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CHINA PAVILION COP28

Joint Statement on Carbon-Neutrality Pathways for China and the United States

8 November 2021

ICCSD

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1. ORIGIN OF THIS STATEMENT

The authors are senior members of teams from Harvard University (Cambridge, Massachusetts) and Tsinghua University (Beijing, China) who have been working together[1], on how to maximize the likelihood that the carbon-neutrality goals announced by the two governments for around mid-century can be met. This statement conveys key findings from the first phase of the collaborative project. We write here as individuals, not as representatives of our universities or our governments. The affiliations listed with the names of the authors at the end of the document are provided only for purposes of identification.

2. MOTIVATION

We are convinced that China and the United States-the two largest economies and the two largest emitters of greenhouse gases—can most effectively pursue their own emission-reduction goals by sharing ideas, analyses, and best practices and by collaborating in other ways that make sense for both countries. We also believe that such communication and collaboration between the United States and China will accelerate the development of technologies and practices that will benefit other countries around the world in their own pursuit of the emissions reductions needed everywhere if climate catastrophe is to be avoided.

This importance of consistent and collaborative climate leadership by China and the United States was the underlying message of the joint announcement on this topic by President Obama and President Xi in Beijing in November 2014,[2] which helped bring about the unprecedented degree of global consensus reflected in the Paris Agreement a year later. We believe the Obama-Xi message is no less important today, and we hope that our joint work on this project will help to illustrate the value of continuing and building upon such collaboration going forward, even in the face of disagreements between our two governments on many other topics.

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1 The research of Harvard University is funded by Energy Foundation China. www.efchina.org

2 "U.S.-China Joint Announcement on Climate Change," Nov 11, 2014. https://obamawhitehouse.archives.gov/the-press-office/2014/11/11/us-china-joint-announcement-climate-change

3. SCOPE OF THE PROJECT

All plausible pathways for reaching the stated US and Chinese goals of carbon-neutrality by around mid-century will require rapidly expanding deployment, between now and then, of a variety of low- and no-carbon energy-supply technologies, along with the transmission infrastructure needed to link new supplies with growing demand. All plausible pathways will likewise require new technologies and practices to greatly increase energy end-use efficiency and electrification. No single supply or end-use technology-nor even any small subset of such technologies-holds the key to success in either country. Many such technologies will be required. Yet it is not possible today to specify confidently, for either country, exactly what combination of technologies would be most likely to succeed.

What is most practicial and useful at this point is to:

1. identify the technologies that, on current knowledge, seem most likely to be able to make a major contribution to meeting the mid-century goals;

2. identify and characterize the barriers to those technologies' achieving their full potential; and

3. describe and advance regulations, policies, and protocols that could be implemented in the current decade such that, between now and 2030, our two countries travel paths that keep open the possibility that subsequent steps, based on continuing technological and analytical progress, along the way, will be adequate to achieve the zero-emission goals around mid-century.

These are the aims of our joint project, which includes exploring which insights developed about each side's pathway can be helpful to the other side. Finally, we are committed to communicating our interim and final findings directly to national climate policymakers in each country and to the Conferences of the Parties to the UN Framework Convention on Climate Change. This joint statement is the initial public manifestation of that effort.

4. CARBON-NEUTRALITY PATHWAYS AND CHALLENGES IN THE UNITED STATES

The U.S. government's announced goals are to eliminate carbon dioxide emissions from electricity generation by 2035 and to reach net zero emissions economy-wide by 2050. Based on critical reviews of more than a dozen recent studies of technology pathways to 2050 for deep carbon reductions in the United States,[3] augmented by our own analyses, we conclude that meeting these goals is likely to require large contributions from most or all of the following:

- solar energy and wind-including offshore wind-for electricity generation;
- carbon capture, utilization, and storage (CCUS) for fossil-fueled power stations and certain industrial facilities;
- renewable hydrogen ("Green Hydrogen");
- a modernized electricity grid with additional transmission;
- electric and hydrogen-fueled light-duty and heavy-duty vehicles;
- further electrification and greatly improved energy end-use efficiency in the buildings, materials, and manufacturing sectors; and
- biological carbon sequestration.

It is possible, but at this point much less certain, that significant new contributions could become available from nuclear energy, sustainably grown biofuels, and negative-emission technologies in the period between now and 2050.

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3 See, particularly, Larson, et al, 2020. "Net-Zero America: Potential Pathways, Infrastructure, and Impacts, interim report" Princeton University, Princeton, NJ. https://netzeroamerica.princeton.edu/the-report; Williams, et al. (2021). "Carbon-Neutral Pathways for the United States." AGU Advances, 2(1), e2020AV000284. https://doi.org/10.1029/2020AV000284

In the first phase of our work on the U.S. case, we selected four of the above technologies for more detailed analysis: (i) an expanded and modernized electricity grid; (ii) CCUS; (iii) electrolytic hydrogen production; and (iv) electricity and hydrogen for space heating and water heating in buildings. Selected points from our initial findings about the status of these technologies, the challenges facing them, and the needed policy responses follow.

- **The electricity grid**

Modernizing and expanding the U.S. electricity grid is required to support electrification of sectors of the economy that currently depend heavily on direct use of fossil fuels, including transportation and home heating, as well as to allow increased reliance on the intermittent renewable sources, wind and solar.

U.S. annual electricity generation could increase 2- to 4-fold from today's figure by 2050. If electricity generation from wind and solar energy relies on large generating units located where the solar and wind resources are greatest, moreover, additional transmission lines will be needed to carry the electricity from the areas where power is generated to distant centers of demand. And where solar and wind systems are built at community scale, challenges around balancing loads, voltage, and system integration will require new investments. Both centralized and distributed options for expanded generation from renewables will require new institutional capacity to design, implement, and operate a modern grid that is quite different from the current one.

The institutional reforms must take place at both the national and subnational levels. A national grid plan is needed that includes carbon-emission guidelines to help shape regional and state electricity forecasts, and national institutions are needed to coordinate the development and implementation of transmission infrastructure across state and regional transmission systems. And state regulators and regional transmission planers must begin to emphasize carbon reductions in addition to their current focuses on reliability and cost. Without these changes, the existing grid planning and operating systems will become a bottleneck for the expansion of renewable energy.

- **Carbon capture, utilization, and storage (CCUS)**

Widespread deployment of CCUS is required for most pathways to net zero emissions in the United States by 2050. Neither renewable electricity generation nor (if its challenges could be overcome) nuclear energy can be expanded rapidly enough to bring fossil-fueled electricity generation to zero in the short term, not only because sufficiently deep reductions in carbon emissions will require total electricity generation to increase but also because some continuing fossil-fueled generating capacity will be needed to back up wind and solar generation unless and until affordable electricity storage is available to cover prolonged weather-related outages.

Certainly, fossil-fueled electricity generation must continue to decline. But an adequate pace of carbon-emission reductions requires that the natural-gas plants be equipped with CCUS technology. Additionally, CCUS could be used to decarbonize hard-to-electrify industrial processes and to support provision of net-carbon-neutral synthetic fuels.

Up until now, the key barrier to CCUS meeting its technical potential in these various roles has been its high capital and operating costs for capture, but additional challenges await on the sequestration side. An adequate regulatory framework for piping the captured CO_2 and storing it, including clarifying liability in event of CO_2 escape from pipelines or storage, will need to be developed.

The situation with respect to cost of capture is starting to change. Recent U.S. estimates of the costs of using current technology to capture CO_2 from natural-gas power plants, from steel production, and from ammonia production, indicate that the CCUS for ammonia is close to economic under the current U.S. tax credit of $36 per ton for CO_2 capture and sequestration-and will become economic with the scheduled increase in that tax credit ito $50 per ton in 2026.[4] It appears that CCUS for some steel plants would also become economic at that point; and if a proposal to raise the tax credit to $120 per ton in 2026 is implemented, CCUS might well be attractive then for most steel plants and for natural-gas power plants, as well.

Once incentives are high enough to motivate wider use of CCUS, "learning by doing" is likely to bring down costs and reduce the size of the needed incentives over time. Other innovations in CCUS technology currently in the early stages of development may also lead to cost reductions in the future. There is also some promise in reducing net costs through expanded industrial uses for CO_2 that are profitable, even with the tax-credit for utilization as low as the current $24 per ton.[5]

- **Decarbonizing building space and water heating**

The commercial and residential sector accounted for 35% of United States greenhouse gas emissions from energy in 2019, with more than a quarter of the sectors emissions coming from space and water heating in buildings. Much of that energy comes not from electricity but from onsite combustion of fossil fuels.

Many net-zero pathway studies have assumed that decarbonizing heating is a straightforward matter of widespread deployment of high- efficiency electric heat pumps. Currently, however, roughly half of buildings use natural gas for heating and an additional 10-15 percent use oil or propane heating. Only around 10 percent of households in the United States use heat pumps as a main heating source, and these are located primarily in the southern part of the country in which winter

4 See Elias, R. S., Wahab, M. I. M., & Fang, L. (2018). Retrofitting carbon capture and storage to natural gas-fired power plants. Journal of Cleaner Production, 192, 722–734, https://doi.org/10.1016/j.jclepro.2018.05.019; National Petroleum Council. Meeting the dual challenge – A roadmap to at-scale deployment of carbon capture, use and storage, updated on March 12, 2021, https://dualchallenge.npc.org/files/CCUS-Chap_2-030521.pdf;' and Biermann, M., Normann, F., Johnsson, F., & Skagestad, R. (2018). Partial carbon capture by absorption cycle for reduced specific capture cost. Industrial & Engineering Chemistry Research, 57(45), 15411–15422. https://doi.org/10.1021/acs.iecr.8b02074.

5 See, e.g., https://globalco2initiative.org

temperatures are usually warmer.[6]

The major barrier to widespread deployment of electric heat pumps is cost. Taking into account current state-by-state electricity and natural gas prices, the operating cost of an air-source heat pump is generally higher than that of natural gas heating for the entire United States excluding the South, even if the total energy used to heat the home is less with a heat pump. This means that policies that incentivize heat pump usage by subsidizing installation are likely to have limited success in spurring heat pump adoption, unless natural-gas prices rise significantly..

To spur decarbonization of heating in the United States additional policies are needed to either bring the cost of natural gas up or the cost of heating via heat pumps down. The United States should continue and expand investments in heat pump research and development to help to commercialize even more efficient air-source heat-pump technology. Localities and states interested in expanding air source heat pumps should also explore providing discounts or rebates on electricity bills for homes heated by air-source heat pumps in addition to existing incentives which subsidize installation.

- **Renewable hydrogen**

Renewable hydrogen could play a significant role in the U.S. transition to net-zero carbon emissions, particularly for hard-to-abate sectors. In the mobility sector, hydrogen could complement existing efforts to electrify road and rail transportation, especially in the long-distance and heavy-duty domains, and it could provide a scalable option for decarbonizing shipping and, ultimately, aviation.

Thanks to its renewable-resource endowment, the United States has the potential both to meet its internal demand for renewable hydrogen

6 Kaufman et al., 2019. "Decarbonizing Space Heating with Air Source Heat Pumps." New York, NY: Columbia University Center on Global Energy Policy. https://www.energypolicy.columbia.edu/research/report/decarbonizing-space-heating-air-source-heat-pumps

and to become a global export champion for this fuel. Our analysis shows, for example, that the United States could competitively supply up to 20% of the European Union's demand by 2050-if the hydrogen were to be shipped as ammonia.

Taking full advantage of renewable hydrogen's potential will require a coordinated effort between the public and private sectors focused on scaling technologies, reducing costs, deploying enabling infrastructure, and defining appropriate policies and market structures. These are challenges that neither the private nor the public sectors can address alone. Stakeholders need to thoroughly assess renewable hydrogen's economic, environmental, and geopolitical implications and define long-term implementation plans.

- **Carbon pricing to advance all of the needed technologies**

Comprehensive pricing of greenhouse gas emissions-through a tax, a cap-and-trade system, or instruments facilitating trading of emission reductions required by performance standards-is the single most effective and economical policy lever available for advancing the prospects of all of the technologies we have considered and achieving an appropriate mix in their implementation over time. Such pricing, at a suitable level, would immediately render economic the use of low- and zero-carbon energy technologies that are not competitive today, accelerate the use of those that are already competitive even without carbon pricing, and motivate increased investment in research, development, and demonstration in improved and new technologies that would make expanded contributions to emission reductions over time.

A dozen U.S. states are using cap-and-trade systems to price CO_2 emissions to some degree, but comprehensive carbon pricing is the policy lever that the United States government has proven most reluctant to embrace. The reasons for this reluctance are many, but paramount in importance are the political aversion to "raising taxes" and the lack of conviction of many elected officials that the seriousness and urgency of the climate-change challenge demand such strong measures. The aversion to taxation might best be addressed by returning part or all of the revenues from carbon pricing to the population on a per capita basis, as Alaska does with part of that state's oil revenues. Lack of conviction of elected officials about seriousness and urgency is being addressed increasingly by the drumbeat of growing impacts of climate change all across the nation and the public's growing clarity about the cause. If political ideology could somehow be put aside with respect to this particular issue, comprehensive carbon pricing could happen quite quickly.

5. CARBON-NEUTRALITY PATHWAYS AND CHALLENGES IN CHINA

China's goals of striving to peak CO_2 emissions before 2030 and to achieve carbon neutrality before 2060 have become an important driving force in China's economic and social development. But China faces large challenges in terms of the pace and scale of emission reductions, technology, policy (including financing), and governance, both in the current decade but even more so in the deep-reduction phase after 2030.

Key preliminary conclusions of the project team at Tsinghua University concerning the most relevant technologies for the task, the challenges they face in reaching the needed contributions, and the policies needed to meet those challenges are presented in the remainder of this section. They are based on our work in the project to date and on related work at Tsinghua University's Institute for Climate Change and Sustainable Development.[7]

We find that the set of low- and zero-emission energy technologies most likely to play significant roles in China's path to carbon neutrality

7 Institute of Climate Change and Sustainable Development of Tsinghua University, etc., 2021. Research on China's long-term low-carbon development strategy and transformation path. Beijing, China Environmental Publishing Group. (in Chinese); He J, Li Z, Zhang X, et al. 2022. China's Long-term Low-carbon Development Strategies and Pathways. Springer and China Environment Publishing Group. (upcoming)

is similar to the set described above for the case of the United States, despite the many differences of detail in the circumstances of the two countries. As in the U.S. case, the key-technology list for China includes solar and wind energy for for electricity generation; a modernized electricity grid; CCUS for coal power plants; renewable hydrogen; electric and hydrogen-fueled vehicles; and improved energy-end-use efficiency across all sectors[8].

Important contributions from new-generation nuclear technologies, biofuels, energy storage, and hydropower will also likely be needed. Greatly increased carbon sequestration in agriculture and forests will be required to offset residual emissions in sectors where getting to zero is most difficult. Finally, improved technologies for reducing non-CO_2 greenhouse gases will be increasingly needed over time, after the relatively inexpensive reductions using currently available measures have been fully utilized. Some key points on options we examined closely in the first phase of our work follow.

- **Electrification and the electricity grid**

Meeting China's decarbonization goals will likely require electricity's share of energy end uses to rise from its 2020 value of 27% to about 70% in 2060. This massive transformation will require greatly increased contributions from most or all of wind, solar, hydro, and advanced nuclear technologies for electricity supply, as well as replacement of direct fossil-fuel use by electricity or electrolytic hydrogen in end-use applications including light-duty and heavy-duty road vehicles, railways, and ships; industrial processes of many kinds; and residential and commercial buildings.

Supporting the large expansion of electricity end uses and making optimal use of wind and solar resources far removed from demand centers will require a greatly expanded national electricity-distribution

8 He J, Zhang X, Li Z, et al. Comprehensive Report on China's Long-Term Low-Carbon Development Strategies and Pathways[J]. Chinese Journal of Population Resources and Environment. 2020, 18(4): 263–295. DOI:10.1016/j.cjpre.2021.04.004.

grid. Early and continuing effort will need to be devoted to making the grid smarter with improved optimization, integration, and regulation. This effort should be augmented by creation of an intelligent and flexible integrated energy-service system on the load side.

- **CCUS for coal power plants**

Large coal-fired power plants will continue to be needed for baseload power and load following in China for some years to come, until their replacement by a combination of renewables with energy storage and advanced nuclear plants can be completed. For this continued, albeit declining, dependence on large coal power plants to be consistent with meeting China's decarbonization goals, it will be essential to develop, incentivize, and deploy CCUS for these plants as rapidly as possible. It will also be necessary to improve and deploy Bioenergy Carbon Capture and Storage (BECCS) and other negative emission technologies to offset the fact that CCUS on coal plants cainnot capture 100% of the emissions from these plants.[9]

- **The transport sector**

In addition to completing the electrification of railways and achieving large increases in the production of electric light-duty road vehicles and supporting infrastructure-and, of course, cleanly generated electricity to power them-meeting China's decarbonization goals will require surmounting the larger technological and economic barriers associated with heavy-duty road vehicles and aviation and marine transport. Heavy-duty road vehicles will likely need to be fueled by hydrogen in fuel cells or burned directly and/or by sustainably grown and produced biofuels. Electrifying heavy-duty vehicles by using rechargeable or swappable-battery is also receiving increasing attention. Aviation and waterway transport may be able to rely on

9 Huang X, Chang S, Zheng D et al. The Role of BECCS in Deep Decarbonization of China's Economy: A Computable General Equilibrium Analysis. Energy Economics, 2020, 92. DOI:10.1016/j.eneco. 2020.104968.

battery storage of electricity for some light-duty and short-haul applications, but most applications will require some combination of hydrogen (either as H_2 or ammonia) and sustainably grown biofuels[10].

- **Industry and buildings**

Large increases in industrial process efficiency will be key in the early part of China's energy transition. Electricity's share of industrial energy use must increase rapidly and continuously, becoming dominant by 2060. After 2035, CCUS would be implemented for those CO_2-emitting industrial processes suitable for carbon capture (production of ammonia and steel, for example). Renewable hytdrogen will also need to play an increasing role in those industrial processes for which electricity is not suitable or economically competitive with hydrogen. Remaining use of fossil fuels in industry should shift increasingly to being embodied in raw materials, such as petrochemicals.

Residential and commercial buildings account for about 20% of final energy use in China today, and the energy consumption is increasing over time with continuing urbanization and rising living standards. Bringing down carbon emissions in this sector will require major contributions from building energy conservation, electrification of cooking and hot water, replacement of direct fossil-fuel use in space heating with industrial waste heat, combined heat and power, electrically driven heat pumps, development and implementation of building-integrated photovoltaics, and the intelligent and flexible building energy management[11]. There will be particular challenges in implementing an appropriate subset of these options to the energy transition in rural areas.

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10 Yuan, Z. y., Li, Z. y., Kang, L. p., Tan, X. y., Zhou, X. j., Li, X. h., Li, C., Peng, T. z., Ou, X. m., 2021. A review of low-carbon measurements and transition pathway of transport sector in China. Clim. Change Res. 17, 27–35. DOI: 10.12006/j.issn.1673-1719.2020.202 (in Chinese)

11 Guo, S., Yan, D., Hu, S., Zhang, Y., 2021. Modelling building energy consumption in China under different future scenarios. Energy 214, 119063. https://doi.org/10.1016/j.energy.2020.119063.

Some policy priorities for China's energy transition

China released in September, 2021 a long-term strategy to achieve carbon-peaking and carbon-neutrality[12], which mapped the top-level design and implementation path for climate change. Meanwhile, China issued an action plan for carbon dioxide peaking before 2030[13], to encourage provinces, cities, regions and high energy-consuming industries to do their share in reaching the emission peaks. Much effort will be needed to build social consensus and ensure that top-down and bottom-up approaches are mutually reinforcing.

The challenges of developing and deploying advanced low-carbon technologies at the needed pace are immense. Meeting the challenges will require greatly accelerated efforts in research and development (R&D), as well as in demonstration and rapid deployment of the most promising options that emerge. Increasing the amount of the needed R&D done in international collaborations would be highly beneficial both to China and to her partners. As in the United States, a comprehensive approach to carbon pricing would both accelerate the deployment of the best available current low- and zero-carbon technologies and and incentivize increased R&D to develop better ones.

The magnitude of investment needed to achieve China's target of carbon neutrality by 2060 is daunting by itself. In our preliminary work in the pathways project, we found that the cumulative investment in energy supply in China between 2020 and 2050 could reach nearly 140 trillion RMB (equivalent to 22 trillion U.S. dollars at current exchange rates).Mobilizing investment of this scale will require improved green-finance mechanisms, including strong government incentives to motivate increased private investment.

12 Central Committee of the Communist Party of China, State Council. Working Guidance for Carbon Dioxide Peaking and Carbon Neutrality in Full and Faithful Implementation of the New Development Philosophy. (September 22, 2021)

13 State Council. Action Plan for Carbon Dioxide Peaking befor 2030. (October 24, 2021)

6. CHINA, THE UNITED STATES, AND THE WIDER PICTURE

The degree of commonality in the technological components of the Chinese and U.S. pathways to carbon neutrality by mid-century, as just outlined, underscores the value of cooperation between us on analysis relating to these pathways, despite the differences in circumstances on the two countries. Many of the technologies and challenges common to our two pathways, moreover, will also be relevant to the decarbonization of countries besides ours, at various stages of economic development. Given that the vast majority of nations will need to achieve near-zero emissions if global targets of well below 2 degrees C and pursuing efforts to limit to 1.5 degrees C are to be met, wider international collaboration on analysis and R&D relating to pathways is clearly needed.

In addition to the kinds of major transitions in the world energy sector discussed here, an adequate global strategy for reducing the danger of catastrophic impacts from climate change must include large efforts in land-use management and climate-change adaptation essentially everywhere. We have not addressed those requirements in our joint study of decarbonization pathways, but they are very important.

Financing the infrastructure investments for pathways to net-zero carbon emissions-not to mention the investments for land-use management and adaptation-will be a challenge for all nations, but most challenging of all for the poorest ones. The largest share of investment in energy supply comes today from the private sector, and much of the needed increase will likewise need to come from there. But governments also have a large role to play, above all through policies that shape private-sector incentives to invest in low- and no-emission energy technologies and through bilateril and multinational green-finance mechanisms.

The special needs of the poorest countries for financing decarbonization and adaptation were recognized explicitly in the Paris Agreement. While there is some lack of clarity in the accounting, the goal of $100 billion per year by 2020 in climate assistance to countries in need, pledged in Paris by developed countries as a group, is widely believed not to have been met. Increased international efforts, not only finally to meet the Paris goal for increased assistance for countries in need but to significantly surpass it, are urgently needed.

7. SIGNERS OF THIS DOCUMENT

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ABOUT THE PROJECT

"Tsinghua University – Harvard University Project on Technological Systems and Innovation Policy for Climate Neutrality"

In September 2020, a three-party project focused on deep-decarbonization technologies and innovation policy in China and the United States was initiated by China's Special Envoy for Climate Change Affairs, Mr. Xie Zhenhua. The three teams are: the Tsinghua University's Institute of Climate Change and Sustainable Development (ICCSD) Team, led by Professors He Jiankun and Li Zheng, the HKS Global Energy Technology Innovation Initiative (GETI) Team, led by Professor John Holdren, and the SEAS Harvard-China Project (HCP) Team, led by Professor Michael McElroy. The project is designed to run for three years in total.

ABOUT ICCSD

Institute of Climate Change and Sustainable Development (ICCSD) of Tsinghua University was founded in October 2017. ICCSD is committed to building a collaborative platform for strategy and policy research, talent cultivation, international dialogue, bridging the gap between academic research and policy, and providing support and solutions related to climate change and sustainable development.

ICCSD has accomplished several flagship research projects, such as Strategy and Pathway of Low-carbon Transition in China, and Synergizing Actions on the Environment and Climate, etc. Also, ICCSD has established the Methane Emission Reduction Cooperation Platform and Nature-based Solution Cooperation Platform to foster broader collaboration and knowledge sharing. The Institute has also launched extensive bilateral and multilateral dialogues, including "Climate Change Global Lectures" and "Friends of the Paris Agreement"; and provided full support for "Global Alliance of Universities on Climate" and held two South-South cooperation climate training programs.