CHINA DECARBONIZATION MARKET REPORT 1: *MARKET OVERVIEW AND U.S.-CHINA COLLABORATION*

Innovation Center for Energy and Transportation

U.S.-China Cleantech Center

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We would like to thank the U.S. Department of Commerce's International Trade Administration (ITA) for funding support of this report. This research is the first in a series of four reports focusing on China's decarbonization market. This report provides an overview of China's drive to reach net-zero goals and its burgeoning decarbonization market. In the ensuing reports, we will focus on in-depth and individualized analyses of the decarbonization market in China's key emitting sectors and in China's Greater Bay Area in particular.

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Background

1.Background

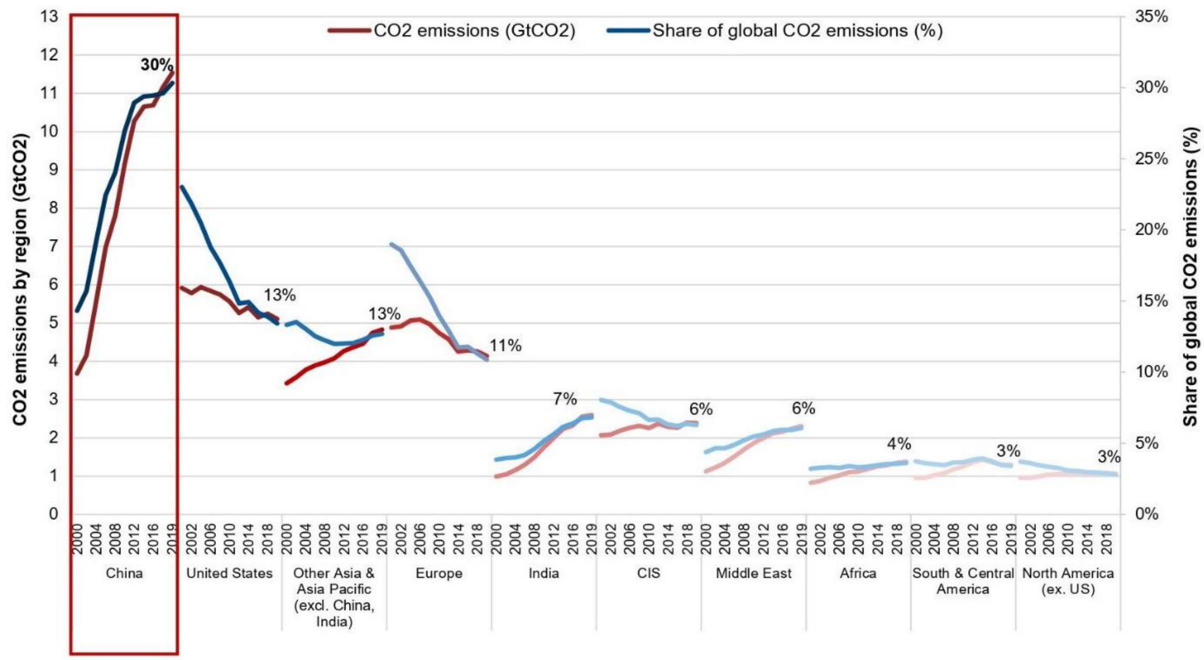
Global climate change caused by carbon dioxide emissions and other greenhouse gases has become one of the greatest challenges facing mankind in this century. To urgently solve the climate crisis, the world faces the arduous task of transitioning into a clean energy future enabled by decarbonization technologies and solutions. As the world's biggest carbon emitter, China hosts the biggest market opportunity to deploy a broad range of climate-friendly technologies and decarbonization solutions.

1.1 China as the Biggest Global Carbon Emitter

Over the past 40 years, China's economic development has made remarkable achievements. Total GDP has expanded with breakneck speeds, and the urbanization rate has reached 60%. However, this massive economic expansion has also led to exponential growth in natural resource consumption, carbon emissions and environmental deterioration, which has contributed to today's unprecedented environmental and climate crisis. In 2020, China consumed nearly 5.02 billion tons of standard coal, an increase of about 647% compared with the level of 1980. China's energy-related carbon dioxide emissions have also increased rapidly, reaching a total of 9.899 gigatons (Gt) in 2020.

China currently accounts for about 30% and 26% of global carbon dioxide and greenhouse gas emissions respectively, making it the country with the highest global emissions. As shown in Figure 1, China's emission growth path is quite remarkable when compared with other major geographic and economic regions; China's emissions accelerated most dramatically between 2000 and 2010, when its economy was growing at a historical rate. In contrast, during the same period, carbon emissions in many other major economies had stabilized or even declined. Combining rapid economic growth with a high-energy consumption rate and high-carbon intensity has made China the world's largest carbon emitter. It is estimated that China's accelerating carbon emissions have accounted for about 45% of the world's new greenhouse gas emissions since the 1970s.

Figure 1. China's Carbon Emission Status



Source: Goldman Sachs, European Commission Joint Research Centre (JRC). Emission Database for Global Atmospheric Research (EDGAR)

1.2 Major Sources of Carbon Emissions

As mentioned above, the combination of resource-intensive economic and industrial growth, high carbon-intensive energy supplies, utilization and operational inefficiencies have led China to become the world's largest carbon emitting country.

Energy-Intensive Economy

China's industry-led economic structure still relies heavily on "dirty" energies. In terms of carbon emissions per unit of GDP, China is still among the highest in the world - about 1 metric ton of CO2e (carbon dioxide equivalent) per $1,000 of GDP, compared with a global average of about 0.4 metric ton of CO2e per $1,000 of GDP in 2016, the last year for which global data are available. Heavy industries such as China's steel and cement manufacturing account for about 50% of global production and 17% of China's total carbon emissions.

High-Carbon Energy Supply

China's primary energy supply from coal still accounts for close to 60% of China's total energy consumption. Although it's down significantly from 80% in 1990 and 70% in 2000, it's still much higher than the world average of less than 30% during the same period. Due to price advantages and the large number of recently constructed Chinese mines, China's coal dependency will continue to be a major challenge for China to reduce carbon emissions.

Low Energy Utilization Efficiency

Compared with energy consumption from developed economies, China still has substantial room for improvement in energy efficiency. Taking cement production as an example, the energy consumption per ton of cement produced in China is 30% higher than the average level of developed countries. The reasons include the proliferation of competing small scale productions, frequent shutdowns caused by overcapacity, and generally low production efficiency. In 2019, only about 30% of cement production lines in China reached the international high-performance level.

Continued Energy Demand Growth

Despite slower economic growth during the past decade, China's urbanization process has continued to advance. Urban construction, infrastructure developments and transportation needs continue to drive energy demand growth. For example, China's urban residential area is roughly 1.5 times that of 10 years ago, and the annual sales of passenger cars is roughly 1.8 times that of 10 years ago. It's widely expected that the urbanization rate will continue to grow and reach 70% within the next ten years.

1.3 Carbon Emission Reduction Targets

Under the framework of the Paris Agreement, achieving carbon neutrality globally by mid-century is a critical step to mitigate climate change. In the Paris Agreement, China pledged to reduce the carbon intensity of its GDP by 60%-65% from 2005 levels by 2030, and to peak carbon dioxide emissions by 2030 at the latest.

In his seminal speech at the UN General Assembly in September 2020, Chinese President Xi Jinping stated that China would expand its Nationally Determined Contributions (NDCs) by adopting stronger policies and measures, with the government's goal to achieve CO_2 emissions peak before 2030 and achieve carbon neutrality before 2060'. Li Gao, Director of the Department of Climate Change at the Ministry of Ecology and Environment, reiterated the goal in October. The announcement is expected to provide more impetus for Chinese government agencies, municipalities, and industry to set decarbonization targets.

Shortly after making the 2060 carbon neutrality pledge, Chinese President Xi made an important speech titled "Continuing the path and opening the future to start a new journey in global response to climate change" at the Climate Ambition Summit on December 12, 2020, announcing that China will raise national voluntary contributions to fight climate changes to achieve by 2030:

1) Carbon dioxide emissions per unit of GDP will be reduced by over 65% from the 2005 level.
2) Non-fossil energy will account for about 25% of primary energy consumption.
3) Forest storage volume will be increased by 6 billion meters from the 2005 level.
4) Total installed capacity of wind and solar power generation will reach more than 1.2bn kilowatts.

In November 2021, at the COP26 climate summit in Glasgow, Scotland, China promised to make more efforts to cut emissions this decade and committed for the first time to reduce methane, a potent greenhouse gas.

The Chinese government released its 14th Five-Year Plan (2021-2025) in 2021, establishing binding targets for reducing both carbon and energy intensity. It aims to reduce carbon intensity (the amount of CO_2 emitted per unit of GDP) by 18% and energy intensity (the amount of energy consumed per unit of GDP) by 13.5% by 2025. Also, it promises to increase non-fossil fuel primary energy resources to 20%, a critical step in decreasing China's coal dependency. In addition, it requires the country to develop an action plan for peaking carbon dioxide emissions by 2030 as soon as possible.

Moreover, the Ministry of Environment and Ecology (MEE) publishes official policy to address the coordination of governance between carbon reduction and other forms of pollution reduction. MEE describes this approach as "synergizing" carbon and pollution reduction: reducing both carbon emissions and the atmospheric, water and soil pollutants produced by fossil fuels, including volatile organic compounds, particulate matter, and heavy metals that have often been regulated separately.

Decarbonization Market Potential

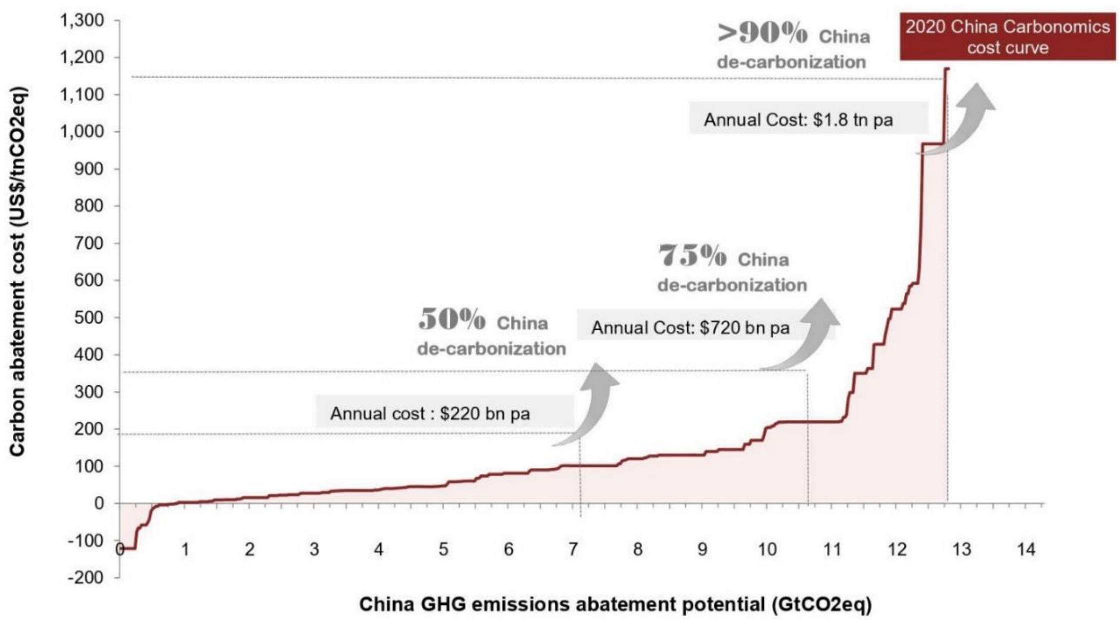
2. Decarbonization Market Potential

To achieve carbon neutrality, China's major emitting sectors need to reduce their emissions between 65% and 100% by 2050, meaning that some industries must reach near-zero levels a decade earlier than others. Achieving carbon neutrality while continuing economic growth requires structural changes to industries, infrastructure development and the way cities operate, and enables deep decarbonization in unprecedented ways. In the process, more business opportunities will emerge, especially in the application of green and low-carbon technologies and products to promote green transformation of traditional industries.

According to the Chinese Academy of Environmental Planning, achieving the 2030 carbon emission peak during the 14th Five-Year Plan and the 15th Five-Year Plan periods will require RMB 9.3 trillion (USD 1.5 trillion) and RMB 11.5 trillion (USD 1.8 trillion) of investment respectively. China International Capital Corporation (CICC) estimates that China demands nearly RMB 140 trillion (USD 22.1 trillion) in green investment over the next 40 years, of which RMB 22 trillion (USD 3.5 trillion) is required by 2030 and RMB 117 trillion by 2060 (USD 18.4 trillion). Green investment mainly includes the adoption of zero-carbon production capacity and transformation of old equipment with the low-carbon and clean technologies. Green investments in industry, power generation, transportation, and building sectors have substantial demands.

Goldman Sachs has forecasted the annual costs associated with China's net-zero target in its cost curve of carbon economics (2020). As shown in Figure 2, the estimated annual abatement cost of China's first 50% GHG emissions reduction (low-cost decarbonization) is approximately $220 billion. After reaching 75% decarbonization, the curve will enter a "high-cost decarbonization" range - the annual cost of achieving 90% decarbonization could be as high as about $720 billion. The annual cost could be as high as about $1.8 trillion by the time China achieves net-zero emissions by 2060.

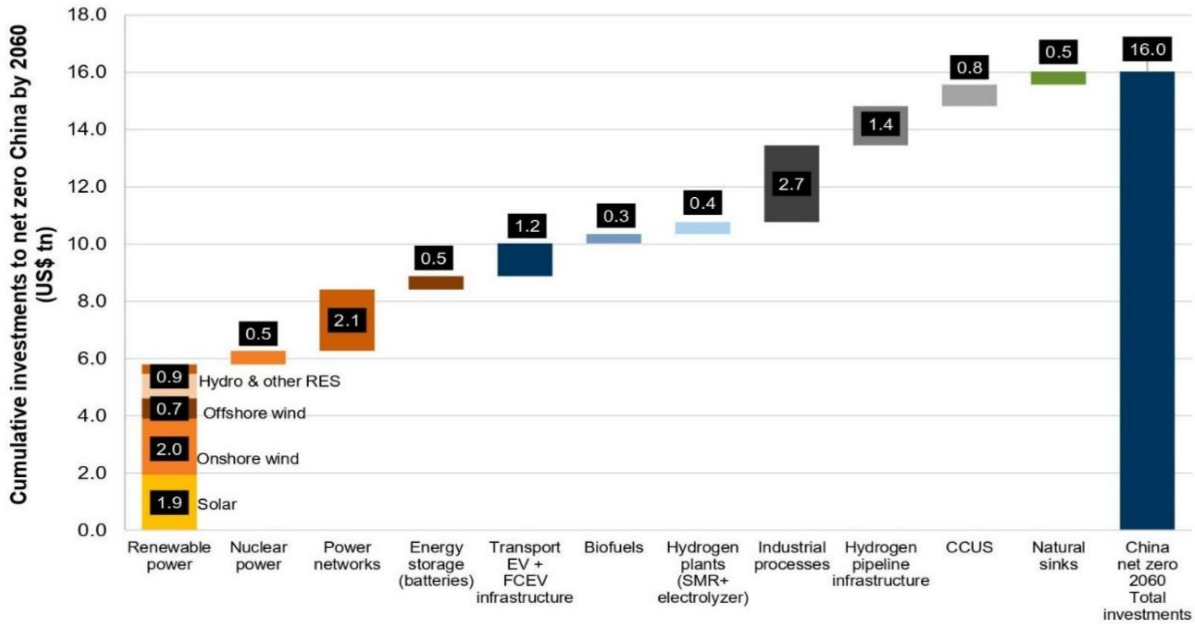
Figure 2. China's Decarbonization Cost



Source: Goldman Sachs

Cumulatively, as shown in Figure 3, Goldman Sachs estimated that approximately $16 trillion in related investments will be required by 2060. Among them, about $9 trillion will be invested in the power generation sector (including new energy infrastructure construction, energy storage, and major upgrades); $1.2 trillion in new energy vehicle and transportation infrastructure; $1.3 trillion in CCUS and natural carbon sinks; and $2.6 trillion in hydrogen energy in transportation systems, industry, and heating infrastructure.

Figure 3. Investment Demands in Different Sectors of China's Decarbonization Market



Source: Goldman Sachs

Major Decarbonization Sectors

3. Major Decarbonization Sectors

China's ambitious climate goals present substantial business opportunities for the decarbonization market. China's greenhouse gas emissions mainly come from five sectors: power, industry, transportation, building, and agriculture and land use. Among them, the power and industrial sectors accounted for the largest proportion. Below we will analyze some of the most significant emission reduction opportunities in these sectors.

3.1 Power

Although China has made great strides in renewable and nuclear energy since 2000, it still relies heavily on fossil fuels: in 2020, about 85% of China's total primary energy needs was met by fossil fuels, with coal alone accounting for nearly 60%. China is the largest coal consumer in the world with total coal consumption in 2020 reaching 3 billion tons, accounting for more than 50% of the world market. The power generation sector emitted about 5.4 billion tons of carbon dioxide in 2020 and expects to continue increase in near future. Therefore, the transformation of the power sector is one of the most significant measures in achieving carbon neutrality.

Major Decarbonization Solutions

The *Work Plan for Controlling Greenhouse Gas Emissions during the13th Five-Year Plan* issued by the China State Council noted that the carbon dioxide emissions per unit of power supply of large power generation facilities should be controlled within 550 grams of carbon dioxide per kilowatt-hour, which is still about 30% higher than the global average of about 450 grams per kWh. For China to achieve carbon neutrality by 2060, the carbon emissions per unit of power supply in the power industry must decrease from the current 600 grams/kWh, at least at a rate of about 150 grams/kWh per 10 years on average (that is, about 15 grams/kWh per year). Achieving this target will require vigorously developing and utilizing renewable energy, retiring coal power plants, electrifying end-use energy, and strengthening energy storage and CCUS (carbon capture, utilization and storage) solutions and the construction of new and safe nuclear power plants.

Renewable Energy

To achieve power sector deep decarbonization, China vigorously promotes renewable energy development. The renewable energy sources mainly include hydropower, photovoltaics, wind power, biomass energy (including waste-to-energy, biofuels, etc.), geothermal energy and tidal energy that is still in development infancy. Solar and wind are major renewable energies in China due to their abundant resources and market maturity. It is estimated that by 2050, there will be 2,400 GW wind power installed and 2,500 GW solar photovoltaic installed in China's power generation portfolio, and they will account for 70% of the total power generation in China. In addition, biomass power generation and natural gas power generation combined with CCUS technologies can play critical roles for power grid systems with high proportion of renewable energies by providing reliable power dispatch when wind and solar energies are insufficient to meet highly variable demands.

It is expected that China's renewable energy power generation capacity will increase by 6 times from 2020 and 2060 to reach 80% of total capacity. Over the years, the cost of renewable energy power generation has dropped significantly. For instance, the photovoltaic power generation cost has declined by about 85% from 2010 to 2020. Currently, the cost per kilowatt-hour of renewable energy power generation in China is already close to that of coal power generation. The economies of scale will continue to drive down the installation and operation costs of renewable energies and contribute significantly to the net-zero emission goals.

Energy Storage

Energy storage technology has been widely used in all aspects of the power industry. To meet the challenge of system flexibility, the cumulative installed capacity of the energy storage system needs to increase from about 32GW in 2019 to about 1,400GW by 2050. As renewable power generation accelerates, energy storage solutions must address fluctuations in daily and seasonal demands of electricity. Goldman Sachs research notes that in order to achieve complete decarbonization of the electricity market, two main technologies – the utility-scale energy storage batteries and hydrogen energy systems, are expected to help solve the challenges faced by energy storage deployments, and these two technologies can complement each other. It is estimated that by 2060, the scale of utility-scale energy storage batteries will exceed 400GW, and the proportion of CGGT power generation based on clean hydrogen energy will also reach about 3% market share at a similar time.

Lithium-ion batteries dominate current energy storage applications, and their costs have also fallen rapidly over the past decade. However, solely relying on lithium batteries is not enough to achieve carbon neutrality. The power system needs energy storage technologies with larger capacity, longer discharging time, longer lifetime, and lower commercial and retail prices to support the large-scale deployment of renewable energy. Fluid-based battery energy storage, physical energy storage system, heat-based storage and other technologies all have the potential to create values in the power generation system.

While batteries are the most effective energy storage technology during daytime power generation, research shows that hydrogen energy can be a suitable solution for seasonal energy storage and distribution. For example, sunny climates are particularly suitable for battery technology, where photovoltaic power generation is largely stable, and electricity can be stored for usage at night. Hydrogen energy (and the process of storing energy in chemical form and converting it back into electricity via fuel cells) can be used to compensate for seasonal imbalances between electricity demand and renewable energy generation.

Nuclear Energy

Nuclear power generation is less affected by the natural environment, stable in power supply, clean and highly efficient, and does not emit sulfur oxides, nitrogen oxides and greenhouse gases. It is a very attractive option to reduce carbon emissions. According to the 2020 Energy Technology Outlook released by the International Energy Agency (IEA), nuclear energy is indispensable in the global energy transition to significantly increase clean electricity supply. China is also actively promoting the development of nuclear power. In the 2021 "Government Work Report", it is proposed that nuclear power should be actively and orderly developed on the premise of ensuring safety.

According to the China Nuclear Energy Development Report (2021), it is estimated that by 2025, China's nuclear power will have about 70 million kilowatts of installed capacity and 50 million kilowatts under construction; by 2030, the installed capacity of nuclear power will reach 120 million kilowatts and account for 8% of China's electricity generation. Nuclear energy is becoming one of the key effective resources for China to tackle climate change and achieve "carbon neutrality" in the future. However, due to the sensitivity of national security concern, it may not be a suitable field for business and trade cooperation, thus we won't go into too much detail in this report.

Distributed Energy and Microgrid

Compared with centralized long-distance transmission, locally distributed energy consumption has certain economic advantages due to the absence of transmission costs and losses. By the end of 2018, of the total installed capacity of photovoltaic power generation in China, large-scale centralized power plants had a proportion of 71%, and distributed building photovoltaics accounted for 29%. Microgrid can be defined from the perspective of distributed energy or control systems.

At present, microgrid projects are rapidly developing under the impetus of policies from all over the world. In China, the primary goal of developing a multi-energy complementary energy smart microgrid is to make full use of renewable energy to meet diversified future energy needs and maximize the application of renewable distributed energy, thereby enhancing the efficient use of green energy and improving energy efficiency.

On July 13, 2015, the "Guidance of the National Energy Administration on Promoting the Construction of New Energy

Microgrid Demonstration Projects" was issued, encouraging all provinces (cities, districts) to construct at-least one or two new energy microgrid projects. In accordance with the concept of Energy Internet and the utilization of advanced Internet and information technology, these projects aim to achieve intelligent matching and coordinated operation of energy production and demand, participate in the power market in an innovation way, and form a new and efficient energy utilization carrier. On February 7, 2017, the "Microgrid Management Measures" opinion publicly solicited by the National Energy Administration pointed out that the distributed power and the microgrid system were included in the annual construction scale indicators, and the existing subsidy policy for distributed energy generation can be implemented. At the same time, local governments and private capital are encouraged to cooperate, and the construction and operation of microgrid projects can be carried out in the form of franchising, and microgrid project operators are encouraged to engage electricity sales.

Carbon Capture, Utilization and Storage (CCUS)

CCUS is currently the key technology to achieve zero emission goals for large-scale fossil energy use. Thermal power combined with CCUS will balance the volatility of renewable energy generation and provide guaranteed power and grid flexibility. "New energy power generation + energy storage" and "thermal power + CCUS" will be an indispensable combination of technologies, and the deep synergy between them will become the key to a clean, zero-carbon, safe and efficient energy system in the future. According to the research results of the International Energy Agency (IEA), under the sustainable development scenario, all non CCUS-capable coal-fired power units will be phased out globally by 2045, and 1,000 TWh of electricity will be produced by coal-fired power combined with CCUS technology.

Since CCUS can capture 90% of carbon emissions, adding CCUS to coal-fired power plants will produce a relatively low-carbon power generation technology. If coal and biomass are co-fired for power generation, it would generate negative carbon emissions. In this way, the existing coal-fired power units can still be utilized, and the waste of resources caused by the early retirement of some coal-fired power assets can be avoided.

3.2 Industry

Industry (including industrial combustion, industrial processes, and waste disposal) is the largest contributor to China's greenhouse gas emissions. The proportion of energy consumption in the industrial sector in the country has always been higher than 65%, and the proportion of carbon emissions has exceeded 70%. Industrial emissions generally come from the following three sources: energy consumption and combustion, operational processes, and raw material and waste-related emissions (including fugitive emissions). In terms of sub-sectors, iron and steel, cement, chemicals, and petrochemicals are critical emissions-intensive industries. This section will provide breakdown analysis to outline each sector's carbon footprint and how its developmental path resulted in being a major emitter of greenhouse gas.

Iron and Steel

China is the world's largest steel producer and consumer. In 2019, it was responsible for producing more than 50% of global steel. Nearly half (48%) of steel consumption is dedicated to infrastructure and building construction to support urbanization and industrialization. However, with the recent slowing downs of China's infrastructure projects, there is a gradual decline in demand for iron and steel consumption.

Globally using recycled scrap steel is now a major method of steel production, accounting for 60% of all developed countries and 30% globally. Scrap metal is vital in suppressing industry emissions as it is more cost efficient, requires less additional natural resources (namely iron ore), and relies much less on fossil fuel combustions. However, due to the scarcity of scrap metals, only 9% of all China's productions are achieved with recycled steel.

Mirroring a typical developing country, most of China's steel production depends on iron ore, which requires a longer time to process and is much more energy intensive. About 75% of the sector's energy needs are met with coal for fuel combustion and by-products that is an integral part of the chemical process. As fossil fuels offer a high temperature which is hard to be replaced and critical for the chemical process, iron and steel account for 32% of China's industrial emissions and is the largest emitter of the industries.

Cement

Cement is the most widely used man-made material and generates a significant carbon footprint. China produces more cement than the rest of the world combined. The sheer quantity of China's

cement production has led it to become the second-largest industrial emitter responsible for 21% of carbon emissions. Reducing carbon emissions in the cement industry needs to aggressively deploy CCUS technologies, utilize limestone substitutions, and upgrade systems to improve operation efficiency.

Chemicals and Petrochemicals

China's chemical industry is the largest in the world and generates diverse products. Three basic products - methanol, ammonia, and HVC (high-value chemicals including ethylene, propylene, benzene, toluene, and mixed xylenes), are the vital components of many manufactured products, including plastic, and consume ¾ of all energy use in the chemical industry. Overall, China's chemical industry contributes 15% of carbon emissions. However, as China has limited domestic supplies of oil and gas, which are the main feedstock for the global chemical industry, China has heavily relied on coal gasification technologies, which tend to be more capital and energy intensive. The major options to reduce carbon emissions in this sector include improving overall system efficiency, deploying CCUS technologies, and introducing hydrogen and sustainable low-carbon fuels as substitution fuels.

Others

Other industries also consume large amounts of energy and generate significant CO_2 emissions that add up to approximately 32% of all industrial emissions. These industries include aluminum and other non-ferrous metals, as well as light industries such as bulk raw materials (wood and paper), construction, machinery, and textiles. Similar to the steelmaking industry, the aluminum industry generates less emissions when there is increased availability of scrap metal to shorten the industrial process. Digitization and increasing recycling also lower carbon emissions in the wood and paper industries. Energy usage in the light industries, on the other hand, contain heat, mechanical work via machinery and motors, and additional lighting and refrigeration needs. These emissions can be substantially reduced by electrification.

<u>Major Decarbonization Solutions</u>

Decarbonizing the industrial sector is critical for China's path toward carbon neutrality. The *2021 Government Report* outlined a two-part strategy to reach carbon neutrality. In industrial processes where carbon emissions are relatively easier to abate, system upgrades and optimization, electrification, and hydrogen proliferation are the key pathways to neutralize energy-related carbon. In processes where carbon emissions are hard to remove, carbon capture, utilization, and storage (CCUS) and natural-based carbon absorptions come into play. The *Implementation Strategy to achieve Carbon Peak by 2030* recognizes the industrial sector as a major emitter that influences the success of whether China can achieve carbon peak by 2030, and recommends optimizing industrial processes, replacing outdated infrastructure, increasing energy efficiency, and encouraging clean energy usage in general.

Energy Transition: Electrification and Substitution

30% of China's emissions stem from the primary energy usage in the industrial sector. Central to reducing energy consumption lies in three paths: 1) electrification via renewable energy and nuclear energy; 2) the proliferation of hydrogen fuel; and 3) when fuel combustion is necessary, substitution through bioenergy and hydrogen fuel.

Electrification aims to take advantage of low-carbon renewable energies, mostly from solar and wind, and hydrogen-based electricity generation. Specifically tailored to the industrial sector, the wide application of "green hydrogen" would mark a general deterrence from using fossil energy. As the largest hydrogen producer, the China Hydrogen Energy and Fuel Cell Industry Alliance predicts that, by 2050, 56% of all domestic demands for hydrogen will rise from the industrial sector. The use of hydrogen for making ammonia and methanol is already widely used in the chemical industry. For other specific implementation, as the steelmaking industry gradually transitions to secondary production (using scrap metal), the demand for hydrogen-based energy will minimize fossil fuel demands.

When fuel combustion is required, substitutions through the use of biofuels, either direct burning or derived from renewable biomass feedstock, can make use of marginal lands or agricultural waste. China already makes considerable use of its urban and agricultural waste to produce biofuels and biogas to aid its steelmaking and chemical production. When fossil fuel is unavoidable, the proliferation of CCUS technology will be vital for achieving carbon neutrality.

Waste Management

Waste management seeks to cut down indirect emissions from industrial products and takes on two paths: 1) systematic recycling of scrap materials (which is already a scarce resource) and plastic; and 2) increasing product quality and efficiency to ease pressure off unrecyclable or resource-intensive recycling. Standardized, systematic recycling, as mentioned above, can effectively create more products through secondary production. Steelmaking from scrap metal can utilize electricity rather than fossil fuel combustion. Systematic recycling of plastics can also be vital to sustainable development and cutting carbon emissions, not only countering plastic pollution but also lowering the demand of HVC and methanol through recycling production.

Carbon Capture, Utilization and Storage (CCUS)

CCUS is a key to carbon neutrality as it contributes to directly reducing emissions or to removing CO_2 to balance emissions that are difficult to abate. The first-generation CCUS technologies has been deployed thus far is cost-inefficient, while the second-generation is still being lab-tested or featured on small-scale deployment. China has already made significant progress in the development of CCUS, featuring 21 pilot projects in different regions across the country. As the country's power and industrial plants are relatively new, CCUS can be integrated in the early stage to permanently store and utilize CO_2. As discussed above, CCUS technologies will be most likely to be deployed in the cement and chemical sectors, since it is still one of the few available technologies to significantly reduce these sectors' process-related emissions.

3.3 Transportation

Transportation is a key area of fossil energy consumption and greenhouse gas emissions. In recent years, it has become one of the fastest growing areas of greenhouse gas emissions in China. The carbon emissions in the transport sector mainly come from the fuel combustion of transportation vehicles. In 2019, CO_2 emissions from the sector accounted for nearly 11% of the total CO_2 emissions in China. Particularly, road transportation is the key aspect of carbon emissions in the transport sector, accounting for 87% of the total carbon emissions in the sector.

Achieving carbon neutrality in China's transportation sector faces significant challenges. The overall transportation activities continue to grow, with growing demand for improving services in travelling, convenience, and consumer experience. Without aggressive and effective mitigation measures, the emission growth from the transport sector will outpace other end-use sectors, and the transportation sector will become the largest contributor to CO_2 emissions like in other developed economies.

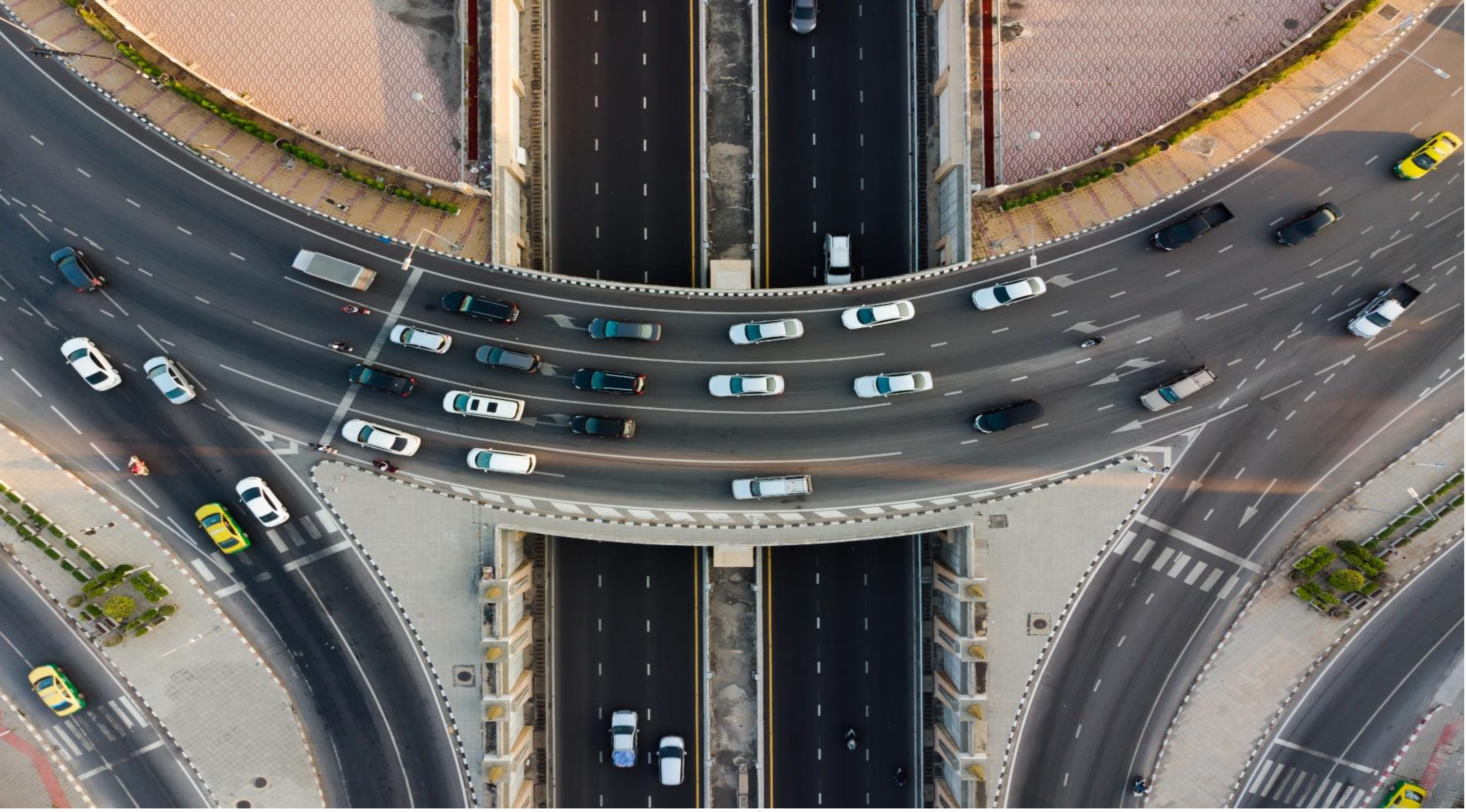
Major Decarbonization Solutions

The transportation industry mainly includes road transport, railway, ocean shipping, and aviation. It's estimated that around 30% of the transport sector carbon emissions can be reduced through traditional measures such as energy savings, efficiency gains and modal shifts. However, achieving complete carbon neutrality requires a comprehensive energy transition that replaces traditional fossil fuels with clean energy.

Electrification

Electrification is the much-needed solution for clean transportation. Thanks to the rapid development of battery technologies, electrification has the potential to expand from light-duty vehicles and railways to commercial vehicles, small ships, and even short-range aircraft.

Accelerating transportation electrification requires coordinated efforts among policy design, technology development, market creation and infrastructure build-up. Relevant policies introduced in China in recent years include setting ambitious electric vehicle (EV) promotion targets, strengthening emission standards, setting a phase-out schedule for gasoline-powered vehicles from the market, and providing road privilege policies and subsidies to support the growth of the electric vehicle market. In addition, China supports the large-scale deployment of charging infrastructure and promotes various measures to significantly reduce the operational costs of electric vehicles.



Hydrogen

While electric vehicles are considered the most effective decarbonization solution for passenger cars and short- and medium-haul transport, clean hydrogen is expected to be an important decarbonization option for long-haul heavy-haul transport. Hydrogen is an attractive transportation fuel due to its high energy content per unit mass and zero direct carbon emissions when derived from renewable energy sources. Hydrogen energy can be used in fuel cell vehicles in the form of pure hydrogen, as well as be converted into hydrogen-based fuels such as synthetic methane, methanol and ammonia through a process commonly referred to as "power to liquid", which is expected to be suitable for areas where the direct use of hydrogen or electrification is quite difficult. China attaches great importance to the development of hydrogen energy and has announced plans to deploy 1 million fuel cell vehicles by 2030, and have more than 1,000 hydrogen refueling stations, more than 50,000 fuel cell vehicles and more than 300 hydrogen refueling stations by 2025. Various regions such as the Greater Bay Area in China have introduced further exploration plans for using hydrogen energy. 30 provinces and 158 cities have mentioned hydrogen energy development in their "14th Five-Year Plan", and 57 cities have issued special projects for the development of the local hydrogen energy industry.

Biomass

Electrification and hydrogen play big roles in low carbon transportation. It's projected that they will contribute about 80% of the total energy demand in the transportation sector by 2060. The remaining 20% of energy demands comes from large airlines and long-haul shipping, where electrification or hydrogen options are difficult to meet these demands. Compared to other clean energy sources, biomass fuels are a viable solution. Biomass fuels exhibit similar performance to fossil fuels, and many transportation applications can use biomass fuels directly with little modification. It is conservatively estimated that by 2060, biomass fuel can provide energy equivalent to 30 million tons of standard coal for China's transportation industry, accounting for 5% of the total demand. Demand for biofuels in the transport sector is projected to reach a level of nearly 2.5 million b/d in 2060.

3.4 Building

Building construction and operations are among the largest contributors to climate change, accounting for nearly 40% of energy-related CO_2 emissions globally. Energy use and emissions from buildings in China have grown rapidly in recent decades in line with urbanization and rising incomes, especially since the turn of the century. The current carbon emissions from buildings in China are about 2.1 billion tons, accounting for around 20% of China's total emissions – about 25% from direct use and 75% from the indirect use of fossil fuels in providing heat and electricity consumed in the sector. Demand for energy services has risen in parallel with increasing dwelling size, with residential floor area jumping from less than 20 m^2 per person in 2000 to more than 35 m^2 in 2020 – close to the European average. The advancement of urbanization also promotes a sharp increase in the construction of commercial buildings. The total floor area (including residential and commercial) is projected to reach 85 billion m^2 by 2050.

Heating and cooling are the main sources of energy consumption, accounting for 67% of total buildings energy consumption in China in 2020. Climatic conditions vary enormously across the country, significantly affecting energy needs for heating and cooling. China's building energy standards

identify five climate zones. Among these climate zones, around 5% of China's population live in areas needing cooling, 15% in areas needing heating, and the remaining 80% require both heating in the winter and cooling in the summer. Nationally, space and water heating are responsible for nearly 60% of final building energy consumption, followed by cooking (14%), electrical appliances and devices (14%), space cooling (7%), and lighting (5%).

The relatively young age of buildings in China and the heavy reliance on fossil fuels for heating are big problems that need to be solved. Over three decades, regulatory efforts have helped to reduce the average energy intensity of buildings by more than 40%, but energy consumption in the building sector has been continuously rising. The average age of buildings is just over 15 years old, and nearly half of the existing floor area may still be in use by 2050, so retrofitting measures to reduce energy use and switch to low-carbon technologies are particularly important. Over one third of the total final energy consumption of buildings is still supplied by fossil fuels, and more than 50% of space heating nationwide (80% in the Northeast of China), uses inefficient fossil fuel equipment inside buildings.

Adopting low-carbon development approaches for buildings is critical to decarbonize the building industry. Since 2006, China has implemented a green building certification system - China Green Building Three-star Certification. The new version of Green Building Evaluation Standard GB/T 50378 was officially implemented in 2019, and it has four levels: basic, one-star, two-star, and three-star. By the end of 2020, the proportion of newly built green buildings in cities and towns nationwide has reached 77% of new buildings in that year. By 2025, the Chinese government requested new buildings in cities and towns fully implement green building standards. Strong government support and regulations create great opportunities for more and more green building and renovation projects in China.

Major Decarbonization Solutions

In its move to achieve carbon neutrality in the building sector, China is expected to take a combination of measures including improving energy efficiency, increasing electrification, and switching to alternative clean fuels including clean hydrogen, biomass, solar thermal energy, and waste heat etc., to facilitate the transition to a net-zero emissions building ecosystem.

Energy Efficiency

Among the measures to achieve carbon neutrality in the building sector, an especially important task is to promote energy-saving renovation measures in buildings to improve energy efficiency, including heating network renovation, strengthening wall insulation, using energy-saving electrical equipment, improving lighting, and green roofs etc. In terms of building materials and construction renovation, emission reduction and efficiency improvement can be achieved by using hollow or Low-E materials, energy-saving architectural design and innovative glasses to reduce building energy consumption, as well as lightweight partition materials such as gypsum board to replace traditional cement and brick walls to reduce carbon emissions from the producing and transportation of cement and building bricks.

Cooling and lighting are also key areas for improving building energy efficiency. Although China is the largest market and producer of room air conditioners, the average cooling energy efficiency in China is only 60% of the best technology currently available. It is estimated that by 2050, by adopting more efficient room air-conditioning technologies, China's cooling energy efficiency could be further improved by 30% by raising the minimum cooling energy efficiency standards. In addition, from 2010 to 2018, light-emitting diode (LED) lighting technology has advanced rapidly, increasing energy efficiency from 50 lumens per watt to 100 lumens per watt. By 2050, the energy efficiency of LED lighting could reach 200 lumens per watt, which means a further 100% increase in energy efficiency.

Electrification

Electrification is one of the most significant steps towards achieving zero carbon emissions in buildings. With cooling, lighting, and appliances now fully electrified, decarbonizing heating energy use will be critical to achieve net-zero targets for the building sector. One specific technology is to vigorously promote the use of heat pumps in suitable areas, which helps drive electrification in the heating sector. Compared with the traditional heating furnace, the energy consumption of the heat pump is only half that of the traditional heating furnace. According to IEA estimates, heat pumps accounted for only 5% of global household energy use in 2019, and this proportion is expected to increase to 22% by 2030, which will reduce heating energy consumption and reduce carbon emissions in the building sector by 50%. In China, the average energy efficiency of installed space heating equipment is expected to increase by 40% in 2030 and more than double in 2060 due to the deployment of electric heat pumps. In addition, the electrification of cooking is also promising and could be a major contributor to energy conservation and emission reduction in the building sector. However, it will require a significant increase in public acceptance of electric cookers and expand the power grid capacity of residential buildings.

Clean Energy

To fully decarbonize the building industry, all energy inputs to buildings must come from renewable sources or clean fuels such as solar panel, clean hydrogen, biomass, solar thermal, waste heat, etc. By 2050, under the zero-carbon scenario, the building and construction sectors need to phase out fossil fuels completely.

One important type of renewable energy is geothermal energy and hot dry rock geothermal resources. The development and utilization of large scale geothermal resources with wide distribution channels will be an important development direction. The use of biomass, industrial waste heat that does not generate additional carbon emissions, and solar heat, which can be widely used for building heating and hot water heating in rural areas, should be vigorously promoted.

The promotion of zero-carbon buildings requires the coordination of various energy sources to provide systematic solutions. For example, the combination of photovoltaic roofs, biomass applications, hydrogen energy for heating and cooling, and energy storage systems which can ensure buildings continuously use zero-carbon energy supply during both daytime and night. In the selection of building materials, zero-carbon construction can also be achieved by means of industrial decarbonization technology or the substitution of new materials.

U.S.-China Collaboration on Decarbonization

4. U.S.-China Collaboration on Decarbonization

Despite geopolitical tensions between the U.S. and China, tackling climate change has become one of the few potential areas of cooperation between the two countries. Collaborative effort to reduce carbon emissions is of significant interest to China, the U.S. and the international community as a whole. The U.S. Special Presidential Envoy for Climate, John Kerry, has visited China twice in 2021 for climate negotiations and plans to visit China for the third time. This clearly demonstrates the importance of U.S. and China collaboration to achieve net-zero goals.

Climate Agreement

In a "U.S.-China Joint Statement Addressing the Climate Crisis" released on April 17, 2021, both sides agreed to continue to discuss concrete actions in the 2020s to reduce emissions aimed at keeping the Paris Agreement-aligned temperature limit within reach. The areas of cooperation include:

- Policies, measures, and technologies to decarbonize industry and power, including through circular economy, energy storage and grid reliability, CCUS, and green hydrogen
- Increased deployment of renewable energy.
- Green and climate resilient agriculture.
- Energy efficient buildings.
- Green, low-carbon transportation.
- Cooperation on addressing emissions of methane and other non-CO2 greenhouse gases.
- Cooperation on addressing emissions from international civil aviation and maritime activities.
- Other near-term policies and measures, including with respect to reducing emissions from coal, oil, and gas.

Furthermore, in November of 2021, at the COP26 climate summit in Glasgow, Scotland, the United States and China announced a joint agreement to "enhance ambition" on climate change, saying they would work together to do more to cut emissions this decade while China committed for the first time to reduce methane, a potent greenhouse gas.

The two sides agreed to strengthen and accelerate climate action and cooperation, including speeding up green and low-carbon transitions, encouraging decarbonization and electrification of end-use sectors, enhancing the development of circular economy, as well as climate technology innovation, to accelerate the transition to a global net-zero economy. Positive attitudes towards cooperation between China and the United States on climate and decarbonization not only opens more business opportunities but also helps mitigate risks for U.S. companies facing increasing challenges navigating geopolitical uncertainties.

Business Cooperation

The United States is a world leader in implementing net-zero concepts as well as developing zero-emission technologies, products, and services, thanks to some of the strictest regulatory requirements and standards implemented in states such as California and Massachusetts. In addition, as mandated by the Congress, the Export-Import Bank of the United States (EXIM), approved a program on China and Transformational Export Content Policy focusing on a key set of 10 strategic industry sectors, including water treatment and sanitation, renewable energy, energy efficiency and energy storage. The program is designed to help U.S. exporters better compete in the China market. The Transformational Export Content Policy offers a total level of up to 85% financing for contracts having at least 51% U.S. export content.

Many U.S. firms' products and solutions have been developed a long time ago but reached saturation or declining demand in the US market. Many of these products are readily available to export to the Chinese market which are still dominated by heavy industries and pollution intensive businesses. U.S. firms will benefit from exporting these products and bring back revenues and jobs to the United States to support their local operations.

Decarbonization Market Opportunities

Based on the above analyses of China's decarbonization market needs and the consensus reached between U.S. and China to cooperate in climate change, we list herein some of the major products and solutions that are in demand in the Chinese market. Please note that this list is neither exhaustive nor exclusive.

<table>
<tr><th colspan="2">List of Major Decarbonization Products / Solutions</th></tr>
<tr><td>Renewable / Clean Energy</td><td>Power Generation
o Wind energy related products and solutions
o Solar energy related products and solutions
o Geothermal energy related products and solutions
o Tidal energy related products and solutions
o Biomass based products and solutions
o Clean coal + CCUS related products and solutions
Distributed Energy
o Smart grids and microgrids
o Distributed power generation
o Combined heat and power (CHP)
Building Application
o Building-integrated photovoltaics (BIPV)
o Air-source and geothermal heat pumps
o Smart windows and thin films</td></tr>
<tr><td>Electrification</td><td>Transportation
o Batteries manufacturing
o Electric vehicles manufacturing
o Charging equipment
o Battery recycling and secondary utilization
o Battery management system
o Raw material exploration
o Electric aircrafts and ships
Building
o Electric pumps
Industry
o Electric boilers
o Electric arc furnace steelmaking
o Variable speed drive high-efficiency motors</td></tr>
</table>

Hydrogen	o Hydrogen production (industrial by-product hydrogen, water electrolysis hydrogen production, natural gas hydrogen production, etc.) o Hydrogen storage (gaseous hydrogen storage, liquid hydrogen storage and solid hydrogen storage) o Hydrogen transportation (gaseous transport, liquid transport and solid transport) o Hydrogen fuel cell products (catalysts, proton exchange membranes, gas diffusion layers, bipolar plates, fuel cell stacks) o Hydrogen refueling station o Hydrogen fuel cell vehicles o Hydrogen-based fuels: shipping fuel ammonia and synthetic aviation fuel o Hydrogen boiler
Carbon capture, utilization, and storage (CCUS)	CO_2 Capture o BECCS (Bioenergy with carbon capture and storage) o Direct air capture (DAC) o Carbon mineralization o Chemical absorption o Physical separation o Membrane separation o Negative emission technologies (soda lime, augmented ocean disposal, biochar etc.) CO_2 Utilization o CO_2 flooding o CO_2 to make chemical raw materials and chemical products o CO_2 to make fuel o CO_2 to make building materials CO_2 Storage o CO_2 storage in depleted oil and gas reservoirs on land and in the ocean o CO_2 storage in deep saline aquifers

Biomass	o Bioenergy power generation o Liquid biofuel o Corn ethanol o Biodiesel (fatty acid methyl ester biodiesel and hydrotreated vegetable oil) o Renewable diesel and biokerosene using wood feedstocks (including cellulosic ethanol, Fischer-Tropsch biofuel, and renewable alcohol-based aviation fuel (ATJ) kerosene) o Biomethane
Energy Efficiency	o Power supply and distribution system o Industrial motor system o Heating, ventilation, and air conditioning system (HVAC) o Industrial cooling and heating system o Lighting system o Industrial thermal energy saving o Industrial boiler (kiln) energy saving o Alternative building materials for steel and cement
Energy Storage	o Mechanical energy storage (pumped hydro energy storage, compressed air energy storage and flywheel energy storage, gravity energy storage) o Electromagnetic energy storage (superconducting energy storage and super capacitor energy storage) o Electrochemical energy storage (lead-acid batteries, lithium-ion batteries, sodium-sulfur batteries, and flow batteries)

<table>
<tr><td>Waste Management and Recycling</td><td>Waste Treatment
Industrial solid waste treatment
Bulk industrial solid waste treatment (tailings, coal gangue, fly ash, smelting slag, industrial by-product gypsum, red mud, carbide slag)
General industrial solid waste treatment (scrap ships, scrap cars, scrap household appliances, scrap tires, scrap paper, scrap plastics, scrap non-ferrous metals, scrap iron and steel)
Hazardous waste treatment
Domestic waste disposal
Agricultural and forestry waste treatment
Food waste treatment
Sludge treatment industry
Industry waste heat recovery
Recycling
Recycled steel from scrap iron
Battery recycling
Physical and chemical recycling of plastics
Waste electrical and electronic products recycling
Waste non-ferrous metals recycling
Waste tires recycling</td></tr>
<tr><td>Methane Mitigation</td><td>Technologies and solutions in agriculture and landfills
Technologies and solutions in oil and gas, coal</td></tr>
</table>

Pollution Control	o Air pollution control related products and solutions (dust removal, desulfurization, denitrification; mercury removal, VOCs treatment) o Soil remediation related products and solutions (heavy metal contaminated soil, industrial site contaminated soil, agricultural soil) o Water pollution control related products and solutions (urban domestic sewage, industrial wastewater, rural sewage) o Environmental monitoring related products and solutions (online monitoring of fixed pollution sources; routine air quality monitoring; water quality environmental monitoring) o Other pollution control related products and solutions

5. Conclusion

China is the largest national source for global carbon emissions. China has committed to peak carbon emissions by 2030 and achieve net-zero carbon emissions by 2060. The ‘dual carbon’ targets have been a high priority for China’s central and regional policy makers.

To achieve carbon neutrality, major emitting sectors in China need to reduce their emissions between 65% and 100% by 2050. This climate commitment would require massive technological and structural changes in infrastructures, industries and urban systems to deploy decarbonization technologies and solutions in unprecedented ways.

It is estimated that China would demand nearly RMB 140 trillion (USD 22.1 trillion) in green investment over the next 40 years. As the world's top carbon emitter, China has the biggest market to deploy a broad range of decarbonization technologies and net-zero solutions.

Despite geopolitical tensions between the U.S. and China, tackling climate change has become one of the few significant and potential areas of cooperation between the two countries. Both countries agreed to take concrete actions during the ten years in the 2020s to reduce emissions and accelerate the transition to a net-zero economy.

After analyzing the decarbonization market needs in China’s major sectors as well as the consensus reached between U.S. and China for cooperation in climate change, we concluded that the decarbonization products and market solutions in the following categories - Renewable Energy, Electrification, Hydrogen, Biomass, Carbon Capture, Utilization and Storage (CCUS), Energy Efficiency, Energy Storage, Methane Mitigation, Waste Management, and Pollution Control are the most promising areas for business and trade cooperation and have the biggest potentials for US companies to export to China.

This research is the first in a series of four reports focusing on China's decarbonization market and provides an overview of China's drive to reach net-zero goals and its burgeoning decarbonization market. In the ensuing reports, we will focus on in-depth and individualized analyses of decarbonization markets in China’s key emitting sectors and in China’s Greater Bay Area in particular.

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CHINA DECARBONIZATION MARKET REPORT 1: MARKET OVERVIEW AND U.S.-CHINA COLLABORATION

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