POLICY FORUM

CLIMATE AND ENERGY

China's key role in scaling low-carbon energy technologies

Meeting the Paris goals will require collaboration with China

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Meeting the goals of the Paris Agreement will require net zero greenhouse emissions by 2050 and substantial reductions before then. It will also require collaboration with China, which has emerged as the global leader in the mass production of low-carbon energy technologies (LCETs). In part because of China's investments in manufacturing, the LCETs required to meet climate targets have become increasingly cost-competitive with fossil fuel sources (*1*). But some attribute China's rapid rise in LCET sectors to unfair industrial policies—such as forced technology transfer requirements, massive subsidies, and outright intellectual property (IP) theft—aimed at strategically dominating the next generation of energy technologies (*2*). Trade relations between China and the world are currently unsettled, especially with the United States, a leading producer of both LCET research and development (R&D) and greenhouse gas (GHG) emissions. Against this backdrop, we outline why engaging with China is the more promising path to accelerate the global deployment of LCETs and to rapidly bring new technologies to mass production.

Chinese contributions to LCETs highlight key distinctions between invention and the complementary assets required to commercialize a product at scale, such as financial investment and competitive manufacturing capabilities (*3*). Since joining the World Trade Organization in 2001, China has gone from producing 1% to producing 66% of the world's solar panels (*4*), and Chinese wind turbine manufacturers now represent roughly one-third of global supply. China is also the largest supplier of (and market for) electric vehicles (*5*), and according to Bloomberg New Energy Finance, Chinese firms are set to increase their control of the world's supply of lithium-ion batteries from 69% to 76% in the near future. Plans are also under way to nearly double China's nuclear reactor fleet from 45 to 88 plants in the coming decade.

We suggest that it is unrealistic to expect that another nation will be able to rival China's capabilities in LCET scale-up in the time frame needed to limit climate change to below 2°C. The question is not whether to engage, but how, acknowledging that China has applied protectionist policies and has used government procurement directives to discriminate against foreign companies in domestic markets, including in LCET industries. Although it may be improbable that one nation can control all aspects of the innovation process—from invention to mass commercialization—in the global economy, it is just as unreasonable to ignore the importance of upholding IP rights and following international trade rules. Given the common goal of combating climate change, LCET in-

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A worker inspects a solar panel at a factory in Lianyungang in China's eastern Jiangsu province. China's capabilities in mass manufacturing low-carbon energy technologies are critical to combating global carbon emissions.

dustries are a promising place to start negotiating better rules of engagement while increasing global collaboration to achieve rapid emission reductions.

MANUFACTURING INNOVATION

China's capabilities in commercialization and mass manufacturing of LCET technologies are unmatched in the world today. These capabilities did not emerge overnight. They relied on unique institutional features of China's domestic economy that supported investments in both innovation and manufacturing at a massive scale and over multiple decades. No other economy has been willing and able to pour even a remotely equivalent level of resources into manufacturing expansion and R&D in recent history. It is therefore highly unlikely that another nation will be able to replicate China's skills in the time frame needed to avoid the worst consequences of climate change.

In China, more than 30 years of institutional support from both national and local governments enabled entrepreneurial manufacturers to thrive in LCET sectors. Beginning in the 1980s, the central government used financial incentives to encourage domestic R&D, including applied research in manufacturing. Government R&D support expanded in 2006 when the central government began encouraging "indigenous innovation" (自主创新) to reduce dependence on foreign technologies through increased domestic R&D efforts. Such efforts further accelerated under President Xi's "Made in China 2025" initiative, which has also designated the development of domestic LCET sectors as a strategic national priority.

Central government support for R&D capabilities was augmented by provincial and municipal governments, which, dependent on tax revenue from the local manufacturing economy, set aside indigenous innovation goals in favor of mass production. They brokered bank loans and provided land, facilities, and tax incentives to manufacturers, including in LCET sectors that were unable to attract large-scale financing in other parts of the world. State investment in domestic clean energy markets further supported local manufacturers by boosting domestic demand for their products (see the figure, upper panel).

In this environment, our research shows that Chinese manufacturers centered their R&D efforts on production improvements rather than new product R&D. Whereas "New Energy" (新能源) technologies could be licensed, bought, or contracted, capabilities in innovative manufacturing—including the ability to rapidly re-engineer a complex product for "cost-out" mass manufacturing—were difficult to obtain. Chinese manufacturers continued to rely on partnerships with foreign firms to access new technologies while gradually developing their own knowledge-intensive capabilities. As Chinese manufacturers in LCET sectors focused on commercialization, scale-up, and cost reduction, their innovative manufacturing capabilities (rather than basic factor cost advantages) emerged as their source of competitive advantage (*6*, *7*). Even with China's highly supportive domestic institutions, it took decades of growing at a breakneck pace for Chinese firms to establish the capabilities in commercialization and scale-up that the world now needs to bring new energy technologies to market.

COLLABORATIVE COMMERCIALIZATION

If the world has any hope of deploying the LCET portfolio in the time frame needed, collaboration with China will be essential for firms from around the world. The United States in particular needs to forge closer relationships with China on climate.

The United States and China account for 40% of the world's annual energy consumption, putting these two nations at the center of global efforts to mitigate GHG emissions. They are also uniquely equipped to jointly address this challenge. Historically, the U.S. government has been the largest investor in LCET R&D (see the figure, lower panel), which has led to major advances in key technologies such as solar photovoltaic cells. Since the 1980s, however, the U.S. innovation ecosystem has followed a trend away from large, vertically integrated firms that were able to invent and produce new technologies, and toward smaller, entrepreneurial firms focused on the generation of new ideas. Manufacturing was increasingly outsourced and offshored (*8*). In many sectors, the United States now lacks China's strengths in commercialization and scale-up. Many U.S. LCET firms, and startups in particular, stand to benefit from collaborating with foreign partners to access the capital and specialized manufacturing capabilities needed to turn their innovations into mass-produced, commercially viable products.

Such collaboration is not without precedent. Access to financial capital and the innovations of Chinese manufacturers in product scale-up and cost reduction have increasingly led firms from a variety of countries to commercialize technologies in China. In LCET sectors, collaborations between Chinese manufacturers and non-Chinese innovators have enabled new technologies to be commercialized in larger quantities and at increasingly competitive prices.

Germany, for instance, has benefited from China's rapidly growing wind and solar industries through the sale of components, production equipment, and industrial robots. As China's manufacturers became early adopters for a variety of mass production technologies, relationships with Chinese customers became important sources of learning and innovation for German firms (*7*). In the United States, Innovalight, a Silicon Valley startup, was able to commercialize its core technology, a silicon ink, only after a Chinese solar manufacturer invested a year into jointly testing the technology under mass production conditions that were only available in China (*6*). In some sectors, such as nuclear energy, multinationals are seeking Chinese partners as part of a survival strategy. With Western nuclear energy markets disappearing, these firms are moving away from engineering design and toward operational and system integration services for Chinese facilities in a bid to gain access to the capital, customers, and competitive component manufacturing available in China.

Successful collaborations with Chinese manufacturers have led to multidirectional learning: Chinese manufacturers gain technological know-how from advanced foreign incumbents, and the foreign partners feed the manufacturing and scale-up solutions their Chinese partners identify back into upstream R&D activities (*6*, *7*). Multinationals absorbing production improvements from their Chinese manufacturing partners has been a long-observed phenomenon in many industries (*9*). If any reshoring of manufacturing is going to occur in the U.S. economy, partnering with and learning from Chinese manufacturers may be a fruitful strategy.

RISKS AND CHALLENGES

Entering into collaborations with Chinese firms has not been without risk. China has historically set an uneven playing field in its domestic market in favor of Chinese firms; in some sectors, such as wind energy, foreign firms have been systematically pushed out of China's market through discriminatory government procurement policies. In other industries, such as the auto sector, foreign firms have been forced to share IP and profits with Chinese partners in order to gain market access. Although research has shown that forced partnerships have often failed to produce serious Chinese competitors (*5*, *10*), these policies do not create an inviting environment for collaboration. Allowing foreign firms fair access to its domestic market is one step China could (and should) take to encourage increased collaboration with foreign firms.

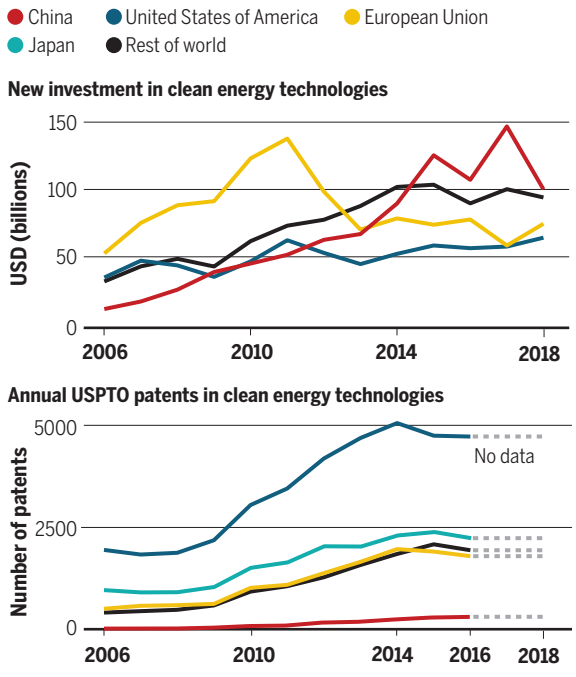
In some areas, the situation is improving. In 2018, the central government announced that it would remove the joint venture requirement for electric vehicle manufacturers so that foreign firms can wholly own their enterprises in China, and this ruling will extend to all auto manufacturers in 2020. China's IP institutions are also strengthening, even though IP theft remains a serious problem. In 2014, China established the first dedicated IP courts in Beijing, Shanghai, and Guangzhou, with additional courts added in 2017. Researchers estimate that the vast majority of cases in the Beijing and Shanghai courts have ruled in favor of foreign plaintiffs against Chinese infringers, with payments of damages to foreign plaintiffs exceeding those to Chinese victims of IP theft by as much as a factor of 3 (*11*). And it's not just foreign litigators; in 2015, 88.5% of the 11,607 patent cases in these courts involved a Chinese plaintiff and Chinese defendant (*12*).

Governments in China, the United States, and elsewhere have an important role to play in mitigating concerns over IP and fostering global ties. They can level the playing field and reduce risks for firms to work with one another, and they can help to build and support networks of innovators across national borders. One example is the U.S.-China Clean Energy Research Center (CERC). Spearheaded by former U.S. energy secretary Steven Chu in 2009, CERC established a $150 million joint pledge by the U.S. and Chinese governments to increase innovation in clean energy technologies. Perhaps most important, CERC established a Technology Management Plan that governed and helped mitigate IP concerns. Although little of the IP produced by the initiative was jointly created, CERC built trust among participants, enabling them to develop new technologies, establish new business ventures in both markets, and gain additional support for technology demonstration projects, all with limited IP conflicts (*13*).

Beyond IP, concentrating investments in scaling current technologies can also threaten progress in leading-edge innovation (*14*). In sectors with more constrained markets, such as optoelectronics, shifting manufacturing to East Asia prevented innovation in more advanced technologies in the United States (*15*). Nonetheless, in the case of LCET sectors, the speed of technology deployment is a more pressing matter. Despite the remarkable growth in renewable energy in recent years, the world is already well behind schedule on deploying the necessary 300 GW of renewable energy capacity every year from 2018 to 2030 to meet the goals of the Paris Agreement. The world simply does not have time to wait for the next generation of LCETs, irrespective of where they are developed. Greater quantities of current LCETs can be immediately deployed with the existing capabilities of Chinese firms in mass manufacturing, which will set in motion the critical learning processes required to effectively integrate these technologies into future energy systems.

U.S. innovation, Chinese investment

The United States is a leader in low-carbon energy technology (LCET) innovation, and China is the largest investor in LCET, with innovative capabilities in manufacturing and scale-up.



Top: data from Bloomberg New Energy Finance; bottom: U.S. Patent and Trademark Office (USPTO) data from U.S. National Science Foundation Science and Engineering Indicators. Code and data to produce the charts are available at https://github.com/jhelvy/charts/tree/master/ scienceCommentary2019.

NOT FIXED OR INEVITABLE

Climate change is a global problem of unparalleled dimensions that requires a global response, including in the invention, commercialization, and production of technologies that can forge deep decarbonization. Collaboration was central to the emergence of contemporary renewable energy technologies (*7*), and collaboration will be equally important in rapid decarbonization through deployment of LCETs. Governments around the world should work to foster such collaboration, and establishing initiatives like CERC is one promising path toward this goal.

Addressing grand challenges such as climate change will also require fundamental advances in technology. In the United States, this means continuing to support the core strengths of U.S. firms and universities—the invention of new technologies—through increased investments in basic and applied research. But the technologies that emerge from these efforts must eventually be scaled and deployed. Working with Chinese manufacturers can accelerate this process.

The division of labor between Western inventors and Chinese manufacturers is not fixed or inevitable. Other nations can (and should) continue investing in domestic manufacturing capabilities as part of continued technological innovation. But in a global marketplace such as energy technology, it is unlikely that the entire value chain for a complex, manufactured product would lie entirely within national boundaries. As unsettled trade relations between China and the world threaten to undercut efforts to strengthen global ties in LCET sectors, we cannot lose sight of the climate challenge or risk missing the narrow remaining window to reduce global emissions. Building on the advanced mass manufacturing capabilities of Chinese LCET firms is the most promising path toward rapid global decarbonization. ■

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