenment stage. To continue the development of the industry to enter the Plateau of Productivity stage, lithium-ion batteries need to make further technological breakthroughs, continuously reduce costs to consolidate existing markets, and optimize performance to penetrate into new markets.

The major breakthrough direction of lithium-ion battery technology lies in the upgrading of electrode materials and the optimization of electrolyte materials. In terms of upgrading electrode materials, the energy densities of lithium iron phosphate and lithium manganate oxide batteries are close to the theoretical limit. Room for development still exists for lithium cobalt oxide batteries and ternary lithium-ion batteries. By developing ternary materials with high nickel, low cobalt, or no cobalt, further cost reduction and efficiency improvements can be achieved. If lithium manganese-based anode materials are used, the theoretical capacity limit will reach as high as 480 mAh/g. The best levels that can be achieved by the Chinese laboratory and industry currently are 400 mAh/g and 300 mAh/g respectively, however, both can be further improved.

In addition, the specific capacity of the anode material is the key, and can be as high as 1,000 mAh/g, far exceeding the existing anode material. However, due to the structural limitations of the anode material, the actual specific capacity generally does not exceed 150 mAh/g. However, the improvement of battery energy density must be based on the guarantee of safety. Therefore, the safety of material systems and technology is very important. The development of battery safety technologies that prevent short circuits, overcharging, thermal runaway, and combustion is an effective way to solve the safety problem.

In terms of the optimization of electrolyte materials, solid-state batteries using solid electrolytes have greater potential in terms of safety and energy density, and have been widely monitored by academia and industry in recent years. In principle, solid electrolytes have good adaptability, which is conducive to the improvement of energy density, while solid electrolyte insulation can avoid short circuits and act as a diaphragm.

The new solid-state batteries developed by Solid Power not only replace the graphite anode with a lithium metal material but also replace the liquid electrolyte and diaphragm with a solid piece, usually ceramic, glass, or flame-retardant polymer. This increases the energy density by at least 50%.

In addition, the optimization of electrolyte materials will greatly improve the safety of lithium-ion batteries. From the perspective of technology analysis, "dendrite" is a problem unique to the liquid electrolyte used in lithium-ion batteries, in which the reductive crystal of lithium-ion keeps growing and may puncture the diaphragm. To overcome this issue, breakthroughs are mainly sought from two perspectives: one is coating and the other is the study of solid electrolytes.

The first-mover advantage of lead-acid batteries has occupied part of the market share in the early stage and the market is mainly focused on specific scenarios such as 5G base stations. However, the rapid cost reduction and efficiency improvement of lithium batteries have a great impact on lead-carbon batteries.

Lead-acid is one of the most mature battery chemistries. Because of its early development, it has a first mover advantage in the market, and its cost advantage is very significant. At present, the sales revenue of lead-acid batteries accounts for a large portion of the entire battery industry. Although part of the market share is gradually being replaced by lithium-ion batteries, the market position of lead-acid batteries is still hard to shake in the short term.

Lead-acid batteries will still be a promising investment hotspot given that continuous technological breakthroughs can be achieved. However, whether it will be phased out in the long run depends on whether its cost performance can meet the requirements of the market, and whether it can maintain its competitive advantage compared with increasingly cheaper and more efficient lithium-ion batteries.

Lead-carbon batteries are a technology evolved from traditional lead-acid batteries. The performance of lead-acid batteries is improved significantly by adding activated carbon to the cathode. Through continuous technological breakthroughs, lead-carbon batteries’ performance has been improved by eight times for charging speed compared with traditional lead-acid batteries, three times for discharging power, and six times for cycle life, with the number of charging cycles reaching 2,000.

Lead-carbon batteries are in the Slope of Enlightenment stage on the technology maturity curve. Based on the existing advantages of lead-acid batteries, lead-carbon batteries have locked up a certain market share and become one of the preferred technologies in some distributed power generation and micro-grid projects. However, if lead-carbon batteries want to further enter the Plateau of Productivity stage, similar to lithium-ion batteries, the existing market needs to be consolidated through cost reduction and efficiency improvement. Additionally, performance breakthroughs need to be sought to take on the market for new application scenarios.

At present, China still lags behind developed countries in key technologies and engineering applications of lead-carbon batteries, with high-performance carbon materials still highly dependent on imports and insufficient system integration capacity. Moreover, although lead-carbon batteries cost less than lithium batteries, because of the higher energy density and higher charge and discharge capacity of the latter, lead-carbon batteries are still at a competitive disadvantage in seconds/minutes-level frequency adjustment or land-sensitive applications.

In the long term, the rapidly reducing cost and improving efficiency of lithium batteries may also pose a great threat to lead-carbon batteries. As a result, while we expect technical breakthroughs, it is also important for investors to keep an eye on the competitive landscape of different types of batteries.

Flow batteries have broad prospects in the large-capacity energy storage market, but the technology needs to be optimized quickly and cost must be reduced before the market erupts. Potential breakthroughs lie in the reduction of upstream material costs and the improvement of system energy density.

Unlike lithium-ion and lead-carbon batteries, flow batteries are aimed primarily at the high-capacity energy storage market because they are best suited to the high-capacity needs of a grid with a high share of wind and solar. A large amount of electrolyte solution can be stored externally, so the capacity of flow batteries can be greatly improved compared with ordinary batteries. Flow batteries generally have long lives unless they are polluted and can be charged and discharged with higher power. Moreover, because the electrolyte is stored separately for the anode and cathode, it has a high level of safety, which is unmatched by other batteries in large-scale energy storage applications.

At present, flow batteries are still in the Technology Trigger stage. Although demonstrative pilots have been established, they have not been commercialized on a large scale. A market for capacity-type energy storage has not really emerged and the technology cost is still high. But under the trend of zero-carbon energy transition, if wind and solar power supply 70% of China's power generation by 2050, the market for large-scale energy storage could explode shortly. Therefore, for the further development of flow batteries, the main breakthrough lies in the rapid optimization of technology to be prepared before the full opening of the market.

Vanadium flow batteries are the most promising flow batteries in the market, and their technical breakthroughs lie in the reduction of material cost and the improvement of energy density. First of all, the diaphragm is a key component of a flow battery, and its performance significantly restricts the performance and production cost of the battery. A diaphragm with high ion selectivity can greatly improve cell efficiency. At present, domestic diaphragms are mainly dependent on imports, so the cost is high.

The new generation of battery packs developed by Dalian Institute of Chemical Physics uses a weldable multi-porous ion conductive film to achieve the process improvement of the battery pack. This greatly improves the ion selectivity and not only maintains the high power density, but also reduces the total cost by 40%. In addition, research into new electrolyte and material replacement shows significant cost reduction potential. Vanadium ions are used in both anode- and cathode-side liquids on two sides of the diaphragm of current commercial flow batteries, but the cost is high, and the potential pollution problems need to be avoided.

The world's largest flow battery is being used at a wind farm in China, with a cost that may reach as high as US$1,000/kWh. In recent years, organic flow batteries are also an exciting field. Foreign studies have shown that low-cost quinone substances used in flow batteries can perform well in charge and discharge, while the cost can be reduced to less than US$100/kWh. Due to their large volumes, the energy density of conventional flow batteries is relatively low. The organic flow battery developed by domestic institutions has improved the energy density to more than four times the traditional flow battery level of 50 Wh/L. It additionally avoids the limitation of low reserve of metal elements in electrolyte, has relatively simple processes, and can be produced at a large scale.

Under the carbon-neutrality goal, the future development direction of energy storage will be closer to specific application scenarios. The three core elements, including economics, safety, and battery recyclability, need to be considered comprehensively.

Overall, China's energy storage technology as a whole is still in the early stage of industrialization, but due to the diversity of application scenarios and the differences among applicable technologies, technologies most in line with the future trends have already emerged, or are in the Slope of Enlightenment stage and are rapidly entering the Plateau of Productivity stage of the industry (such as lithium-ion batteries and lead-carbon batteries), or are in the Technology Trigger stage but have broad market prospects (such as flow batteries). Therefore, for investors, attention should be paid to the timing of the key factors that promote the development of the entire energy storage industry; while at the same time identifying the stages in which some key technologies with the best prospects are located.

From the perspective of the energy storage industry as a whole, the price mechanism of energy storage in China is not clear at present. This makes it difficult to estimate project investment recovery and profitability, and regulation and support by relevant policies are needed. At present, reform of the electricity market is the most anticipated.

As part of this, it is necessary to define and implement earning mechanisms for energy storage. These include recognition of the status of energy storage in the auxiliary services market, the establishment of pricing and transaction policies and patterns, optimization of compensation mechanisms, and opening of power sales to release the application market for energy storage in distributed generation and micro-grid applications. Additionally, some preferential policies should be adopted to support the early market, such as expanding the procurement support for energy storage projects and encouraging the launch of financial tax incentives, tax credits, or loan incentives for energy storage projects.

For promising technologies, investors can pay attention to the improvement of cost-competitiveness of the technology in its development stage and its penetration in key markets. Due to the diversity of application scenarios and the differences between applicable technologies, China's energy storage industry will present a state that is led by mainstream technologies where multiple technologies co-exist. The technological level of lithium-ion batteries and lead-carbon batteries is relatively mature, and this has been tested in the market to a certain extent. They have entered the Slope of Enlightenment stage and are moving rapidly toward the Plateau of Productivity stage. Accordingly, potential targets of investment should have the following characteristics:

- They must be able to maintain and optimize a cost advantage.

From 2010 to 2019, the average market price of lithium-ion battery packs dropped 87% from US$1,100/kWh to US$156/kWh, with further room to fall. It is likely to fall to US$100/kWh by 2024 and to US$60/kWh by 2030.[42] Under this trend, the energy storage cost of lithium-ion batteries will enter into the full commercial range shortly. Similarly, the cost of lead-carbon batteries is very competitive, being only one-third that of lithium-ion batteries. In application scenarios without too high of requirements for energy density, the market advantage of lead-carbon batteries will be maintained. However, the rapid cost reduction and efficiency increase of lithium batteries may also reverse this competitive pattern.

- They must achieve performance breakthroughs and penetrate into new markets.

While lithium-ion is widely regarded as a promising chemistry for EV batteries, it does not have a competitive advantage in the field of high-capacity energy storage applications. This is because lithium-ion batteries for energy storage have relatively lower requirements on energy density, but higher requirements on safety, cycle life, and cost. Whether lithium batteries can occupy a larger share of the market depends on whether the contribution of the established economy of scale to the cost reduction will enable them to compete with other current large-scale energy storage technologies with higher costs but better performance. It also depends on the performance improvement of future lithium-ion batteries through technological breakthroughs.

Lead-carbon batteries evolved from traditional lead-acid batteries. By adding activated carbon in the cathode, it not only has the high specific energy of a lead-acid battery, but also realizes large capacity charging in a short time. This greatly broadens its applicable scenarios. Therefore, new market opportunities created by improved performance are also worth investors' attention.

In addition, the technologies in earlier stages represented by flow batteries are also rising rapidly. Although they are still in the Technology Trigger stage, flow batteries have drawn wide attention thanks to the huge potential market space. For flow batteries, investment recommendations include:

- Focus on technological progress to preempt preparation time before demand outbursts.

The technology maturity level of flow batteries is lower than that of lithium-ion batteries and lead-carbon batteries. However, at the same time, the initiation of the target market for flow batteries is also later than that for lithium-ion batteries and lead-carbon batteries.

At present, vanadium flow batteries are already used in industrialized applications, but because the large-scale energy storage market is still small, the scale effect has not been formed. Addressing the question of how to quickly reduce costs and establish absolute competitive advantages before the explosion of market demand for large-scale energy storage is the key for flow batteries to successfully pass the Technology Trigger stage and survive the Trough of Disillusionment stage.

In this process, breakthroughs are urgently needed in core technologies, including highly stable electrolytes, high-selectivity ion exchange membranes, and mass production of key materials at a low cost. If the technological breakthrough lags behind the market explosion, the advantages of flow batteries will not necessarily translate into market success. But if the technology is in place, the market prospect will be very broad.

- Follow policy signals, especially support for the large-scale energy storage market.

For the development of flow batteries it will be necessary to quickly reap the benefits of the scale effect, and policy support is particularly important in the Technology Trigger stage. The positive signals at the policy level include two aspects. The first is strong support for technology development and the establishment of demonstration projects for approximately 10–100 MW systems. The second is investment in a practical business model.

Because the capital cost and risk brought by large-scale systems are major obstacles in the commercialization process, policy design should

ensure investors of grid-connected renewable energy storage projects can recover their investments and obtain profits. Without market mechanisms and a policy foundation, it is difficult to establish commercial energy storage applications that can be regulated by the market and achieve a high share of renewable energy integration.

- Focus on market segments and accurately analyze market competition patterns.

Flow batteries are recognized as the most suitable battery technology for large-scale energy storage in the industry. They have inherent advantages in issues including long-term and large-scale energy storage that other technologies cannot solve easily. Therefore, flow batteries are most applicable in inter-day or even seasonal storage applications.

From the perspective of competition, lithium-ion batteries have a low cost due to their scale advantage and are considered powerful competitors to flow batteries in some scenarios. However, it is difficult for lithium-ion batteries to enter specific market segments due to limitations on size and cycle life. It is critical for investors in flow batteries to find this part of the market, make full use of its strengths, avoid shortcomings, and expand advantages.

VI. Hydrogen: A Vital Solution toward the Carbon-Neutrality Goal

Hydrogen is an important pillar of the global energy transition. As an energy carrier that can be produced entirely from renewables, that has high energy density, and that only produces water when burned, green hydrogen will definitely play a vital role in the clean and zero-carbon energy transition in China and the world.

Studies by the International Energy Agency, McKinsey & Company, the Energy Transitions Commission, and the Hydrogen Council all confirm that hydrogen can help solve many challenges facing the current energy industry. It can provide the most promising alternative route for zero-carbon steelmaking. It can be used to decarbonize chemical production including ammonia and methanol by material substitution and fuel switching. It can also serve as a new, green fuel for freight, shipping, aviation, and other long-distance transportation industries given its high energy density and low volumetric density. At the same time, hydrogen can provide a lower-cost way to provide energy storage and flexibility services and promote diversification of energy structures and security of energy supply.

Exhibit 15

Hydrogen Consumption in 2050 under the Zero-Carbon Scenario (million tons)

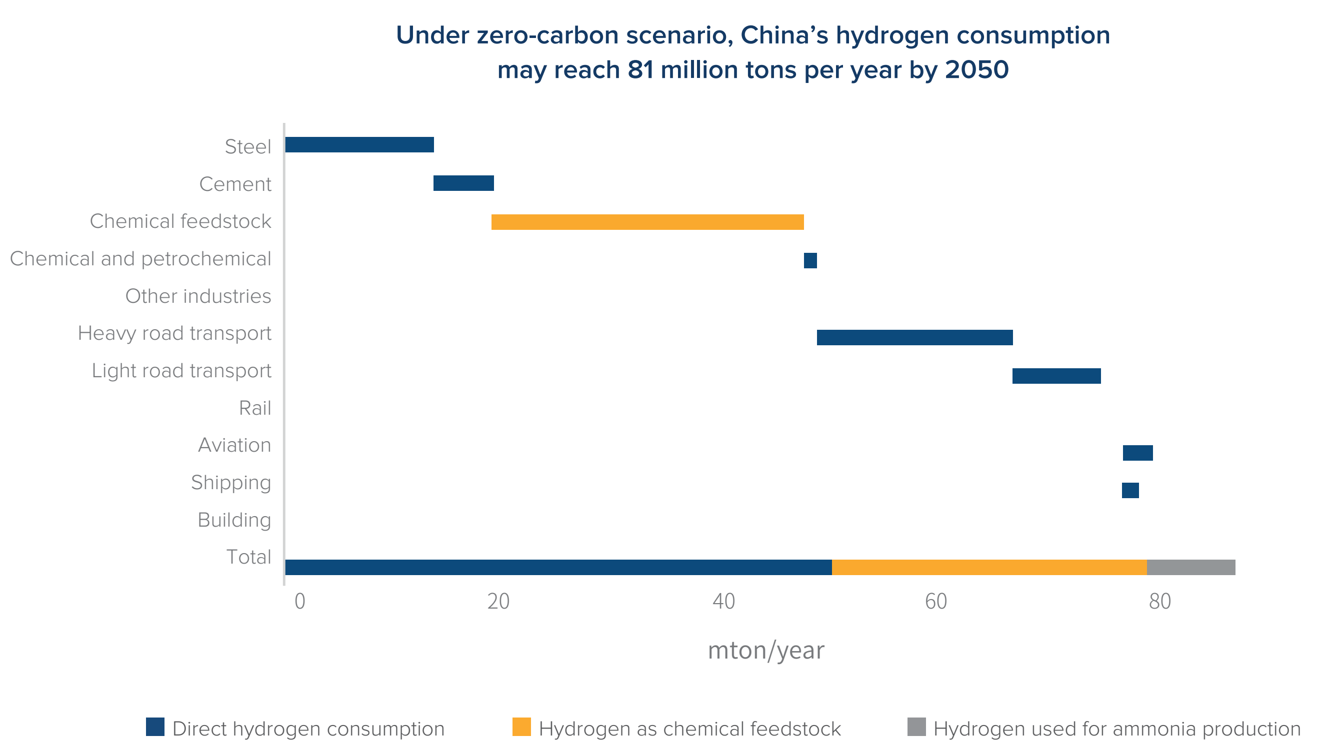
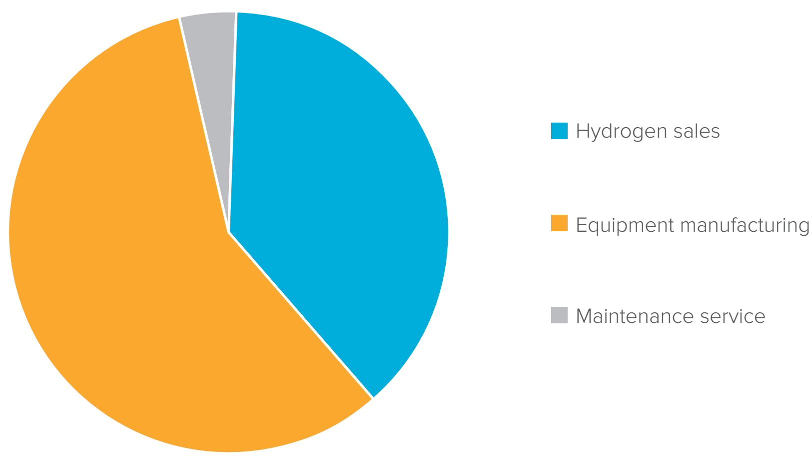


Exhibit 16
Potential Market Size of the Hydrogen Industry Value Chain in 2050



According to the RMI's estimates, under the zero-carbon scenario, China's hydrogen demand would increase from the current 25 million tons per year to 81 million tons per year in 2050 (Exhibit 15). Using only green hydrogen would decrease carbon dioxide emissions by more than 20 billion tons within the next three decades for the zero-carbon energy transition.

The future market potential of hydrogen is huge, and the sales of hydrogen alone would bring an annual market value of ¥630 billion (US$98 billion) in 2050. At the same time, the whole hydrogen value chain—the electrolyzers at the production end; the storage tanks, transmission pipelines and refueling stations at the transportation end; and the fuel cell vehicles, ships, airplanes, and equipment such as new synthetic furnaces and combustion furnaces in steel and chemical industry at the utilization end—will also bring huge economic contribution. RMI estimates that the output value of equipment produced would reach ¥900 billion (US$140 billion) in 2050 alone, bringing the total output value of the hydrogen industry to ¥1.6 trillion (US$248 billion) in 2050 (Exhibit 16).

1. Industry Status Quo and Future Trends

The development of hydrogen requires the co-construction of two ends: the hydrogen source and market demand. Under the zero-carbon China scenario, the hydrogen source has to be green and clean, mainly from water electrolysis combined with renewable energy. The market demand for hydrogen includes many energy sectors such as transportation and industry. This market demand will drive the scaling of hydrogen production and the decrease of hydrogen cost will in turn further promote the market expansion of hydrogen applications. The two ends in this relationship will mutually reinforce each other. At the same time, the market demand for hydrogen will drive the development of hydrogen storage and transportation.

From the perspective of development stages, hydrogen technologies are in the early periods of growth as a whole and have different speeds and multiple phases in the future. First, the production path will gradually shift from combined green and grey hydrogen to completely green hydrogen. Multiple technology routes for green hydrogen production will bloom simultaneously with expanding capacity sizes. While alkaline electrolyzer technology is relatively mature, emerging routes such as polymer electrolyte membrane (PEM) electrolysis and solid oxide electrolyzer cells (SOECs) provide stronger adaptability to renewable energy fluctuation, and other green hydrogen production routes like methane pyrolysis are also under development.

Second, on the market demand side, the transportation sector may develop prior to the industry sector. Hydrogen fuel cell technology is entering the Peak of Inflated Expectations phase, becoming a market hotspot. An increasing number of companies and volume of investment is rushing into the hydrogen market across the country and industrial forms like hydrogen industry parks are emerging continuously. Meanwhile, more than 40 provinces and cities have established development plans for the hydrogen industry.

The industrial application of hydrogen technology is still in the Technology Trigger phase, but it has the potential to be a huge market in the future. Demonstration projects such as green hydrogen direct reduction iron and green ammonia have been established in many countries around the world, which will bring new directions for industrial technology and create a huge demand for green hydrogen.

Finally, for hydrogen storage and transportation, the development will start with compressed gas hydrogen and move to liquid hydrogen, and then a pipeline network. In terms of market shape, we expect a start from point-to-point transportation of hydrogen storage tanks, to a national transportation network of storage tanks, and finally to pipelines with a potential international market gradually forming in the future. The development of the hydrogen industry chain will create an ecosystem consisting of production, storage, transportation, and use that will jointly promote technological progress, cost reduction, and market expansion of the hydrogen industry.

However, for hydrogen industries, especially those technologies in the Inflated Expectations phase, it will be vital to avoid low-quality development and blind expansion, prevent the arrival of the Trough of Disillusionment phase, and reduce the risk of investment failure. It is important to focus on the breakthroughs of key technologies, the establishment of core competitiveness, and the systematic support and cultivation of industry chains.

1) Hydrogen Production Technology: Factors Needed for Green Hydrogen to Compete with Fossil Fuel-Based Hydrogen

Only real green hydrogen can realize the clean energy aim of hydrogen. As the main route to produce "green hydrogen," water electrolysis powered by renewable energy only accounts for 4% of the 25 million tons of hydrogen currently produced annually in China. Another 40% comes from coal gasification, and 12% from steam methane reforming and other fossil-based routes. Under the zero-carbon goal, hydrogen production from water electrolysis powered by renewable energy will become the main source of hydrogen. At present, the application scale of water electrolysis is expanding, and it is gradually stepping into the megawatt level.

At present, water electrolysis hydrogen production routes mainly include alkaline electrolysis, polymer electrolyte membrane (PEM) electrolysis, and SOECs. Alkaline electrolysis was first commercialized and applied on a large scale, but it has some disadvantages. These include low energy efficiency, limited ability to operate at low loads, and large space requirements. Although PEM technology is not fully mature, many experts believe that it will become the mainstream technology in a future power system based on distributed energy due to its better flexibility and rapid system response that makes it more suitable for combining with renewable power.

The main challenge for water electrolysis is cost. The cost of hydrogen production from water electrolysis is still two to three times that of hydrogen production from coal, given the current technology level, industry scale, and cost of electricity (Exhibit 17).

But the cost reduction potential of hydrogen production from water electrolysis is huge. According to estimates by BNEF and other organizations,[43] the cost of hydrogen from water electrolysis will fall by about 50% by 2030, and it will reach cost parity with the production of hydrogen from fossil fuels by 2050. The major drivers of hydrogen cost reduction are cheap electricity, improvements in the efficiency of electrolyzers, and equipment cost reduction. These in turn will depend on the interaction of technological breakthroughs, production scale effects, and electricity price reforms.

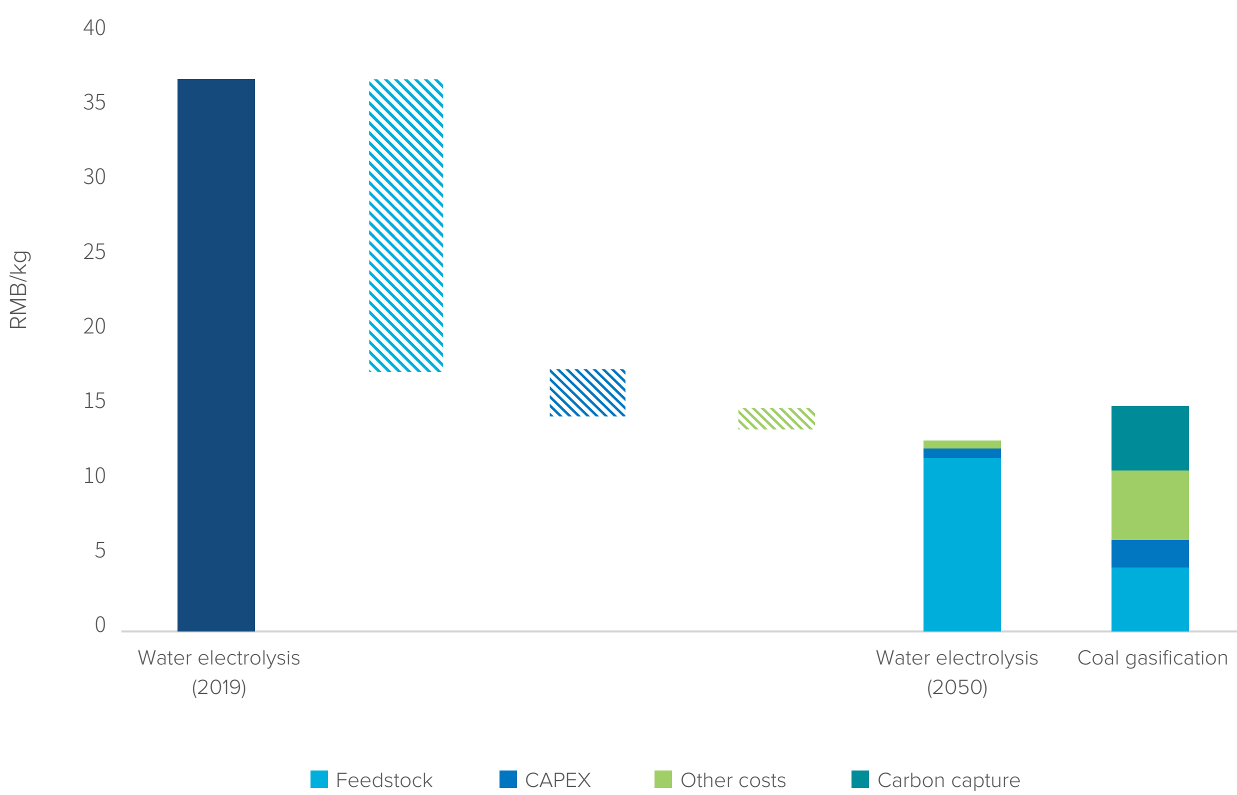
Trend 1: Optimization of electrolyzer technology routes, with electrolysis energy efficiency improvements catalyzing cost reductions.

While the cost of electrolyzers in China is already far lower than in Europe and the United States, domestic electrolyzer technology is not fully mature. In particular, the energy efficiency of electrolyzers can be further improved. The current power consumption intensity of electrolyzers is around 55 kWh/kg H_2 in China. Whereas the target value by the US Department of Energy is 44 kWh/kg H_2, and the theoretical limit value is 40 kWh/kg H_2.

The main influencing factors for the energy efficiency of electrolyzers include the type of electrolyte, the form of electrode, and their combination mode (spacing, quantity, surface shape, and combination mode of connection configurations). For electrolyte types, the electrolytes of PEM electrolyzers are solid polymers and their theoretical energy efficiency can reach a higher level than that of alkaline electrolyzers. However, PEM still needs technology improvement. SOECs use solid oxides as electrolyte materials, which are expected to further improve the efficiency of water electrolysis hydrogen production. However,

Exhibit 17

Hydrogen Cost Comparison between Water Electrolysis and Coal Gasification



the technology maturity of SOECs is low, and it is still limited to the laboratory or small-scale demonstrations.

As for the form and combination mode of the electrodes, specific parameters still need to be optimized to achieve optimal energy efficiency. These include the specific electrolyte concentration, the number of electrodes, and the form in which they are arranged. For example, some experiments have designed platinum electrodes in PEM in pinecone-like structures to expand the reaction area and accelerate the rate of hydrogen generation.

The production cost of PEM electrolyzers are still high due to the need to use precious heavy metals such as platinum and iridium as catalysts, making material replacement of catalysts another key area ripe for technological breakthrough. Recent research has focused on new catalysts such as ferro-nickel and chromium phosphide.

In addition, anion exchange membrane (AEM) electrolysis provides another technical direction. This technology combines solid electrolyte and alkaline systems and uses low-cost non-precious metals such as iron and nickel as catalysts under alkaline conditions. This greatly reduces the cost of electrolyzers. However, the AEM route is still in the early stages of commercialization. Many research teams and university laboratories around the world are working in this field, including the US Department of Energy's National Renewable Energy Laboratory, Proton Onsite, Dalian Institute of Chemical Physics of Chinese Academy of Sciences, and Wuhan University.

Trend 2: Scaling the market and improving automation levels will help reduce the production cost of electrolyzers.

At present, the production cost of alkaline electrolyzers in China is around $200 per kilowatt, which is about one-sixth of the foreign level. To a certain extent this is due to the low labor cost and the scale economy effect. In the future, with the further expansion of market scale and the continuous improvement of production automation levels, the production cost of alkaline electrolyzers and PEM electrolyzers will be further reduced significantly. According to BNEF analysis, the production cost of alkaline electrolyzers could be as low as $80 per kilowatt (kW), and that of PEM electrolyzers could fall to about $100/kW by 2050.[44]

Trend 3: Reduce the power cost of hydrogen production and use curtailed wind and solar power as power supplies for green hydrogen production.

Electricity costs account for more than 70% of hydrogen costs. Reducing the cost of electricity is key to improving the cost-competitiveness of hydrogen production from water electrolysis. With further decreases in the cost of wind and solar power, the production cost of "green hydrogen" will be greatly reduced in the next few decades.

In the short term, water electrolysis hydrogen production could be first deployed in regions including North China, Yunnan Province, and Sichuan Province by using cheap power resources such as curtailed wind, solar, and hydro power to provide clean hydrogen. In addition, hydrogen produced as an industrial by-product can be used as another transitional option for clean hydrogen supply. Hydrogen from industrial production, such as from steel and chlor-alkali, can be separated using the pressure swing absorption method with insignificant additional carbon emissions at a low cost.

2) Application in the transportation sector: Key points under rapid market expansion.

The transportation sector will undoubtedly be the initial market of hydrogen considering technological development, policy support, and current market size. Due to their low emissions level, high energy density, good environmental characteristics, and adaptability to longer driving range, hydrogen fuel cells can be applied to passenger vehicles, heavy-duty trucks, ships, aircrafts, and other modes of transportation. Although current fuel cell technology is still imperfect and the market is small compared to that of electric vehicles, the next decade will be an important period of strategic opportunity.

Hydrogen fuel cell vehicles are entering the Inflated Expectations phase and the market is expanding rapidly. Companies including Toyota, Honda, and Hyundai have already achieved mass production of fuel cell vehicles. In China, many provinces and cities have successively launched policies to support the fuel cell industry and made great efforts to deploy this emerging technology.

In 2018 alone, the related investment and planning funds of the hydrogen fuel cell industry exceeded ¥85 billion (US$13 billion). The sales numbers of hydrogen fuel cell vehicles in China also increased rapidly from 10 in 2015 to 2,737 in 2019, with a series of companies including Sinohytec emerging in the hydrogen fuel cell vehicle industry chain. Policy incentives and capital inflows are gradually pushing fuel cell vehicles to a hotspot, boosting technological breakthroughs and industrial development.

Fuel cells are also emerging as the next key market for hydrogen transport applications in the shipping and aviation sectors. Ballard launched its first fuel cell power module for ships in September 2020, with a 200 kW power capacity that can be connected in series to the megawatt level. Companies including ZeroAvia, HES, and others are developing small fuel-cell passenger planes, and the former has made its first test flight.

It is important to note that there is a "chicken and egg" issue between the market demand and infrastructure of the hydrogen industry. The development of hydrogen applications in the transportation sector is not only about the fuel cell vehicles, but more a dynamic process that also involves hydrogen refueling stations and hydrogen storage technologies. Fuel cell vehicles bring initial demand for hydrogen storage and transportation, and the deployment of hydrogen refueling stations is an important link in reducing the total use cost of fuel cell vehicles.

Starting from fuel cell transportation, it is necessary to develop the technology and market in a complete ecosystem from material, storage, transportation, and fueling to the final operation and user service. It will also be necessary to constantly provide feedback and optimization, so as to avoid any link becoming defective.

Trend 1: Fuel cell vehicles need to overcome the constraints of system durability and cost to improve market competitiveness.

At present, the biggest technical challenge restricting the commercialization of fuel cell vehicles is the durability of fuel cell systems. Take heavy-duty truck fuel cells as an example: the stable life of hydrogen fuel cells produced by relevant companies in China can only reach about 10,000 hours, while better ones can reach 20,000–30,000 hours in foreign countries. The main reason for the reduced durability is that the wear and tear of the fuel cell materials will be accelerated in the frequent variable operation conditions of the vehicles such as starting and stopping and changing speed.

To improve the durability of fuel cell systems, vehicle control systems and strategies should be optimized to delay deterioration. Additionally, it is necessary to improve key materials such as catalysts, membrane electrodes, and bipolar plates by finding stable and cost-effective new materials that can resist the harsh working conditions of vehicles.

In particular, for the bipolar plate, it is necessary to meet the requirements of conductivity, corrosion resistance, and low weight to improve the durability of the fuel cell system. At present, there are three types of bipolar plates: graphite, metal, and mixed graphite and metal. Graphite plates have been used earlier, but they cannot meet the requirement of low weight at present, and there are potential safety problems. Thin metal bipolar plates can meet the requirements of low weight, and these are the current focus of research. However, challenges including conductivity, corrosion resistance, and cost-competitiveness still exist. Mixed graphite and metal bipolar plates that combine the advantages of the two are also in development.

Exhibit 18

Development of the Chinese Hydrogen Fuel Cell Vehicle Value Chain

Upstream
Fuel cell stack manufacturers

Domestic production scale of core components of fuel cell stack (MEA, electrode, bipolar plates, etc.) is small and dependent on import.

Midstream
Fuel cell engine system manufacturers

At present, the fuel cell engine system has a relatively complex stack structure and has high requirements for auxiliary parts, in which China still lags behind.

Downstream
Vehicle OEMs

Some OEMs haven't grasped the core technology of fuel cells and rely on fuel cell system manufacturers to provide vehicle power system engineering solution

In addition, the cost of fuel cell vehicle systems is still high. But with the expansion of market supply and demand, scale effects will greatly accelerate the pace of cost reduction. RMI's estimates based on the learning curve show that the unit cost of battery stacks could fall by 50% from ¥6,500/kW (US$1,006/kW) today to as low as ¥400/kW–¥600/kW (US$62/kW–US$93/kW) by 2050.

Trend 2: The fuel cell industry is constantly improving its localization level but needs to fill the technical gaps and improve the quality of equipment.

From the perspective of the fuel cell industry chain as a whole, China's manufacturing strength in key materials and core components is still relatively weak. First, the upstream fuel cell battery stack components have not been fully localized. The production of membrane electrodes and bipolar plates has not been fully scaled. Components such as carbon paper and rubber gasket are dependent on imports with high prices. And though materials such as PEM and catalysts have achieved mass production in recent years, their performance still lags far behind foreign alternatives.

Second, fuel cell engine manufacturers such as Sinohytec and Refire have emerged in China, and domestic manufacturers in fields like air compressors and hydrogen pumps also have gradually achieved breakthroughs. However, for humidifiers and other key equipment, China still has no mature products, and relies on the United States, Japan, Germany and other countries to supply these.

Finally, for original equipment manufacturers (OEMs), without mastering the core technology, the overall performance of fuel cell vehicles will be limited by the performance of upstream equipment components. In 2020, Toyota, FAW, Dongfeng, GAC, and BAIC established a fuel cell system R&D company in cooperation with Sinohytec, indicating the gradual emergence of a trend of automobile manufacturers entering the upstream market. This will drive the localization of core components and key materials.

Trend 3: Fuel cell transport and hydrogen storage and transportation industries will develop together to establish a hydrogen ecosystem.

The development of hydrogen storage and transportation technology is an indispensable foundation for a hydrogen ecosystem. As fuel cell vehicles are creating a demand for hydrogen, as their use grows so must hydrogen storage and transportation, as well as hydrogen refueling station systems. Reducing the cost of hydrogen storage and transportation and the cost of hydrogen refueling stations will help reduce the total use cost of vehicles and promote the adoption of fuel cell vehicles.

At present, hydrogen storage and transportation systems mainly operate on short distances and in a distributed fashion. These use the form of compressed gas hydrogen storage. In the future, the hydrogen storage and transportation system will shift toward a diverse form consisting of multiple technical paths such as gas or liquid hydrogen storage for short-to-medium distances, hydrogen pipelines and chemical storage (liquid ammonia storage, organic liquid storage, etc.) for long distances, and coexistence of distributed and centralized systems.

Currently, the energy density of short-to-medium-distance hydrogen storage still needs to be improved. The US Department of Energy requires domestic on-board hydrogen storage to have a hydrogen energy density of 4.5% by 2020, 5.5% by 2025, and an eventual target of 6.5%.[45] For gaseous hydrogen storage, the materials used in hydrogen storage tanks need to be optimized. At present, type III tanks using carbon fiber with a metal liner have a hydrogen storage energy density of 3.8%–4.5%, type IV tanks using carbon fiber with a plastic liner have a hydrogen storage mass density of 4.0%–7.0%, while the type V tank removes the liner from the lightweight carbon fiber-wrapped tank.

The core technology of hydrogen tanks lies in the efficient and low-cost outer layer carbon fiber and wrapping, as well as metal valves, sealing, and sensors. Liquid hydrogen storage still has relatively higher costs and requires technological breakthroughs and scale expansion. In addition, hydrogen storage by adsorption is another direction of technological development. The adsorption materials used mainly include metal alloys, carbon nanotubes, surface activated carbon, and metal frames. Using these, the energy density of hydrogen can reach 10% or even 15% in the laboratory.

The scale of long-distance hydrogen transport by pipeline and chemical hydrogen storage is still small. However, in recent years, with an increasing number of green hydrogen projects, several pipeline hydrogen transport projects are under development in Europe and elsewhere. In addition, the development of an international hydrogen trade has also promoted the development of new means of storage and transportation, such as hydrogen storage in liquid ammonia that are suitable for shipping. The scales of these technologies are expected to expand in the future.

The technology of hydrogen storage and transportation in China still lags behind that in Europe, the United States, and Japan. Japan and the United States have formed a monopoly on high-end carbon fiber technology and have realized the application of 70 Megapascal (MPa) high-pressure hydrogen storage tanks for passenger vehicles. While China has issued a relevant standard for 70 MPa hydrogen storage tanks, 35 Mpa tanks are still mainly used. China's liquid hydrogen technology is used mainly in the aerospace sector, it is limited in electronic industry, and the cost is still high. Pipeline hydrogen transport in China is still in the research stage, which depends on the improvement of gas network density and the optimization of pipeline technology.

3) Application in the industry sector: Industrial applications have huge potential for a global green hydrogen market, but the issues of cost-effectiveness and the obstacle of stranded assets are yet to be solved.

Green hydrogen is an indispensable solution to help steel, chemical, and other heavy industries achieve decarbonization. In the steel industry, a zero-carbon emissions process of creating steel from iron ore can be enabled by hydrogen direct reduction iron (DRI) technology. In the chemical industry, the hydrogen supply for ammonia can be replaced by green hydrogen. A variety of chemical products such as methanol and synfuels can be synthesized by combining hydrogen and carbon dioxide. These technologies, although still in the Technology Trigger phase, have reached a relatively mature technology readiness level (TRL) of 6–8 and can help heavy industry achieve real zero-carbon.

Therefore, industrial applications will represent a huge potential market for green hydrogen, with a size even larger than that of the transportation sector. According to RMI, under the zero-carbon scenario, industries such as steel, chemicals, and cement will generate 45 million tons of hydrogen demand by 2050, accounting for 55% of total hydrogen demand. The industrial applications of hydrogen will play an important part in the development of a hydrogen economy.

Green hydrogen steel and chemical demonstration projects are emerging around the world, especially in countries with zero-carbon targets. A number of hydrogen steel projects in Europe are progressing in full swing. Steelmaker SSAB, iron ore company LKAB, and Swedish utility Vattenfall collaboratively completed the first hydrogen-based DRI steel plant, which started operation in late August 2020.

In Europe, the United States, and Australia, there have been a number of green ammonia and green methanol projects. These are based on the production of hydrogen from renewable energy, so as to completely get rid of the use of coal, oil, and natural gas, and provide new possibilities for synthetic fuels and other fields.

And in China, steel companies including Baowu Steel and HBIS Group as well as many chemical companies have started R&D and invested in demonstration projects for hydrogen applications. Under the trend of global zero-carbon development, industrial applications will be a main future direction of green hydrogen deployment and will fully realize the commercialization of the technology in the future.

However, it should be noted that the industrial application of hydrogen energy still needs to face the challenges of cost competition and stranded assets. First, primary products such as steel, ammonia, and methanol are commodities with low profit margin and intense cost competition. However, except that green ammonia in some areas can reach economic competitiveness, the primary product cost using the green hydrogen production route is more than 60% higher than that of the traditional route. This creates great difficulties for wide application.

Cost reductions mainly depend on falling green hydrogen costs, and thus declines in electricity costs and the capital cost of electrolyzers. According to RMI's estimates, if other factors remain stable, the cost of crude steel produced from green hydrogen will reach parity with that from conventional fossil fuel-based processes by 2030. This assumes that the electricity price will fall below ¥0.2/kWh (US$0.03/kWh) for new projects. If a carbon price is implemented, the cost-competitiveness of green hydrogen will be even stronger.

Second, heavy industries operate at large scales and involve long technical processes. This means that using an alternative new technical route based on hydrogen will require substantial investment as it requires replacement of entire processes or at least some equipment in the existing production routes (excluding ammonia). Another route is to build new projects, which likewise will involve large capital investments, and may cause issues with stranded assets.

Therefore, the application of hydrogen in the industry sector is an important strategic move that involves the company's future direction, financial status, and risk management. A comprehensive analysis of internal capabilities, external risks, and possible opportunities and challenges is required for making investment decisions. In particular, governments around the world are discussing environmental costs, including carbon prices and tariffs on heavy industrial products such as steel, and many of the world's leading financial institutions have stopped investing in coal-related assets.

Moreover, the new green hydrogen-based routes may bring new forms of industrial production. Compared with traditional fossil-based production, the electrolyzers require smaller space and simpler raw materials for a convenient source of hydrogen, and thus can support small and distributed industrial production. Ammonia minimills specifically for farm use are being discussed in the United States, Australia, and elsewhere and have the potential to open up entirely new industrial markets.

2. Industrial development and investment suggestions

The hydrogen industry value chain as a whole is in the stage of rapid expansion, and the next decade will be a key strategic opportunity period for hydrogen investment.

First of all, the hydrogen industry value chain benefits from global policy trends, which will directly or indirectly promote the development of hydrogen technology and market expansion in China. The EU launched the EU Hydrogen Strategy in 2020, including plans to invest €575 billion (US$705 billion) in the hydrogen industry over the next decade. Among this, €145 billion will benefit related hydrogen companies in the form of tax incentives, carbon permits, and financial subsidies. The remaining €430 billion will be directly invested in hydrogen infrastructure construction.

In 2019, South Korea launched its "Green New Deal," with the determination to establish a "hydrogen economy." Under this plan, the nation will produce 6.2 million fuel cell vehicles and build 300 refueling stations by 2022 and 1,200 stations by 2040. South Korea also established an "on-site supporting group for future vehicle hydrogen refueling stations," aiming to provide a 50% subsidy for the expansion of hydrogen refueling stations starting next year.

In China, a number of provinces and cities have issued hydrogen industry plans. Hydrogen was written into the national Government Work Report for the first time in 2019. The 2020 Guidance on Energy Work issued by the National Energy Administration also specifically proposed to promote the technological progress and industrial development of energy storage and hydrogen. This includes carrying out development plans for the hydrogen industry, supporting research on key technologies, and actively promoting demonstration applications.

In addition, the improvement of cost-competitiveness will rapidly promote an expanded scale for hydrogen applications. In recent years, electrolyzers and key components of fuel cell vehicles have achieved mass production. Thanks to the scale effect and technological progress, production costs are falling at an extremely fast speed. Analysis by RMI shows that the manufacturing cost of fuel cell heavy-duty trucks is expected to fall by 50% over the next five years, and the life-cycle cost of hydrogen heavy-duty trucks is expected to compete with that of diesel ones by 2035.

Green hydrogen applications in steel, ammonia, and other chemicals will gradually become cost-effective by 2050, further expanding the scale of applications.

However, as for the rising hydrogen industry chain, it is essential to be alert to the possibility of a future Trough of Disillusionment stage and market elimination. With the increasing number of companies and the expanding industrial scale, the trend of low-quality development has begun to appear. Bottleneck issues such as technological constraints, import dependence, and cost-competitiveness will also begin to restrict the development of laggards in a competitive market.

For the whole industry, the success of superior and elimination of inferior companies and products will surely happen in the future in the domestic and even international market. This brings high risks and pressure for the industry. It also makes it necessary for policymakers, investors, and companies to adopt reasonable and effective strategies and actions to help the industry build core competitiveness, explore feasible business models, and jointly promote the steady development of the hydrogen industry.

On the policy side:

- **Hydrogen policy should focus on core technology support and life cycle cultivation.**

Policy support is an essential driving force for an industry such as hydrogen that is in an early stage of development and that has not yet achieved cost-competitiveness with conventional processes. But in order to prevent industrial overheating and a "trough of disillusionment," policymakers should encourage technological innovation, support companies with core technological capabilities, and guide the development of the industry toward stability and sustainability.

At the same time, industrial policies need to change the focus from single products to the whole industry value chain, and from construction subsidies to operation subsidies, so as to achieve the complete cultivation of the industry. Recently, the Ministry of Finance of China issued supportive policies for the hydrogen industry in the form of rewards to specific demonstration projects instead of universal subsidies. The aim of this move is to establish a good environment for the technology development of the hydrogen industry and promote the development of leading companies.

In project screening, other social investors such as government industrial funds should also focus on the technical research and development ability of project teams. This includes evaluating whether these teams have core technologies and whether they can achieve technological breakthroughs. Companies in the industry value chain also need to emphasize the importance of technology.

- **For hydrogen applications, policies need to provide targeted support for research and demonstration projects to help companies reduce risks and to lead long-term strategies.**

Under the zero-carbon transition, green hydrogen is showing increasing strategic importance, but still faces the problem of cost-effectiveness. In particular, the industrial application of hydrogen is still in the Technology Trigger phase of industrial development, which requires high capital investment. This limits most of the companies' ability to utilize wait-and-see approaches.

For these applications, the leading role of the government is particularly important, as it may guide the strategic moves of companies to take the lead in global competition. First, the government needs to provide targeted support for research breakthroughs and demonstration projects, so that manufacturers and technology departments can continue to invest in innovative hydrogen applications. In addition, the government can make use of various policies and financial tools to share risks for hydrogen application projects and improve the enthusiasm of companies to develop demonstration projects without increasing their financial burden.

On the industry side:

At present, the market expansion of the hydrogen industry is focusing on water electrolysis and fuel cell vehicles while the industrial application mainly relies on policy support and research and development by big companies due to its earlier development stage. For hydrogen applications in the transportation sector that are in the Inflated Expectation phase, it's important to prevent a shift into the Trough of Disillusionment and pay more attention to the development of core technologies. This will enable these companies to gain a position in the possible market elimination.

- **Due to the long investment payback period, hydrogen refueling stations are more suitable for large companies with assets and existing infrastructures to deploy in advance, with the support of policies.**

The development of the hydrogen industry needs the support of infrastructure such as hydrogen refueling stations. However, due to the "chicken and egg" issue between infrastructure and hydrogen demand, investors need to have a certain capital capacity and be able to bear a long payback period. One option is that the government can support the hydrogen refueling stations from construction to operation, and establish pilot projects to promote it step by step.

Additionally, companies such as Sinopec and Shell, which have advantages in land resources and infrastructure operation experience, can make deployment in advance based on existing assets. By sharing infrastructure, they can reduce the capital investment pressure of hydrogen refueling stations and penetrate the market at the initial stage. In the future, with the continuous expansion of the market, there will likely be a variety of hydrogen refueling station models.

- **The early market development of the hydrogen industry requires consolidating the basic market demand and at the same time expanding niche markets such as existing cost-effective markets or markets driven by green and sustainable lifestyle trends.**

Hydrogen market expansion is another way to solve the hydrogen "chicken and egg" issue. While the hydrogen industry is in the ascendancy, it is still facing cost-effectiveness challenges. Companies need to stabilize the basic market to provide feedback experience and accelerate scale effects for industrial development. Additionally, they should actively look for niche markets and offer other services to gain more profit and expand the market continuously.

For upstream green hydrogen production, hydrogen energy storage facilities for renewable energy projects create a basic market. For example, offshore wind power hydrogen production projects in the Netherlands, Germany, and the United Kingdom will bring tens of megawatts of market demand for electrolyzers. This will also promote the upgrade and

optimization of large-scale electrolyzer equipment. In addition, for the rigid demand for hydrogen in the chemical industry, a more flexible hydrogen supply can be provided by small-scale electrolyzers.

For downstream hydrogen applications, policy-based procurement projects such as buses can provide an important basic demand market for the fuel cell industry where the product demand is relatively standardized. Through mass production and sales of such products, it can not only provide stable cash flows for fuel cell manufacturers, but also feedback experience for value chain optimization to promote large-scale development of the industry.

In addition, green hydrogen applications have already achieved cost-effectiveness in some fields, and investors could further identify and penetrate these markets. For example, the cost of green ammonia has reached parity with that of traditional production routes in regions with high natural gas prices and low electricity prices. Fuel cell applications, aided by low electricity prices and special business models, are closing the cost gap as well.

To cope with the high price of green hydrogen, it is also necessary to identify niche markets that are willing to pay a premium for the "green" attributes of clean energy. Industries with zero-carbon development requirements will be important potential diversified business markets for hydrogen, including energy companies (such as BP) and aviation industry firms that have made zero-carbon commitments by 2050, and shipping companies that have formed zero-carbon alliances. Ballard Power Systems has targeted the shipping industry and launched the first fuel cell power module for ships in 2020.

Priority can also be given to developing high-end consumer markets such as sightseeing boats, private yachts, and small planes where customers favor green and sustainable lifestyles, enjoy new concepts and services, and have relatively low price sensitivity. Starting from such niche markets can help companies expand their capacity and gain more profits in the early stage, thus contributing to technological breakthroughs and cost reduction. With the expansion of the hydrogen market, the market will gradually shift from specific applications to a more general range, and then explore vertical markets more deeply.

Investors should seek companies with strength to serve these markets mentioned above. They can also help companies accurately identify these potential niche markets or customers and help them overcome the market downturn and obtain investment returns.

VII. Digitalization: Accelerator for Energy System Optimization

The digital transformation based on information and communication technologies is transforming every sector of the global economy. Industries including traditional fast-moving consumer goods, automobiles, financial technologies, and new internet communications are undergoing digital transformations to reshape businesses, and the energy industry is no exception. The application of digitalization in the energy industry covers demand-side digitalization, supply-side digitalization, and digital optimization of the overall system.

Demand-side digitalization mainly involves three sectors: transportation digitalization, building digitalization, and industrial digitalization. As the three traditional sectors, their inherent characteristics of heavy assets and a high degree of dispersed marketization make their digital transformation more difficult than that of the new information technology sector. But at the same time, there are more opportunities for energy efficiency improvements. For the energy supply side, digitalization has brought opportunities for cost reduction, efficiency improvements, and improvement of intelligence levels in industries such as oil and gas, coal, and electric power.

In addition, the increase in electricity consumption due to the large-scale application of 5G communication networks, data centers, and other digital technologies is also worthy of attention. However, it is not within the scope of discussion of this report.

In the above use cases of digitalization of energy consumption and supply, the digitalization of industry, transportation, and buildings on the energy consumption side is mainly aimed at providing better services to customers and meeting their demands. Carbon emissions reductions are among the ancillary benefits of digitalization in these sectors. Fossil fuels on the energy supply side will be gradually replaced by cleaner energy such as electricity under the zero-carbon scenario.

Research from RMI and the Energy Transitions Commission (ETC) shows that achieving China's zero-carbon energy transition by 2050 will require deep electrification, and nearly 75% will come from renewable sources.[46] The key to China's energy transition is to continuously increase the level of electrification and the percentage of renewable energy in the power system. Therefore, digital technologies and related industries that can contribute to the development of this clean power system are the main focus of this report.

Power market reform and the zero-carbon transformation will provide huge market opportunities for the wide application of digitalization technologies in the power system. Digitization of the power industry is not only a process to empower the industry with data and information tools, but also a path to maximize the potential of power market reform on the basis of data and marketization.

Compared with the consumer retail, finance, and internet industries, the power industry is a less attractive market due to system and technology complexity and the monopoly nature of the industry. Yet compared with traditional energy and manufacturing industries such as the petrochemical, oil, and gas industries, the digitalization level of the power industry is already higher as the power industry requires huge amounts of real-time power generation and usage data to ensure dispatch. With the continuous promotion of power market reform, the macro trend of zero-carbon transformation also brings more use scenarios and investment opportunities for the application of digitalization in the power system.

- **Digital technologies can increase grid flexibility and enable integration of a higher share of renewable energy.** The enhancement of digital technology can improve the flexibility of power systems and enable a higher share of renewables in the power system. According to research by ETC and RMI, China could even achieve its zero-carbon goal ahead of schedule by 2050 through deep electrification on the consumer side and deep decarbonization of the power sector.

The continued support of renewable energy subsidies over the past decade has promoted the rapid growth of installed renewable energy capacity. In 2019, the share of renewable generation reached 9.2% of total power generation, and the curtailment rate has been decreasing year by year. To be specific, the curtailment rate for wind has dropped from 17% in 2016 to less than 5% in 2019.[47] In 2019, China officially launched the long-expected mandate for minimum renewable energy purchase (renewable portfolio standard), and the government has allocated renewable energy consumption quotas to retail companies and big power users in all provinces.

As demonstrated by the market situation in the past two years, state-owned power companies including the "big five and small four" power developers have increased investment in the field of new energy. Energy companies have also made zero-carbon commitments. For example, GE has announced that it will stop supplying equipment for new coal-fired power plants. In the future, a higher share of renewable energy in the grid will definitely bring more stability and security of supply challenges. Digital technologies can improve system flexibility through highly precise information approaches and support the integration of more renewable energy.

- **Digital technology enables the shift from centralized power generation to distributed generation.** Due to the economy of scale effect, power generation used to be built mainly in centralized forms in China. However, considering the limited land resources in the southeast coast areas where the main load centers are located, distributed energy generation will become the mainstream of new installed capacity due to its convenient and flexible siting patterns and proximity to load centers.

Small to medium-sized industrial and commercial users, as well as residential users, can install distributed PV panels to meet their own power demand, while selling excess power generation to other buyers in need, bringing in additional income. This will enable the new prosumer model to emerge. In the future—with the support of digital technology—rooftop PV, distributed wind, and household energy storage will become important flexible resources on the demand side. In doing so they will completely overturn the system dominated by centralized large-scale thermal power plants, reduce the cost of electricity for end users, and play a part in the low-carbon transformation of the power sector.

- **With the slowing down of growth of power demand, the focus will shift from demand increments to stock and shift from increasing quantity to improving quality. Digital technology enables power companies to provide better services to their customers.** As the growth of GDP and power demand slows down, new opportunities in the future will shift from demand increments to stock. Therefore, the focus of the grid also needs to shift from how to serve more customers to how to provide more diversified value-added services, such as providing green power packages to corporates or individual buyers, and improving the customer experience.

  At present, with the opening up of the power market, lots of retail companies have been available in the market. With multiple choices provided to the end power users, only those retail companies that can provide differentiated and high-quality services will stand out from the fierce competition. New growth potential for the industry will come from accurately understanding the evolving needs of end-users in real time and providing them with more differentiated services through digital big data analysis and other technologies.

In the post-power reform era, the whole power industry will be more open and industry players will be reshuffled. Over the past few decades, as the foundation of the national economy and people's livelihood, the power industry has been monopolized by the grid companies. After several rounds of power market reforms, with the separation of power generators from the grid companies, and the current overall expansion of the power trading market, more and more new industry players are entering into this big market.

Retail companies, integrated energy service providers, solar and wind power producers, and even internet and technology giants from outside the energy industry are also entering this market. These new players have more flexibility, faster decision-making processes, and bolder ideas than the huge grid companies and centralized thermal power companies. As a result, in the energy industry of the future the major players are likely to be reshuffled and new giants will emerge.

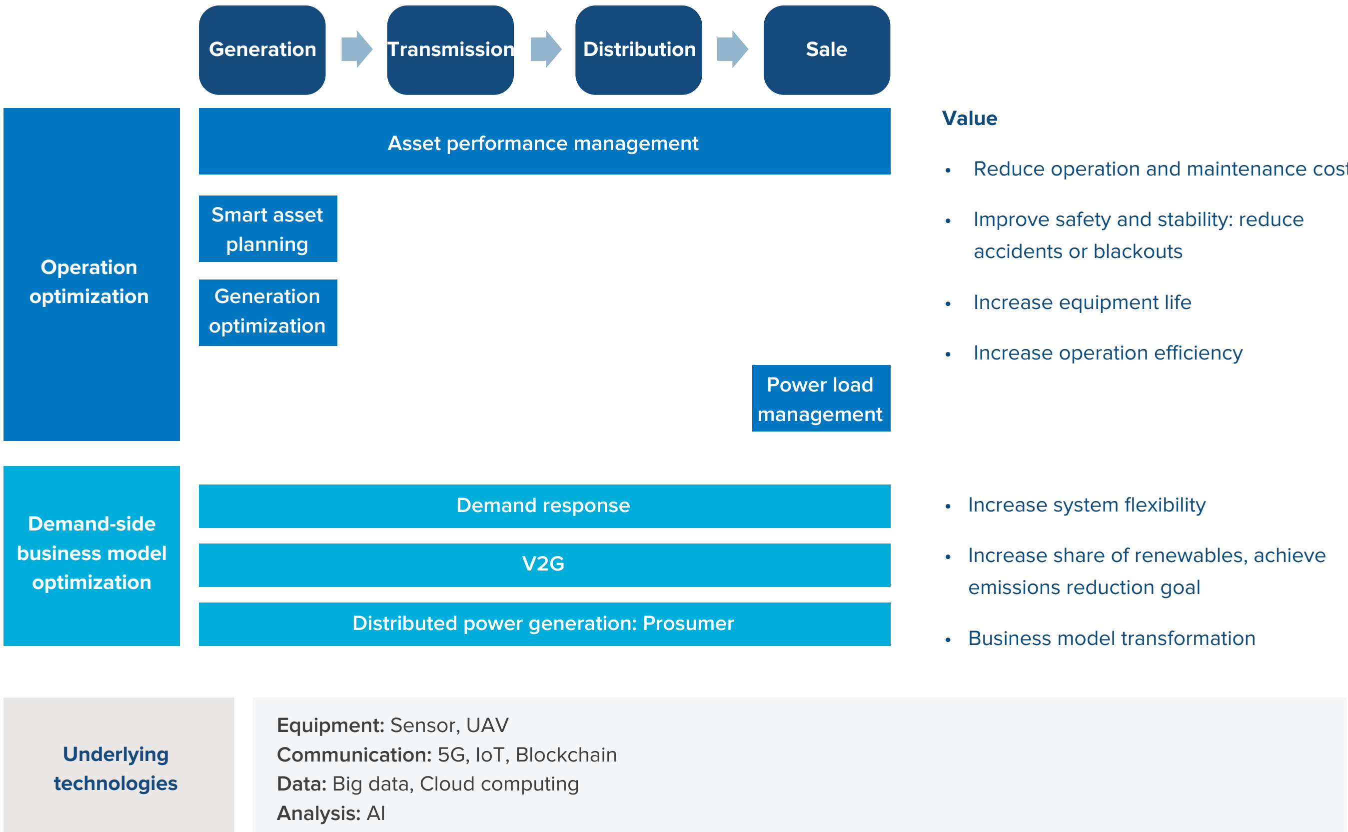
Digital technologies in the power sector are mainly applied in operational optimization and demand-side business model optimization.

- **Operational optimization:** As the power sector is an asset-intensive industry, any slight efficiency improvement in the operation along the value chain from power generation, transmission, and distribution to the final sale of electric power will bring significant cost reduction impacts. In the current operational situation, efficiency can be greatly improved and operational costs can be reduced for companies by comprehensively and intensively installing sensors and continuously collecting a wide range of operation data while optimizing operational parameters through data analysis.

  Take wind power plants as an example. The operation process of wind power generation can be greatly improved through digitalization. Operational optimization tools analyze plant internal data, historical operation data, or external information to make forward-looking recommendations in order to inform relevant personnel, reduce production costs, and improve plant flexibility. As another example, in the process of project development, smart asset planning can optimize project site selection, optimize capital expenditure, and reduce project costs, so as to help meet additional demand in a future highly electrified system with minimum investment cost.

  Another major application of digital technology in the power industry is to reduce operation and maintenance costs through better asset performance management. According to the International Energy Agency's estimate, the operational costs of the global power industry were US$300 billion in 2016. Through the application of digital technology, a 5% reduction in operation and maintenance costs by 2040 could help companies and end-users in the power industry save more than $20 billion a year.[48]

Exhibit 19
Digital Technology Applications



- **Demand-side business model optimization:** While simple data collection and data analysis can bring cost reductions and efficiency increases in operations, the reform of business models comes from the interconnection of the whole data set, which is crucial to the energy industry and a new growth point in the future.

  Take the power industry as an example. Due to the monopoly nature of the industry, the development mode over the past decades has been relatively fixed. There is a lack of pressure on power companies to innovate business models, and the participants are relatively undiversified and monopolistic. But through the process of power market reform, the links among power generation, transmission and distribution, and power sales are gradually broken. Additionally, regulation is liberalized to allow participation of new actors in the market.

Breaking through the original business model by means such as integrated energy management based on digital technology will bring huge market opportunities. System-level optimization will also bring all sorts of new opportunities. Measures including demand response, V2G, and distributed energy prosumer models will be able to improve grid flexibility. This will help intermittent renewable energy sources such as wind and solar to be integrated to the grid, further advancing the goal of a zero-carbon China and creating a huge new market in the future.

The fundamental technologies underlying the process of the digital revolution of the power industry have no big difference with that of other industries. These are based on big data, cloud computing, the Internet of Things, and artificial intelligence. But in the process of technology application, due to its unique characteristics in the policy environment and industry development, the power industry is facing its own difficulties and application scenarios.

The key to the application of digital technology in the power sector is to deepen power market reforms; transform all behaviors and information collection to digital, transparent, and intelligent processes; and achieve the most effective use of resources.

The application of digital technology in operational optimization of the power sector—Slope of Enlightenment:

The application of digital technology in the field of operational optimization, such as energy asset performance management and power generation optimization, is already relatively mature. Its operational optimization of the power sector can help companies improve the service life of power grid equipment, reduce operating costs, and achieve safer, smarter, and more stable power supply and consumption.

There are mature suppliers in the market that can provide corresponding services in terms of hardware and software as well as overall solutions. Additionally, companies benefit directly from significant cost reduction through the management and optimization of these digital technologies in the field of operation, which gives them a greater incentive to embrace these new digital application technologies. We believe that the future operational optimization will shift from the approach of transforming single pieces of equipment and a problem-solving mindset to a proactive, preventative approach that unlocks the potential for deeper efficiency improvements and improves corporate competitiveness.

Asset Performance Management

Up to now, the power industry has had the most complete infrastructure and is one of the most important asset-intensive industries in our society. The investments in power equipment are huge. Measures to improve the service life of equipment and reduce equipment operation and maintenance (O&M) costs have a huge impact on the return on investment of the entire industry.

The power sector has the potential to achieve a comprehensive reform from power generation to distribution through a set of digital asset performance management technologies. There is an opportunity to transform whole sets of power company equipment into smart equipment using digital analysis tools and artificial intelligence algorithms. By doing so, the overall state of the assets can be monitored in order to shift the passive problem-solving approach of O&M to a preventative approach of forecasting maintenance that can effectively help companies reduce their O&M costs. With the reduced asset downtimes, the use efficiency of assets will be improved, and the profits of companies will be increased.

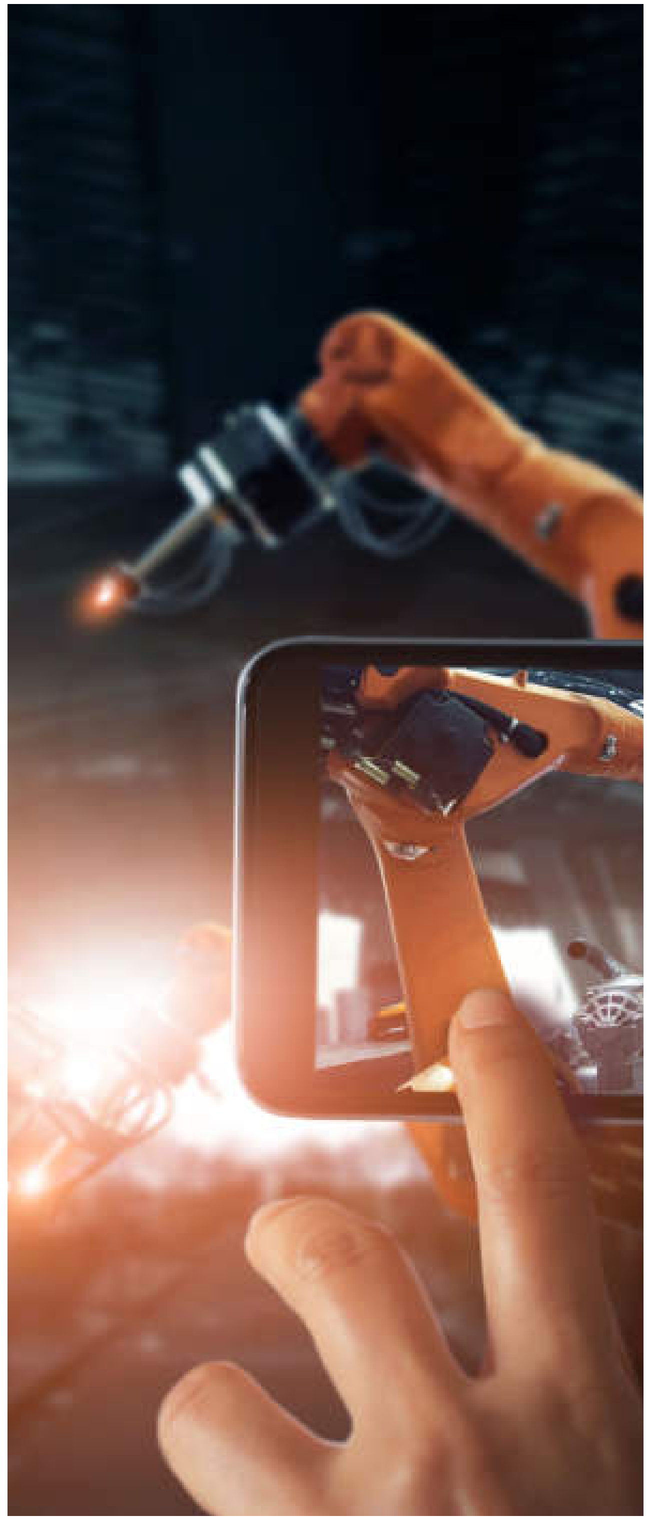
At present, digital asset performance management technology is relatively mature. Schneider, ABB, Siemens, and other giants as well as new start-ups such as Logintel and Windmagics are all providing systematic asset performance management services for companies. In the context of the future zero-carbon energy transformation, taking relatively mature application scenarios such as asset performance management as the entry point to improve digital penetration is crucial to achieve further system optimization.

Smart Asset Planning

In the future, zero-carbon energy transformation requires a large number of newly installed wind and solar power assets, and the site selection and planning of these new assets is not a simple decision. Site selection will have a lasting impact on the power generation efficiency in the coming decades of the life cycle of power stations. By utilizing digital smart technologies, smart exploration, selection, and planning in the site selection process of new projects will significantly improve the efficiency of power generation, maximize the utilization of wind and solar resources, and lock in the revenue improvement of power stations in the next 20 to 30 years. This will be especially true in the future when the land resources in the southeast coastal areas will be limited.

In the site selection of wind and solar power stations, compared with the traditional artificial exploration approach, digital technology can make use of unmanned aerial vehicles (UAV) for cruise exploration. It also can be combined with digital platform and analysis tools to quickly and accurately locate potential wind and solar project sites, estimate generation capacity and cost benefit analysis, and provide development planning of wind and solar projects. Finally, it can provide macroscopic and microscopic site optimization for the government and developers.

At present, site selection technology for solar and onshore wind power projects has been relatively mature, but such technology for offshore wind power technology has only begun to develop in recent years. This represents a major difficulty to be tackled in the next step, due to the high investment required as well as lack of standards and experience due to limited studies on site selection and planning of offshore wind power projects at present. In the new energy sector, leading domestic companies including Goldwind and Envision have developed relatively mature digital platforms and products and can provide developers with smart project site selection and other services.



Power Generation Optimization

After the completion of asset construction, wind power plants can effectively improve the accuracy of controls through the application of new digital technologies. This includes arranging maintenance and repair in the time period when there is no or little wind, so as to improve the generation efficiency and increase the electricity generation revenue. According to Envision's analysis, by installing sensors to turbines, the operator can collect various data including how the fan works, how to generate electricity, and what kind of maintenance is needed. This enables real-time adjustments to the wind turbine based on the monitoring of factors including wind speed and direction—such as changing the inclination of the blade—thereby increasing wind power generation significantly.

In addition, considering the characteristics of the power industry, in order to ensure the stable and secure supply of electricity to power users, power plants need to be assessed by the grid company in the grid-connection stage. The application of cloud computing and other digital technologies can improve the prediction accuracy of power generation efficiency and power and help power generation companies reduce the assessment deviation penalty.

Finally, more stable and accurate prediction of power generation can increase the share of renewable energy in the grid. It is widely acknowledged in the industry that fluctuations in renewable energy generation pose a challenge to the dispatch of the entire power system, and that more reserve capacity is needed to ensure the balance of power supply and demand in real time. Applying more digital technologies can effectively decrease the instability of renewable energy generation and reduce the reserve capacity demand of power grid dispatching. These include approaches that can improve the quality of current prediction data, constantly update and improve prediction algorithms and software, and constantly improve the prediction system and increase the prediction frequency.

Load Management

In the past, power users had no choice in purchasing and using power, and the grid companies would not conduct market management on the demand side. This led to concentrated loads that increased pressure on power dispatch during certain periods, and therefore led to the emergence of administrative demand side management measures such as time-of-use pricing. With the support of digital technology, power users can monitor their power consumption in real time by installing smart meters and control equipment, and even predict future load profiles based on consumption behaviors of the past. This enables smart load management in response to real-time power market price signals.

To put it more simply, users can better choose their own time to use power and arrange their own production based on real-time electricity prices, thus achieving the goal of reducing power costs. Indeed, this kind of application is still relatively small at present for several reasons. First, there is a limited number of industrial companies and residential users with load management ability; most of them still choose the simple process of conventional power purchasing. Secondly, there is a lack of market incentives for users to conduct load management while power market reform is still in progress with limited power market price signals.

As the power market continues to be optimized, in the future retail companies are likely to be able to help users perform load management. Meanwhile, large industrial users can also cultivate their own capacity of load management internally, optimize production plans without affecting productivity, reduce power costs, and help the grid cut peak load and reduce unnecessary investment. The maturity of digital technology will be the premise that makes all of these scenarios possible.

Application of digital technologies in demand-side business model optimization of the power sector—Inflated Expectations:

The application of digital technology in demand-side business model optimization scenarios represented by virtual power plants and demand response are currently in the Inflated Expectations phase of the technology development curve. Although the market pays great attention, the lack of effective policy support and complete market mechanism environment in the next step will likely cause long-term obstacles to the further development and application of technology.

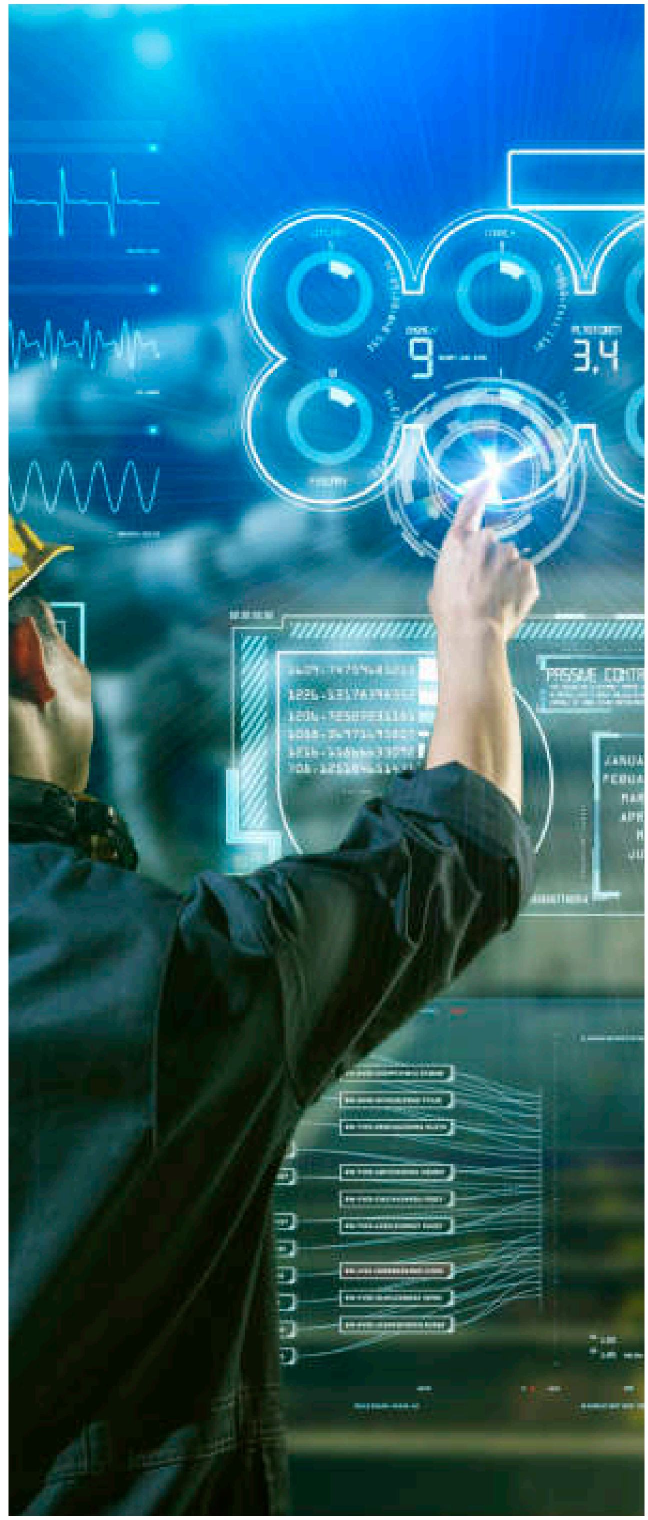
Given the maturity of the corresponding technology, it is necessary to establish an effective collaboration model among market players to ensure that all participants have reasonable returns to achieve large-scale application of these technologies.
This includes allowing power users to benefit from providing flexibility to load aggregators through their own energy storage and EVs and load aggregators to gain profits from the overall regulation and control of decentralized power supplies. It also includes allowing communications technology companies to profit from providing the underlying power control technology and big data analysis.

Demand Response

The complexity of the power market is represented by the fact that the demand curve for power loads is constantly changing, and the supply of power does not come and go as we may wish. The key to power dispatch management lies in implementing measures to ensure that power is supplied continuously, safely, reliably, and in a stable manner.

Demand response refers to a mode in which power users can reduce power consumption or shift the time of power consumption according to price or other incentive signals. This ensures the real-time balance of power supply and demand and the stability of the grid at minimum system cost when the price of power market shows obvious peak or valley, or when there is significant safety and reliability risk in the power system. For example, this can happen when the load reaches peak and the grid faces great dispatch pressure at the middle of a summer day.

With the support of digital technology and internet technology, the new form of automated demand response can be more rapid and accurate, and can achieve full automatic dispatch. When the power supply is limited, the grid company can send demand response signals to users to reduce power consumption. After receiving signals, industrial and commercial users and residential users can respond in a timely manner and adjust usage through their smart automatic energy management system, so as to maximize the effectiveness of demand response.



While demand response in the United States and Europe has been relatively mature, this model in China has just started and is still dominated by administrative intervention. In the future, the development of the power market, an increasing share of renewable energy, and increasing pressures of peak hour power demand brought by the improvement of people's living standard will further boost the market scale of demand response.

The further development of demand response needs support in the following aspects:

The first is support for the underlying information technology. Demand response projects rely heavily on supporting infrastructure, communications equipment, and unified standards. Individual industrial and commercial users and residential users can provide a relatively low capacity of adjustable demand response of only a few kilowatts. Therefore, load aggregation is needed, which is based on perfect ICT technology, smart equipment, and data interconnection.

Advanced measurement technology, remote control technology, and bidirectional communication technology are the basic premise to ensure the smooth operation of demand response. Therefore, the development of demand response depends on the wide adoption of these smart and digital information management systems. At the same time, it is also very important for the demand response project to use unified ports and standards aligned with national or provincial power management platform systems.

The second is the acceleration of power market reform. The release of demand response potential is restricted by the marketization degree of the power market. China's power market construction is still at an early stage, and the current demand response is dominated by administrative intervention. The subsequent marketization is still relatively difficult.

Finally, from the perspective of the market, demand response participants in China are mainly big industrial users, and market awareness is yet to be cultivated in commercial and small industrial users. Additionally, the economic benefits of demand response are currently limited, which makes it difficult to stimulate the rapid development of the market. User engagement and retention are important indicators to measure the success of demand response projects. Therefore, it is important to design incentive measures for demand response projects and increase their publicity to enhance user awareness and engagement.

V2G

Vehicle-to-grid (V2G) technology is one step further than unidirectional controlled charging. It not only enables EVs to be charged using grid power, but also releases the energy stored in EVs when it is needed on the grid, achieving a bidirectional flow of electrons. As the world's biggest market in terms of EV ownership, China's grid will face huge pressure brought by the charging demand of these EVs in the future. If bidirectional charging can be realized, it will not only relieve the pressure on the power grid, but also leverage EVs as mobile energy storage units to help improve the operational efficiency and flexibility of the grid.

At present, V2G technology is developing fast in Europe and the United States while still in the early stages of research and development in China, mainly driven by the grid companies. In the future, the development of this technology needs to focus on two major technical issues. The first is how to ensure the battery life of EVs. Bidirectional charging increases the number of charge and discharge cycles that EVs are subject to, which will definitely affect the battery life. Therefore, further battery technology development is needed to fully accommodate bidirectional charging.

The second technical issue is how to improve the dispatch and operational capacity of the grid. This includes measures to ensure real-time, accurate, and unified coordination and control between vehicles and the grid after bidirectional charging is adopted by a large number of vehicles, so as to ensure the stability of the grid operation. The key to decide whether the technology can be applied commercially on a large scale is its cost-effectiveness, that is, the attractiveness of the incentives that EVs as flexible energy storage resources can get from the grid. EV owners will only be willing to participate in the bidirectional charging system when the incentives they can get from the grid exceed the cost of battery loss caused by bidirectional charging.

The overall development of V2G is still in the Technology Trigger phase of the technology maturity curve, and progress in charge and discharge times of energy storage technology, especially battery technology, is key. We believe that fixed energy storage as a flexible resource on the grid side will be commercialized prior to the large-scale adoption of V2G technology.

Distributed Prosumer

As mentioned above, in the context of zero-carbon transformation, the power industry will shift in the future from a mainly centralized system to a more distributed one. With an increasing number of industrial and commercial users and households using distributed power generation technologies including rooftop solar, energy storage, and distributed wind installed behind-the-meter to meet their own power demand, users can reduce energy bills. At the same time, they can sell excess power to the grid or to other users to generate additional revenue.

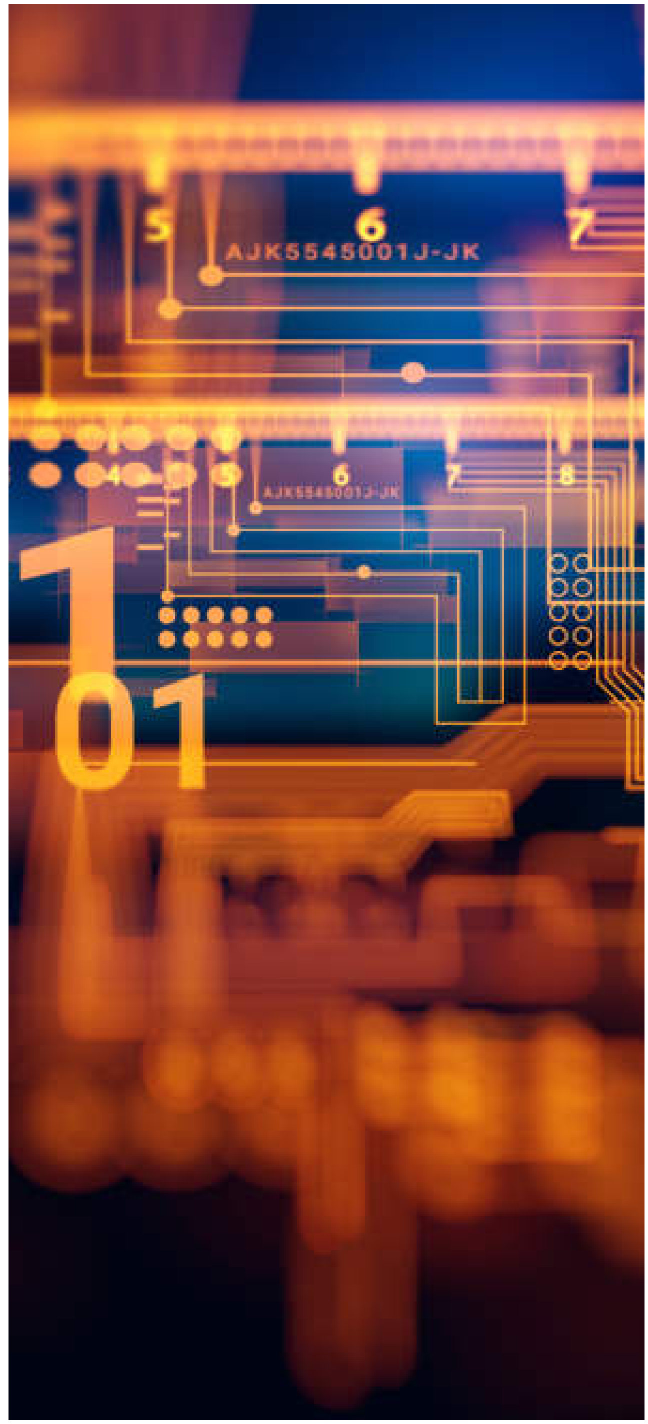
This prosumer model based on distributed power generation has been reflected in the "self-supply first and sell excess power to the grid" mode in distributed projects, with buyers and sellers mainly being distributed project owners and grid companies. In the future, distributed power generation project owners can even sell excess power directly to other surrounding consumers with power demand by paying transmission and distribution (T&D) fees to the grid company or sell directly into the power market. Currently, these kinds of models are still in the pilot stage in China. Major obstacles come from the grid companies that haven't established a clear standard for T&D fees.

In the future, the prosumer model based on distributed generation not only needs the support of more digital technologies such as blockchain and distributed trading, but also further liberalization of policies and system mechanisms to break up grid monopolies. This will reduce costs for power users and broaden the business model for grid companies.

Investment suggestions

The power industry is a foundation for the development of modern society. In order to achieve a zero-carbon society by 2060, the decarbonization of the power industry is key. The power system of the future with a high share of renewable power needs large-scale energy storage to offset intermittent renewable power generation, improve grid flexibility, and ensure real-time balance between supply and demand.

Digital technologies can improve the generation efficiency at the power generation side, optimize and integrate at the transmission and distribution side, and carry out demand-side management at the power consumption side. This will improve the overall system flexibility and achieve a high share of renewable power integration. Compared with other industries, the infrastructure of the power industry is relatively complete and mature, and the degree of integration between power technology and internet information technology is high. Therefore, the digital, smart, and interconnected power system of the future is key to the zero-carbon energy transformation.



The digitalization of the power industry needs further policy guidance and incentives to encourage more market-oriented funds and resources to enter this field. The COVID-19 crisis has put digital investment back on the hotspot after a few years since the last wave of attention. The quarantine brought about by the COVID-19 outbreak has caused many companies to suspend production due to lack of a sufficient labor force. Many traditional companies have also shifted their businesses from offline to online. The epidemic has greatly accelerated the digitalization of these traditional industries.

The social pattern and development direction of the post-2020 pandemic era will be significantly affected by this sudden event. With people gradually realizing the limitations of traditional offline businesses, traditional industries should make efforts to deploy online businesses, adapt to the new social direction, and increase their resistance and flexibility to deal with risks.

However, at present, the application of digital technology hasn't focused on the power industry. According to the investment and financing data over the years, the focus of investment in the current market is more on the application of digital technology in the retail, finance, and internet sectors. Meanwhile, investors and start-ups that focus on digital applications in the power industry are relatively rare. To accelerate the energy transformation, it will be very important to attract more market capital, to understand the market size of the power industry, to pay attention to the digitalization of the power industry, and to participate in this transformation through effective policy guidance and incentives.

The power system is highly intertwined in the process of gradual opening up of the system in China. Market investors need to focus on startups that have a good understanding of the vertical needs of the industry to gain first-mover advantage. From the power Internet of Things to the energy Internet of Things, the digital transformation of the power grid has long been an irresistible trend. In 2020, the total investment of "new digital infrastructure" of the State Grid is expected to be up to ¥24.7 billion (US$3.8 billion). Among ten key construction tasks, the digital platform is the first to bear the brunt, and the scale of the digital power market has huge potential.[49]

Grid companies, power generators, and other energy companies are all putting more effort into investing in the digital transformation. But it should be noted that the power industry is different from other industries and faces more challenges. For example, the power industry has a special demand for data security given the massive real-time power data in the system, and also has extremely high requirements for data accuracy and speed. Most of the digital technologies' R&D and deployment are within grid companies, and there is a lack of market competitiveness. While there are many digital companies in the market, relatively few have a full understanding of the specific vertical needs of the power industry, and investors should focus on such companies.

The distribution side and demand side have a relatively low level of digitalization. The application of digital technology has a large market development potential, which will be a "blue ocean" market in the next 5–10 years. Along the value chain of the power sector's generation, transmission, distribution, and demand sides, the current digitalization level of power generation, transmission, and distribution sides are high, while the digitalization level of power consumption is relatively low. Therefore, there is greater room for efficiency improvements in the future. The application of digital technology in the power operational optimization field, including energy asset performance management and power generation optimization, has become more mature and is not constrained by the current power market reform progress.

However, applications in the distribution and demand side, such as virtual power plants, demand response, and V2G, are still in their infancy in China. And although there is widespread interest in them, and the power reform has also liberalized the retail side to a certain extent, their future development will depend on further policy guidance and opening up the market.

Digital technology applications on the demand side and distribution side will be a better fit for venture capital investors with a higher risk tolerance. We suggest investors prioritize startups and projects within their own areas of experience and unique understanding of the field. We believe that the application of digital technology in the power distribution side and demand side will be a "blue ocean" market—a new market with little competition and a high profit potential—in the next 5–10 years.

Finally, the digital transformation of the power industry depends on breakthroughs and changes in system mechanisms and other related technologies. From the perspective of the technology development stage, the digitalization of the power industry relies on the support of underlying technologies such as big data, cloud computing, artificial intelligence, and the Internet of Things. The zero-carbon energy transformation does not rely solely on digital technology, but more on changes to institutional mechanisms, policy, and market design. It also relies on progress in other key technologies including continuous reduction in the cost of solar and wind power generation, reduction in the cost of energy storage technology, and the large-scale promotion and application of these technologies.

Power market reform is necessary to comprehensively unleash the potential of the digital transformation. Only by breaking existing monopolies, allowing more players to participate in and trade in the market, and having a sound power market price system, can many digital applications in the power industry truly achieve profit instead of simple energy conservation and emissions reduction.

In the future, we believe that the comprehensive digitalization of the energy industry will overturn the existing industrial pattern. For energy end-users, there will be more sources and options to purchase power, heating, and cooling, and more access to integrated energy services. Energy companies can expand existing business models, more accurately understand customer needs, provide new value-added services to increase revenue, and improve the efficiency of existing operating models to reduce costs. For the energy transition, the digital energy future will be an important step to enable clean zero-carbon power generation and achieve a truly zero-carbon China.

4 China's Zero-Carbon Transformation: Stages of Development and Synergies among Fields

China's Zero-Carbon Transformation: Stages of Development and Synergies among Fields

1. **The zero-carbon transformation involves a wide range of industries. Nearly 20 technological innovations in seven areas are at different stages of development, jointly forming broad investment space. The government's role in the early stage of industrial development is particularly important. It is necessary to rationally design gradual and interlocking policy actions, while market forces are the main driving force in the later stage of industrial development.**

Technologies and industries in the seven major areas for a zero-carbon China are at different stages of development, creating a vast and diverse space for investment. Because they are at different stages of development, the key tasks of these technologies or industries vary. Industrial electric heating, industrial direct application of hydrogen, flow batteries, and battery recycling are still in the Technology Trigger phase, and their main tasks are the research and development of basic technology and creation of the first generation of products.

Green hydrogen production and hydrogen fuel cells are moving toward the Inflated Expectations phase, and EVs are already in this phase. These face the danger of low-quality market expansion, with unqualified commercial products. The key task for companies is the establishment of core advantages of technologies and consolidating strengths.

Heat pumps and other industries have experienced the elimination of inferior products and companies in the Trough of Disillusionment phase. These companies now need to survive the competition, create second-generation products, and unlock a new wave of growth under the joint efforts of policy, capital, and technologies.

Several energy storage technologies represented by lithium-ion batteries and circular economy industries of recycled products in energy-intensive industries have entered the Slope of Enlightenment phase. These now need to continuously reduce costs through scale effects, while trying to develop diversified products to establish competitive advantages.

Zero-carbon power generation technologies such as solar PV, wind, and nuclear power have entered the Plateau of Productivity phase. They have achieved cost-competitiveness and need to strive to continuously enhance market penetration.

The development of zero-carbon industries requires large capital investments, is hardware-based, is

Exhibit 20
Characteristics of Various Development Stages of Zero-Carbon Industries

Phase	Technology Trigger	Inflated Expectations	Trough of Disillusionment	Slope of Enlightenment	Plateau of Productivity
Technology	• Industrial Electric Furnace • Industrial Use of Hydrogen • Flow Battery • EV Battery Recycling • Power System Optimization	• Green Hydrogen • Hydrogen Fuel Cell • Electric Vehicle Optimization	• Heat Pump for Building	• Lead-Carbon Battery • Waste Reuse as Energy Heavy Industry • Product Recycling in Energy-intensive Industries • Lithium Battery • Power System Operation Optimization	• Building/Industry Energy Efficiency • PV • Wind Power
Key Task	• Fundamental Tech • 1st Generation Product Development	• Core Tech • Infrastructure Planning	• Market Screening • 2nd Generation Product Development	• Cost Reduction • Segmented Product Development	• Market Expansion
Key Driver	**Government**: Research & Pilot Projects → Industry Policy → Industry Standards			**Market**: Cost Reduction, Product Optimization, Market Expansion, Supporting Service	

susceptible to lock-in effects, and has long payback periods. Therefore, investment and industrial development are greatly affected by policies. Especially in the early stage of industrial development, the government must effectively act as a "compass" and play a guiding role in industrial development through a combination of various policy instruments.

For innovative technologies in the Technology Trigger phase, the government needs to provide scientific research support and establish pilot projects to encourage the strategic deployment of new industries such as industrial direct hydrogen utilization and battery recycling.

For technologies in the Inflated Expectations phase, the government can use industrial policies to effectively guide the fuel cell, EV, and other industries to develop key technologies and establish core advantages in the direction of high-quality development.

For the formulation of relevant standards for products such as heat pumps, the government should help the industry establish order, assist the selection process, and promote the industry to effectively survive the Trough of Disillusionment phase.

For innovative technologies entering the Slope of Enlightenment and Plateau of Productivity phases, the guiding role of policy can be weakened accordingly. For example, subsidies for solar and wind power can be gradually withdrawn, leaving enough space for the industry to conduct benign market competition and self-optimization.

China has great advantages in policy guidance of zero-carbon industry. China's government at all levels has diversified policy means to support and guide the industries. Additionally, China has accumulated rich experience in the past decades and formulated appropriate policies for energy-related industries. This will give China an advantage in the development of zero-carbon industries.

Market forces are the main driving force in the middle and late stage of industrial development. This stage requires long-term coordinated deployment of productivity improvements, product optimization, use-case expansion, and ancillary facilities and services back-up.

In the Technology Trigger and Inflated Expectations phases of industrial development, the role of market forces is exploratory. This is mainly reflected in the research and development of basic products and the advance infrastructure deployment of large companies, which is suitable for high-risk and high-return investment actions.

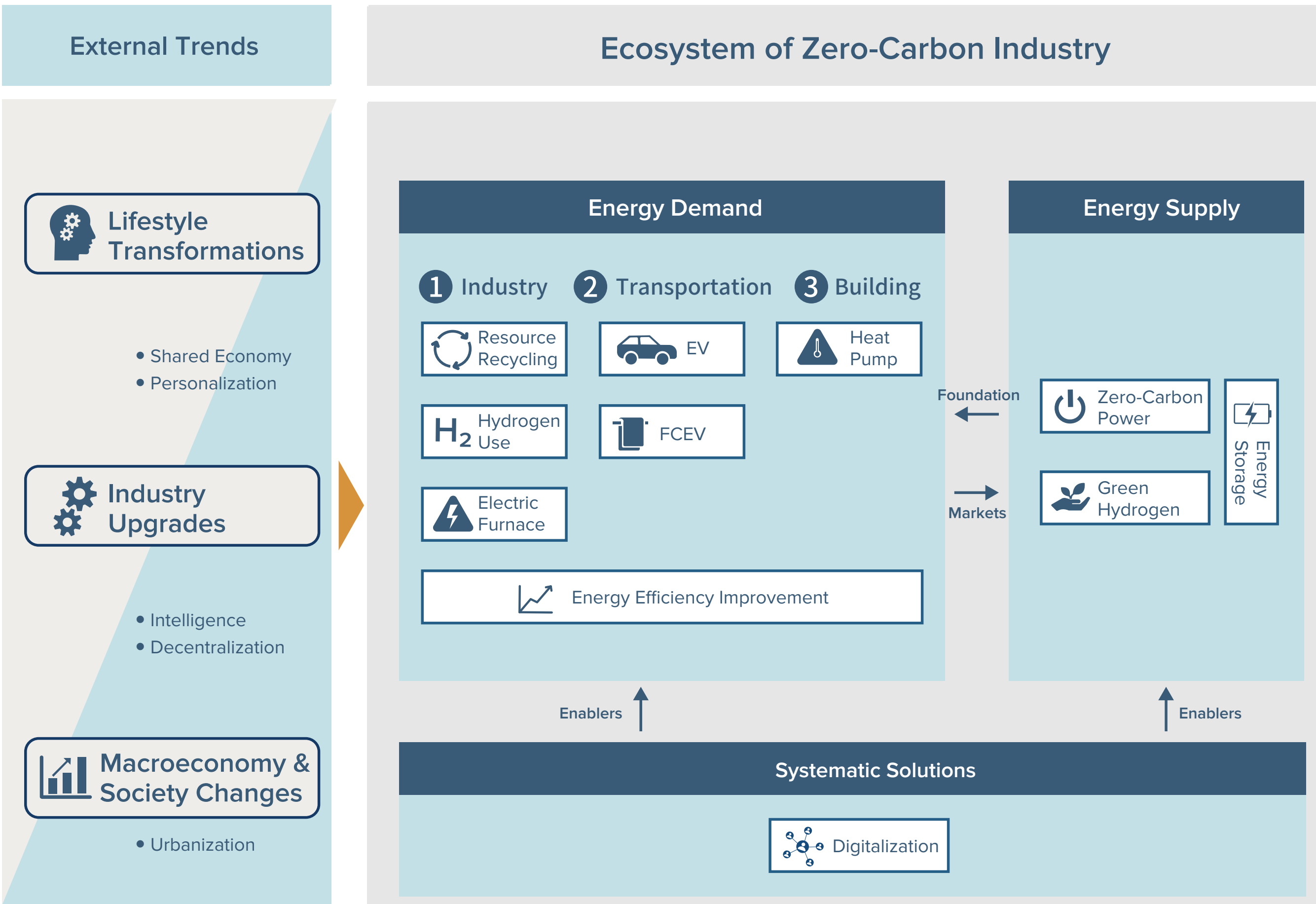
During the Trough of Disillusionment phase, market forces promote the optimization and renewal of products under the relevant industry standards. This stage is also marked by exploration of productivity optimization and mass production as well as the deployment of supporting facilities and judging of accurate use cases. These are the keys to laying a good foundation for the development of industries.

In the Slope of Enlightenment and Plateau of Productivity phases, the guiding role of market forces is more critical than that of the government. The investment in second- and third-generation products, the integration and optimization of production, the improvement of supporting infrastructure, and the expansion of use cases can still play a role in industry development.

2. **The seven areas of zero-carbon China have strong synergies. Policy development and investment should both reflect a strategic,**

Exhibit 21

Synergies of China's Zero-Carbon Industry Development



holistic view and provide insight into the roles and synergies of different technologies in the zero-carbon ecosystem. At the same time, policymakers and investors should consider the development opportunities for zero-carbon industries created by the evolution of the external macro-social economy, industrial technologies, and humanistic consumption concept.

Zero-carbon power, green hydrogen, and energy storage form the foundations of a green energy system. They support each other as well. These innovations are on the supply side of the energy system. They require large-scale construction, technology optimization, and energy price reductions to support the zero-carbon industries on the demand side.

Digital technologies are the "accelerator" of the whole zero-carbon ecosystem development. These can benefit the entire energy system and be applied in almost all fields from industrial digital energy-saving, smart building, EV bidirectional charging, and demand response on the demand-side, to power generation optimization, asset performance management, and distributed prosumer on the supply-side. It is possible to optimize energy supply, operation, and consumption through means of information technology.

Demand-side innovations in the industrial, transportation, and building sectors are an important pivot. Various technological innovations will change patterns of energy use, driving the establishment of new value chains and generating new profit pools. For example, EVs not only drive a new round of investment in infrastructure and the development of upstream battery production, services, and asset management companies, but also become a carrier for new technologies such as autonomous driving. They even have the opportunity to become a tool for energy storage, and by doing so can drive zero-carbon innovations on the energy supply side.

Other external trends in macro socio-economic changes, industry upgrades, and lifestyle transformations will also add new competitive advantages for key technologies of China's zero-carbon transition.

Urbanization: The development of cities and the change of social forms have brought new possibilities to the zero-carbon energy transformation. With the progress of urbanization, the decrease of the rural population, and the strengthening of rural land circulation, the unified management of large farms enables biomass collection to move past the difficulties of the decentralized small-scale peasant economy. It thus promotes the development of biomass energy.

Decentralization: With the development of technologies and institutions, decentralized new business models will break down market barriers for zero-carbon industries. For example, the small-scale, decentralized production of chemical raw materials such as chemical fertilizers will in the future reduce the demand for hydrogen supply, which can be met by existing electrolyzers without further expansion. For another example, power grid reform measures such as distributed market-oriented transaction modes will promote evolution in the upstream and downstream value chains of the distributed solar PV sector.

Intelligentization: Massive shifts in the economy and information technology has made intelligentization a new demand in the industry, transportation, and building sectors. This is conducive to improving efficiency and experiences and will vigorously promote the process of electrifying energy demand.

Sharing economy: The concept of a sharing economy has been penetrating into various sectors in recent years. Sharing represents not only the reduction of aggregated demand, but also more efficient use of the limited value of goods. It has changed people's lifestyles and habits in terms of clothing, food, housing, and transportation, and also gradually changed people's mindsets. Therefore, energy demand-side innovations that can easily become the carriers of "sharing" will have new competitive advantages.

Humanization: With rapid economic development and improved living conditions, the emphasis of consumption has shifted from functional value to humanistic value. Purchasing has become not just an act of trading, but an embrace of new ideas. Sustainable consumer products have been a rising force. In this context, the user-oriented zero-carbon innovations on the energy consumption side (such as EVs, hydrogen fuel cell vehicles, and air-source heat pumps) will have great market potential.

Based on the synergy of industries in zero-carbon China, the government should provide industrial support by means of laws, policies, and plans, so as to achieve "1+1>2" effects. Investors need to pay attention to synergies among sectors, as other sectors can serve as the foundation, potential markets, and systematic enablers for the development of each specific sector. At the same time, we also recommend considering the opportunities created by other external trends in macro socioeconomic changes, industry upgrades, and lifestyle transformations. They are adding new competitive advantages for the key technologies of China's zero-carbon transition.

Zero-carbon China will be the new direction of long-term value investment, thanks to the global trend of zero-carbon development and transition, as well as the Chinese government's increasingly clear strategic goal of zero carbon. Considering that zero-carbon China is still at an early stage of development, the government should introduce related policies and measures in the seven investment areas and continuously improve the investment environment. Investors should also strengthen their understanding of zero-carbon investment sectors and expand their capabilities in order to be fully prepared for these new opportunities and reap the value returns.

Endnotes

1. *Global EV Outlook*, International Energy Agency (IEA), 2020, https://www.iea.org/reports/globalev-outlook-2020.

2. *Power Transition Trends*, BloombergNEF, 2020

3. *China 2050: A Fully Developed Rich Zero-carbon Economy*, Energy Transitions Commission and Rocky Mountain Institute, 2019, https://www.energy-transitions.org/publications/china-2050-a-fullydeveloped-rich-zero-carbon-economy/.

4. "Zero Carbon Cities" *Thomson Reuters Foundation News*. https://news.trust.org/packages/zerocarbon-cities/.

5. *Meeting Climate Change Goals Through Energy Efficiency: Energy Efficiency Insights Brief*, International Energy Agency (IEA), 2018.

6. Qingyi Wang. *Energy Data*, 2017, https://www.efchina.org/Attachments/Report/report-lceg- 20200413-3/2017%E8%83%BD%E6%BA%90%E6%95%B0%E6%8D%AE/view?searchterm=%E8%83%BD%E6%BA%90%E6%95%B0%E6%8D%AE.

7. Jialin Ji, Yilan Ma, Shanshan Wang, et al. "Analysis of energy saving and emission reduction benefits of energy cascade utilization in an industrial park and its impact on urban air quality," *Acta Scientiae Circumstantiae* 40(5): 1884–1893.

8. *Energy Efficiency 2018*, China Council for an Energy Efficient Economy, 2019, http://www.cceee.org.cn/class/view?id=38.

9. *China Energy and Power Saving Analysis 2019*, State Grid Energy Research Institute, 2019.

10. *China Building Energy Conservation Annual Research Report*, Tsinghua University Building Energy Conservation Research Center, 2019.

11. Huaxia Industry Research Institute, 2019.

12. *China Energy and Power Saving Analysis 2019*, State Grid Energy Research Institute, 2019.

13. *China 2050: A Fully Developed Rich Zero-Carbon Economy*, Energy Transitions Commission and Rocky Mountain Institute, 2019, https://www energy-transitions.org/publications/china-2050-a fullydeveloped-rich-zero-carbon-economy/.

14. Ibid.

15. *China Building Energy Conservation Annual Research Report*, Tsinghua University Building Energy Conservation Research Center, 2019.

16. *China 2050: A Fully Developed Rich Zero-Carbon Economy*, Energy Transitions Commission and Rocky Mountain Institute, 2019, https://www.energy-transitions.org/publications/china-2050-a-fullydeveloped-rich-zero-carbon-economy/.

17. Hong Huo et al., "Projection of Chinese Motor Vehicle Growth, Oil Demand, and CO_2 Emissions through 2050, Transportation Research Record," *Journal of the Transportation Research Board* (2038, 69-7), 2007.

18. Ministry of Industry and information Technology of the People's Republic of China, 2020.

19. *China New Energy Vehicle Development Report*, Evergrande Research Institute, 2020.

20. "A Revolution in the Making—How to Race Ahead in China's Soaring NEV Market," Deloitte, 2019, https://www2.deloitte.com/cn/en/pages/consumer-industrial-products/articles/nev-revolution-inthe-making.html.

21. Ibid.

22. *Industrial Heat Decarbonization Roadmap*, Innovation for Cool Earth Forum, 2019.

23. Ibid.

24. Ibid.

25. *China 2050: A Fully Developed Rich Zero-Carbon Economy*, Energy Transitions Commission and Rocky Mountain Institute, 2019, https://www.energy-transitions.org/publications/china-2050-a-fullydeveloped-rich-zero-carbon-economy/.

26. Data was collected from China Electricity Council.

27. Data was collected from National Energy Administration.

28. *Renewable power generation costs in 2019*, International Renewable Energy Agency (IRENA), 2020, https://www.irena.org/publications/2020/Jun/Renewable-Power-Costs-in-2019.

29. "2020 Solar Subsidy Results," National Energy Administration, http://www.nea.gov.cn/2020-06/28/c_139172962.htm.

30. *New Energy Outlook 2019*, BloombergNEF, 2019.

31. *Nuclear Industry Report*, Huatai Securities, 2019, http://stock.tianyancha.com/ResearchReport/eastmoney/1e0901ecbd7ed59530062c68eb67078f.pdf.

32. Data was collected from China Electricity Council.

33. *Hydro Industry Report*, Industrial Securities, 2019, http://pdf.dfcfw.com/pdf/H3_AP201903051302680299_1.pdf.

34. *Future of Solar Photovoltaic*, International Renewable Energy Agency (IRENA), 2019, https://www.irena.org/publications/2019/Nov/Future-of-Solar-Photovoltaic.

35. *International Technology Roadmap for Photovoltaic*, Verband Deutscher Maschinen- und Anlagenbau, 2020.

36. *China Solar Industry Development Roadmap (2019)*, China Photovoltaic Association, 2019, http://www.chinapv.org.cn/road_map/802.html.

37. *Future of Wind*, International Renewable Energy Agency (IRENA), 2019, https://www.irena.org/publications/2019/Oct/Future-of-wind.

38. Ibid.

39. Ibid.

40. Ibid.

41. *Energy Storage Industry Research White Paper*, China Energy Storage Alliance, 2020, http://www.cnesa.org/index/index_search_detail?cid=5eddeb76b1fd3714548b4567&type=2.

42. *2019 Battery Price Survey*, BloombergNEF, 2019.

43. *Hydrogen: The Economics of Production from Renewables*, BloombergNEF, 2019.

44. Ibid.

45. *Target Explanation Document: Onboard Hydrogen Storage for Light-Duty Fuel Cell Vehicles*, US Department of Energy, 2017, https://www.energy.gov/sites/prod/files/2017/05/f34/fcto_targets_onboard_hydro_storage_explanation.pdf.

46. *China 2050: A Fully Developed Rich Zero-Carbon Economy*, Rocky Mountain Institute and Energy Transitions Commission, 2019, https://www.energy-transitions.org/publications/china-2050-afully-developed-rich-zero-carbon-economy/.

47. *2019 National Renewable Energy Power Generation Monitoring Report*, National Energy Administration, http://www.gov.cn/zhengce zhengceku/2020-05/16/content_5512148.htm.

48. *Digitalization & Energy*, International Energy Agency (IEA), 2017, https://www.iea.org/reports/digitalisation-and-energy.

49. "State Grid invests ¥24.7 billion in 'Digital New Infrastructure'," *Caixin*, last modified June 2020, http://www.caixin.com/2020-06-16/101567894.html?NOJP.

RMI China
Room 1606 | Ocean Park Tower C
No. 5 Jinghuananjie Street
Chaoyang District, Beijing

www.rmi-china.com