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China's Capabilities and Ambitions in Clean Energy Technologies

China is the world leader in the development of wind and solar technologies, and is poised to lead in energy storage technologies in the coming years. My testimony will review the evolution of China's wind and solar industries, and how experience in these industries shapes China's emerging policy strategy for promoting energy storage industries. I will also discuss China's energy technology export ambitions, and recommendations for US policy to strengthen the United States' competitiveness in energy storage and renewables.

The Evolution of China's Wind and Solar Industries

Renewable energy has long been identified as a strategic technology sector for China, and it has become even more critical given recent initiatives to reduce the country's reliance on coal due to concerns about climate change and air pollution. China's green innovation strategy has propelled its clean energy sector to be among the largest in the world. China is a latecomer to the clean energy innovation field, therefore cooperation with many of the countries that have expertise in specific clean energy technologies has been a very important way for Chinese firms to enter this sector. These technology transfers to China from overseas firms have led in many cases to fruitful cooperation, and occasionally to tense relationships over intellectual property. This rise has also launched international trade battles with its biggest green technology competitors.[1]

China's ability to leapfrog to cleaner energy technologies will be determined in part by its ability to become an innovator and global leader in the development of these technologies that it so critically needs. Its entry into these sectors also has important implications for the ability of these technologies to diffuse globally. For example, China's entry into the manufacturing of wind and solar technologies has led to significant cost reductions and increased learning globally.

China's policies to promote renewable energy have always included mandates and incentives to support the development of domestic technologies and industries. While some elements of these industrial policies—like requirements for using locally manufactured materials—are unduly protectionist, the policies aimed at promoting domestic renewable energy deployment are less controversial and, in many cases, modeled after similar policies first used in other countries.

China's promotion of renewable energy was kick-started with the passage of the *Renewable Energy Law of the People's Republic of China* that became effective on January 1, 2006.[2] The

Renewable Energy Law created a framework for regulating renewable energy and was hailed at the time as a breakthrough in the development of renewable energy in China. Since the passage of the Renewable Energy Law, numerous policies and regulations have followed to support key renewable energy technology industries. While framework policies set the national stage for the promotion of renewable energy and pricing policies promoted its deployment, another set of policies aimed to promote the technology transfer and then the localization of renewable energy technology.

Of the "non-hydro" renewables, wind and solar have been particularly successful in China in the last decade. By the end of 2018, China had constructed 206 GW of wind power, more than all the EU countries combined, and almost twice as many as the second largest installer of wind power capacity, the United States.[3] China is also becoming the largest market for offshore wind power development, with $11.4 billion in investment and 13 new projects being constructed in 2018.[4] In 2017, China accounted for a record 45% of global investment in renewables investing $126.6 billion that year—its highest amount ever and almost half the global total. [5] In 2018, this number declined due to a decrease in solar project investment, but China still led the world with $100.1 billion of clean energy investments.[6]

A core national innovation strategy in China has been one that targets domestic development of technologies even if they were initially based on foreign-innovated designs. Given this priority, the Chinese state opted to support the development of wind power technology with a strategy similar to what it used in other industries. China has pursued the development of a domestic wind turbine industry almost from the very beginning of its development of wind power.[7] China's development of indigenous wind technology capabilities was aligned with its broader domestic innovation strategy to move away from reliance on foreign technologies and build up local manufacturing capacity in strategic sectors. China's wind power industry has benefited from various forms of government policy support; some policies have specifically targeted industrial development for the wind power industry, while others have indirectly supported industrial development by establishing a local market for wind power. Trade policies have also been used in a variety of ways over time to try to encourage different modes of local manufacturing and industry development.[8]

China is experimenting with the large-scale deployment of renewable energy as no other country has before it. As a result, it is a de facto global laboratory, experimenting with the challenges to large scale renewables deployment that will benefit the rest of the world should they follow China's path. Today, one of the biggest challenges facing China's wind sector is integration: making sure the wind power being produced by China's wind farms is absorbed by the grid and consumed. Curtailment rates for 2018 were around 7.7% for wind and 2.9% for solar, which is a notable improvement on recent years where a fifth of total wind power produced was wasted.[9] Curtailment leads to major losses for wind farm operators, and from an environmental perspective leads to wasted pollution-free electricity.[10] The location of China's wind resources leads to difficulties in transmitting China's wind power to population centers, and many completed wind farms sit idle while they wait for the construction of long-distance transmission capacity.

China's solar technology sector was developed almost entirely for export, while China's wind power sector was developed almost entirely for domestic use. As a result China's global dominance in solar power utilization is recent, while its dominance in manufacturing is not. Most of the past decade saw China increase its solar panel manufacturing primarily for export to wealthier countries, and very low levels of solar power utilization domestically. The global financial crisis was a turning point in China's solar industry, leading the government to introduce many domestic stimulus policies that benefited China's struggling solar industry. As a result, China is now by far the leading country in installed solar capacity, installing 53 GW of solar in 2017 and 43 GW in 2018, bringing the total national capacity to about 170 GW or about 35% of total global solar capacity.[11]

China's innovation model in the solar technology sector has been somewhat similar to the wind sector, in that most Chinese companies have purchased some form of production technology from companies located in countries that were earlier innovators in the solar industry. As the production lines moved to China, PV manufacturers gradually adapted them to local conditions, for example if less expensive inputs were available. Since a major part of the PV manufacturing process includes "know-how" as opposed to just technology hardware, access to skilled employees has been a major asset to Chinese companies.[12] One study estimates that over 60 percent of the leadership (CEOs and board members) of Chinese solar companies studied or worked abroad.[13] By 2016, domestic competition has become steep, and as a result many Chinese PV companies are expanding into emerging markets, building manufacturing plants overseas and even acquiring foreign companies to aid with this expansion.[14]

Chinese government policy support for solar PV goes back to the sixth five-year plan, and has appeared in every plan since. While the majority of China's solar policies in recent years have targeted support for large-scale solar manufacturing deployment, this is actually starting to change as a result of recent integration challenges, seeing China return to its original solar strategy of promoting decentralized applications. As with wind, a challenge for China's solar industry is integration. But unlike with wind, solar can work very well as a distributed source of power. As a result, recent Chinese government policies have targeted increasing the use of distributed solar and building-integrated PV so that the electricity is consumed at the point of generation and not transmitted over long distances.

Most recently, there is pressure to remove the wind and solar industry's reliance on subsidization. The feed-in tariffs for wind and solar have recently been reduced, and the National Energy Administration has released a development plan for "subsidy-free" wind and PV projects, with the first batch of projects (20.76 GW total) spanning 16 provinces.[15]

Evaluating the innovation coming out of China's wind and solar industries is challenging, as traditional metrics for measuring innovation, such as patents, are often not easily comparable across different national contexts. Looking at specific technologies, the crystalline silicon-based solar technology produced by the leading Chinese firms is of comparable performance and quality to that of their foreign competitors. Products along the PV supply chain are generally more standardized than in wind turbines, for example, therefore competitiveness is primarily based on quality and cost. Likewise, in wind, Chinese turbine manufacturers are quickly catching up to the most advanced global turbine designs which are for multi-megawatt offshore turbines.

Perhaps a more important metric than current technology is whether Chinese firms have the ability to innovate to produce the next generation of renewable energy technologies, especially solar. China is arguably still behind the United States in fundamental solar technology research being done at universities and national laboratories, as well as in second generation technologies such as thin film solar cells.[16] NEA's 12th Five-year plan for solar attributed challenges in the industry to inferiority in core technologies and research and import dependence on key machinery.[17] Few Chinese companies have been willing to take the risk needed to move into alternative solar technologies including thin film, and instead focus on incremental innovations targeting process improvements and cost reduction. One exception is Chinese firm Hanergy from Beijing, a large thin film manufacturer that has bought several US startups. As China has consolidated the entire upstream solar supply chain, some have argued that this vertical integration can stifle disruptive innovation making it less likely that we will see the emergence of new, innovative solar technologies from China.[18]

The Rise of China's Energy Storage Industry

If China's first major clean energy technology successes were in wind and solar, their next big success is poised to be in energy storage. Energy storage technologies represent a $620 billion investment opportunity over the next two decades.[19] While China is still in the early stages of energy storage deployment and utilization, its companies are already among the world's top energy storage technology manufacturers.[20] At the end of 2017, the Chinese government released a 10-year plan for developing a domestic energy storage industry for two key purposes: (1) to support battery manufacturing for its already massive electric vehicle manufacturing enterprise; and 2) to help with the serious grid challenges related to integrating substantial amounts of wind and solar power into the grid.[21]

China is a relative latecomer in the development of energy storage technologies, but it has been ramping up its capabilities very quickly over the past few years. As a result, it is already on track to surpass current global leaders in the industry. In 2017 over 40GWh of batteries were installed in electric vehicles, and 121MW/502.3MWh of other electrochemical energy storage projects were installed. With the continued proliferation of EV batteries, prices for energy storage are also expected to continue to decline rapidly. According to the China Energy Storage Alliance, China had 28.9 GW of energy storage capacity projects in operation at the end of 2017, up 19% from the previous year, or 16 percent of the global market.[22] About 99% of this capacity is pumped hydro storage, followed by electrochemical energy storage (389.8MW), which while a small share of total storage was up 45% from the previous year. Li-ion batteries made up the largest portion of electrochemical energy storage capacity at 58%.[23]

The energy storage market in China began to take off in 2015, primarily in response to challenges facing the grid companies. A few earlier guidance documents, including the 2014 Energy Development Strategy Action Plan (2014-2020), mentioned energy storage technologies in the list of technologies being targeted for innovation prioritization, but it was the 2015 push to begin the reform and marketization of the electric power sector that brought energy storage into the national spotlight.[24]

China's 13th Five-Year Planning Period (2016-2020) includes multiple policy efforts targeting the reform of China's energy systems. This includes innovation in new energy technologies, smart grid development, and the increased deployment of renewable and non-fossil energy sources. In particular, 2016 saw a surge of policies promulgated that targeted the development of the energy internet, ancillary service and microgrids, all of which declared the need for increased use of energy storage technologies. The 2016 Guidance for Promoting Internet and Smart Energy Development [25] mentioned promoting the development of distributed ES technologies, and the 13th Five Year Plan mentioned a focus on promoting innovation in new energy technologies that included energy storage.[26] The October 2017 *Guiding Opinions on Promoting Energy Storage Technology and Industry Development* further describes the development goals for China's energy storage industry over the next ten years.[27]

The March 2016 Energy Technology Revolution Innovation Plan (2016-2030) provides detail about Chinese government priorities for innovation in energy storage technologies.[28] This includes a supercritical compressed air energy storage system (goal of 10MW / 100MWh), flywheel energy storage array unit (goal of 1MW / 1000MJ), vanadium flow battery energy storage system (100MW), sodium sulfur battery energy storage system (10MW) and lithium ion battery energy storage system (100MW). Innovation goals for 2030 include having a better grasp of different energy storage technology options, and having achieved demonstration as well as the standardization and verification of ES technologies. Other goals include the development of an industry value chain for ES technology manufacturing, as well as a goal of technological catch-up equivalent to the most advanced international level.[29]

Storage is also increasing in northwestern China in response to increasingly severe wind and solar power curtailment, though it is underutilized in China compared with other countries to aid in renewable energy integration. Most ES targeting renewable energy integration in China focuses on wind power, which has been experiencing the most severe curtailment rates as previously discussed.[30]

Energy storage has only recently emerged as a policy priority for the Chinese government. As a result, the policy support system for energy storage technology development and deployment is still rather immature. While energy storage is frequently mentioned in China's national energy policy documents and plans, but there are yet to be any explicit subsidies for energy storage deployment. Most of the policy focus to date has been on encouraging continued technological innovation. In addition to the central government plans and policies supporting energy storage technology development, several local and regional governments have implemented their own support schemes. If energy storage follows a similar path to that of wind and solar, we can expect to see the increased use of industrial policies targeting the energy storage industry, as well as the emergence of deployment policies to attract large scale project development, including perhaps a feed-in tariff.

While China is still in the early stages of ES deployment and utilization, its companies are already among the world's top ES technology manufacturers.[31]

China's Energy Technology Export Ambitions

Developing countries are the engine for growth in energy demand in the 21st century. India, China and Southeast Asia together account for 60% of the projected future energy demand globally through 2040.[32] While China has been the driver of global growth of the past two decades, due to the rapid economic and population growth expected across Southeast Asia, its projected growth in energy demand will be twice as large as China's over the next two decades, representing one-tenth of the rise in global demand.[33]

Growing global energy demand will require significant investments in new energy infrastructure, and most of this investment will be in renewable energy. Around $7.8 trillion is projected to be invested in renewable power worldwide through 2040 in technologies including onshore and offshore wind; utility-scale, rooftop and distributed solar; and hydropower. Renewable energy in fact comprises the bulk of the investment that is projected to be spent across the entire power sector, compared with $2.1 trillion to be invested in fossil fuels, mainly in emerging economies.[34] BP projects that two-thirds of new power generation will come from renewables over the next two decades.[35] Developing economies committed $177 billion to renewables last year, up 20% from the prior year; this is even larger than the $103 billion in developed countries, where investment was actually down 19%.[36] Last year marked the largest shift towards renewable energy investment in developing countries that we have seen yet. In the Indo-Pacific alone, investment totaled $168.9 billion. [37]

China has emerged as the largest single provider of overseas infrastructure investment in the world, and particularly in Asia. Many of these investments are motivated by China's Belt and Road Initiative (BRI). China does not provide official numbers for outbound energy infrastructure investments, but estimates suggest that, since 2000, China's two state-run policy banks (the China Development Bank and the China Export-Import Bank) may have provided between $150-250 billion in global energy infrastructure financing, of which approximately half stayed within Asia.[38] An increasing amount of that funding is being directed toward Southeast Asia to meet the region's growing infrastructure needs, including energy infrastructure.

China has been dominating the sales of coal plants abroad since the early 2000s. Developing countries tend to want coal plants, not just because they are being sold inexpensively, but because they represent a tried and true model of development that they want to replicate. The vision for technology leapfrogging is like the model we saw in cell phones, where many developing countries leapfrogged over the use of landlines and straight towards mobile phones, allowing access to the internet and financial services even in remote locations. In clean energy this is not always being achieved, because the countries that industrialized first and are already transitioning to clean energy technologies still want to export their polluting technologies elsewhere. For example, we see that even China, still the largest coal user in the world, has put in place very stringent environmental regulations to reduce domestic air pollution, and has established the world's largest carbon market. As a result, there are reports that they are shutting down some of their dirtier, less efficient coal plants before end of their useful life, and exporting these dismantled plants to countries in Southeast Asia.

China is not alone in financing coal-fired power plants overseas. Japanese, Korean, French, and German banks are currently the major sources of finance for coal-fired power plants around the world, but China is beginning to catch up with and will potentially surpass Japan as the region's largest foreign direct investor and component provider.[39] One study estimates that Chinese firms are involved in the construction, ownership, or financing of at least 16% of all coal-fired power stations under development outside China.[40] Chinese energy companies have strong national support and domestic policies that favor them and their overseas investments; they can outbid competitors and provide power plant projects at a lower cost. This access to cheaper labor, materials, and financing has helped China become a leading investor in overseas coal plant development. Of all the power capacity additions in Asia involving Chinese corporations, 68 percent of operating capacity and 77 percent of under-construction capacity is in coal.[41] Most of this coal power finance is concentrated in South Asia and Southeast Asia, with the largest markets in India, Indonesia, and Vietnam.[42]

This goes against the vision for a clean energy future that many governments are putting forward. For example, many emerging Asian countries have pledged aggressive renewable energy targets as part of their Paris Agreement commitments that if met could lead to many gigawatts of renewable power being built in these countries. [43] In addition, there are significant risks to an extensive reliance on coal given the rising environmental and social costs. Around the world, coal plants are increasingly at risk of becoming stranded assets and a frequent target of public protests.[44] Despite the risks, Chinese coal plant development is on a growth trajectory due to the pull from poorer nations that seek the cheapest options for energy finance, as well as the desire for Chinese companies to expand their markets overseas.

In contrast, almost all of the multilateral development banks have been restricting coal plant investments due to environmental concerns. The World Bank pledged in 2010 to stop investments in coal, and more recently in oil and gas as well. The Asian Development Bank (ADB) has not funded any coal plants since 2013. Even the China-led Asia Infrastructure Investment Bank (AIIB) has an aggressive energy sector strategy guiding its investments with very restrictive language about supporting coal and oil investments.

While China actually exports far more solar panels around the world than any other country, this deployment is not evenly distributed across the world.[45] While China's development banks and state-owned enterprises are primarily supporting fossil fuel development abroad, the majority of international investment coming from privately owned Chinese enterprises is in renewable energy. One study estimates that between 2014-2017 Chinese banks and companies invested $190 billion in fossil fuels abroad, and only $12.9 billion in renewable energy.[46]

There does seem to be growing awareness among Chinese SOEs in expanding their involvement in renewable energy industries. For example, Shenhua, the largest coal company in the world, has been partnering with wind and solar companies. In 2016 Shenhua announced a partnership to build 1 GW of solar thermal projects in China with US company SolarReserve.[47] Its 2017 merger with Guodian Corporation also helped to diversify Shenhua's portfolio in renewables.[48] Shenhua also acquired a stake in Greek wind projects in 2017 with plans to build additional wind projects.[49]

Recommendations for US Policy

The transition to a low carbon economy is already underway, and the United States is currently a leader in the development of the next generation of energy technology industries. American companies are leading the world in making solar photovoltaics cheaper with more efficient materials as well as flexible solar cells; in developing advanced biochemical and renewable fuels; in developing solar thermal technologies to operate conventional steam turbines; and in developing smart grid technologies to allow for intelligent energy systems that can shift and reduce demand.[50] We are leading in developing efficient building materials, lighting, and energy management software. We are also leading in the soft, technical skills needed to plan for and design low carbon energy systems. These industries are creating domestic jobs, and are generating new innovation with spillover effects across the economy.[51]

For all countries, the transition to cleaner sources of energy is not just about climate change; this transition will lead to the creation of new, globally competitive industries. For all countries, the low carbon transition is an economic issue, a competitiveness issue, and a public health issue—not "just" an environmental issue. And this transition does not have to come at the expense of economic growth. As global carbon emissions growth slows, economic growth has increased. In the United States, air quality has improved dramatically over the past two decades, even as the economy has expanded. [52]

Now is the time to double down on programs that are accelerating the clean energy transition, ensuring we do not fall behind in innovating the core technologies of the future. The U.S. government has established several sophisticated programs that are directly supporting U.S. energy entrepreneurs. Programs like the Advanced Research Projects Agency (ARPA–E) and Cyclotron Road target early-stage, high-impact energy technologies with the potential to radically improve economic prosperity, national security, and environmental well-being.[53] These innovative programs are being emulated by many other countries around the world. At the subnational level, many U.S. states have been promoting aggressive clean energy policies and developing smarter, more efficient ways to manage power systems. These incentives are creating new job opportunities ranging from installation and manufacturing jobs to high tech jobs. In California, employment in advanced energy technologies grew six times faster than overall employment growth last year.[54]

The United States has been engaging with numerous Indo-Pacific nations on clean energy, natural resources, and climate change; engagement with some countries including China and India spans several decades. In many cases, this engagement has directly benefited U.S. companies, and led to fruitful technology partnerships with researchers at U.S. universities and national laboratories.[55] This cooperation has also played a crucial role in expanding global action on energy and climate change.

In addition, global linkages can spur innovation. The United States benefits from collaboration with other countries, including China: the largest clean energy market in the world. Should the United States decrease its involvement in such efforts, it risks its own technology industries and research community becoming more isolated. The United States is innovative because of its global linkages and partnerships, not in spite of them.

We should launch new bilateral collaboration in emerging Asia. Existing collaborations with China (CERC) and India (PACE-R) have revealed characteristics of effective bilateral collaboration, including an *a priori* intellectual property framework, joint work-planning, and integration of public and private capital and institutions. Now the United States has an opportunity to launch new collaborations that build on and improve upon existing initiatives. For example, in addition to R&D, international technology collaborations should also target industrial-scale demonstration projects that consolidate individual research projects and provide more scope for joint patent filings. Moreover, the funding and prioritization schemes should be even more flexible to adapt to changing needs.

Given the scale of investment that will be directed at the energy sector in Asia in the coming decades, the U.S. Government should partner with the private sector to design and pilot a finance facility for clean energy technology projects in emerging markets. The goal of the facility would be to develop a self-sustaining, replicable and scalable fund that requires decreasing amounts of concessionary capital over time as the risks associated with investment in this space are better understood and quantified. In addition, conventional energy infrastructure has traditionally consisted of large, centralized fixed assets developed using well established project financing structures and instruments, while many of the most promising sources of clean energy are harnessed using smaller scale, distributed facilities. Therefore, the government should look to lay a key role in establishing and incentivizing means of capital aggregation for next generation distributed renewables and low carbon technologies. Such efforts can help to counter Chinese dominated investment in Asia's energy infrastructure.

As existing multilateral agencies like the World Bank are moving away from financing polluting energy sources such as coal, China has emerged as an important alternative source of finance that has yet to enact strict lending guidelines on the environment, particularly in the context of its expansive Belt and Road Initiative. The U.S. should directly, bilaterally engage in expanded dialogue with China on how the two countries can work together to ensure that development finance institutions do not undermine global decarbonization efforts. Commonly agreed safeguards should be developed to promote green over brown investments, particularly in emerging and developing economies in the Indo-Pacific.

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