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Thank you for inviting me today to speak on this topic of great importance for both the future of global emissions reductions and U.S. economic competitiveness. I am a political economist by training and an expert on economic and industrial policy. My research focuses on new energy industries and, in particular, China's role in the global development of wind, solar, battery and electric vehicle sectors. I will focus in my testimony on outlining (1) China's pursuit of these technologies over the past two decades, describe (2) the broad policy environment that has enabled China to dominate the production of new energy technologies, examine (3) U.S.-China competition in this space, and conclude (4) with policy recommendations.

1. China's Pursuit of New Energy Technologies

China's investments—not just in research and development for new energy technologies, but particularly in manufacturing capacity for these technologies—has long been part of a broad strategy to position China's domestic economy in key emerging industrial sectors. Beginning with the wind industry in the early 2000s, then followed by solar sector after the financial crisis in 2009s, and, more recently, in electric vehicle and battery storage industries, the Chinese central government has supported new energy technologies as ways to combine climate and economic goals and create export-ready industrial sectors.

China is now a world leader in the mass production of the technologies most needed to address the climate crisis by decarbonizing the electricity and transportation sectors. These new energy technologies include wind turbines, solar panels, electric vehicles, and batteries. Since joining the World Trade Organization in 2001, China has rapidly grown its global share of solar photovoltaic production, leaping from less than 1 percent to more than 60 percent of the world's solar panels. China is one of the world's largest producers of electric cars; it makes over one-third of global wind turbines, and a much larger share of components for wind turbine installations around the world. China is home to over two-thirds of the world's production capacity for lithium-ion batteries needed for electric vehicles and storage. Together with the European Union, China is now also one of the world's largest markets for electric vehicles.[1]

In large part because of China's unprecedented investment in manufacturing in green technology sectors, the cost of clean energy technologies has fallen sharply. Since 2009, global prices for wind turbines and solar panels have decreased by 69 percent and 88 percent, respectively, making these

technologies competitive with conventional sources of energy in many parts of the world.[2] Wind and solar become especially competitive when they are deployed in conjunction with battery storage, where China's massive investments in new manufacturing capacity have also generated rapid cost declines. The development of these capabilities in manufacturing innovation relied on two features of China's domestic economy that supported investments in both innovation and manufacturing: central government incentives for R&D and local government support for manufacturing. To date, no other economy has devoted a similar level of resources to the expansion of manufacturing capacity and manufacturing R&D in new energy industries.[3]

Although China has moved to a dominant position in the production of new energy technologies, it remains, for now, embedded in broader global industrial ecosystems. According to my research, Chinese firms continue to work with foreign suppliers, customers, and R&D partners to access technology, components, materials, and production equipment. This is the case even though a number of central government initiatives over the past two decades—most importantly China's indigenous innovation initiative and more recently the Made in China 2025 initiative—have pursued broad goals of technological independence.[4] While Chinese firms are dominant players in the production of new energy technologies, their market position often belies their embeddedness in such global networks of firms.

China's new energy technology firms have primarily bet on a set of conventional new energy technologies, including silicon-based solar PV technologies and traditional lithium-ion battery chemistries. The economies of scale—and resulting cost declines—that China has achieved in these sectors have created concerns about technology lock-in, as their cost competitiveness makes it difficult for next-generation technologies to break into the market. This has particularly been a concern in the United States, which has traditionally excelled at the development of next-generation energy technologies and is home to a number of firms seeking to commercialize these products.[5]

China's rise in clean energy industries has promoted European economies in particular to try to develop domestic alternatives to the reliance on Chinese manufacturers. For instance, the European Union's "Fit for 55" proposal seeks to marry climate and economic goals by investing in low-carbon industries that guarantee jobs and prosperity as Europe pushes emissions reductions. Such goals are also noticeable in Europe's transportation sector, where the EU has proposed reducing new vehicles' average emissions by 55 percent in 2030 and 100 percent in 2035. This amounts to an outright ban of internal combustion engine vehicles by 2035, expanding on policies that have already passed in individual member states, including in France.[6]

The EU proposals send a strong signal to European firms that they need to participate in the transition away from fossil fuels or be left behind in a global industrial policy competition with China. In combination with promises to expand renewable energy capacity and charging infrastructure, to increase taxes on conventional fuels, and to develop low-carbon sources of hydrogen, these policies for clean energy industries build on ongoing EU efforts to close key gaps in industrial supply chains. The EU has, for instance, funded a European Battery Alliance to establish a competitive European battery industry that would reduce Europe's dependence on China.

All this fits with a broader response of the EU to China's rise in new energy industries. The EU is seeking to push back globalization and to create domestic sources of growth, particularly in strategic clean energy sectors with rapidly growing global markets and domestic security implications.[7] More than forty percent of Europe's pandemic stimulus package is dedicated to projects that further both economic competitiveness and address greenhouse gas emissions through support for green industries.[8]

2. China's Policy Environment

Particularly in new energy technology sectors, skills in the commercialization and mass production of new technologies are now concentrated in China. In the late 1990s and early 2000s, when the first Chinese firms entered wind and solar PV sectors, few global manufacturers of wind turbines and solar panels were producing at scale. While technology could be accessed in global networks through licensing and joint venture agreements, mass production knowledge was rare in these emerging industries. Chinese firms subsequently focused their efforts on building research and development skills around the commercialization and rapid scale-up of complex wind and solar technologies. Designated R&D teams focused on rapidly translating complex technologies into mass-manufacturable products. Such tasks required improvements to process designs long associated with manufacturing innovation, but also entailed changes to product designs to accommodate manufacturing requirements, to incorporate new materials and components, and to meet cost targets for final products.[9] The majority of these producers continued to license technology and source components and production equipment abroad.[10]

The development of these capabilities in manufacturing innovation relied on two unique institutional features of China's domestic economy that supported investments in both innovation and manufacturing: central government incentives for R&D and local government support for manufacturing. To date, no other economy has been willing and able to devote a similar level of resources in the expansion of manufacturing capacity and manufacturing R&D in new energy technology sectors. Since the beginning of the reform period in the 1980s, the central government in Beijing has used state incentives to encourage the development of domestic R&D, including applied research in manufacturing. Such government R&D support expanded in 2006, when the central government began encouraging "indigenous innovation" to reduce dependence on foreign technologies through increased domestic R&D efforts. Efforts further accelerated under President Xi's Made in China 2025 initiative, which has also designated the development of domestic new energy technology sectors as a strategic national priority. Provincial and municipal governments, dependent on tax revenue from the local manufacturing economy, augmented central government R&D support with incentives for mass production. China's provincial and municipal governments repurposed central government resources to broker bank loans and provide land, facilities, and tax incentives to manufacturers, including in energy technology sectors that were unable to attract large-scale financing in other parts of the world. Such loans for manufacturing facilities were provided even as central government policies encouraged industry consolidation. It is estimated that between 2010 and 2012 alone, wind and solar firms received credit lines of USD 47 billion by Chinese banks. The China Development Bank, one of three state-owned policy banks, reportedly extended USD 29 billion in credit to the 15 largest wind and solar firms.[11] Other reports suggest that state-owned banks provided USD 18 billion in loans to large wind and solar firms for

the expansion of manufacturing facilities. These loans were backed by municipal and provincial governments, allowing firms to expand manufacturing capacity even after the global financial crisis in 2009, when the collapse of European markets led to global overcapacity and few lenders were willing to fund further expansion of manufacturing plants.[12]

While national policies designated strategic technologies and provided funding for R&D, local policies diverted those resources into mass manufacturing clusters. In this environment, Chinese manufacturers continued to center their R&D efforts on production improvements rather than new product R&D.[13] To ensure that firms would rapidly contribute to the local economy, local administrations have frequently made subsidies conditional on meeting production targets and revenue requirements. In many instances, firms were contractually obliged to build facilities with pre-determined manufacturing capacity by a particular date or risk losing government grants, tax reductions, and discounts on land prices. In other cases, local governments informally exerted pressure on firms to rapidly scale production.[14] As Chinese manufacturers in energy technology sectors focused on commercialization, scale-up, and cost reduction, their innovative manufacturing capabilities (rather than basic factor cost advantages) emerged as a key source of competitive advantage.[15] Yet, even with China's highly supportive domestic institutions and rapid developmental pace, it took nearly four decades for Chinese firms to establish the capabilities in commercialization and scale-up that the world now needs to bring new energy technologies to market.

A growing body of research suggests that Chinese firms have also been able to acquire knowledge-intensive manufacturing capabilities in electric vehicle and battery industries, following a pattern similar to that of wind and solar. In the automobile industry, the engineering capabilities of Chinese firms have allowed them to create products particularly suited for China's "middle market" (based on cost and functionality). Although China's automakers are not (yet) outcompeting global incumbents for high-end products, they are able to make changes to product designs to reduce cost and optimize functionality.[16] The ability of Chinese automotive suppliers to build such capabilities marks an unintended consequence of the sequencing of China's economic reforms, which first focused on nurturing domestic manufacturing capabilities before allowing foreign direct investment and trade liberalization.[17] At the same time, Western incumbents, established long before the opening of China's economy to foreign firms in the 1980s, prevented Chinese firms from moving into desirable parts of the supply chain.[18]

In today's automotive sector, incumbent firms appear to be losing—however gradually—their ability to control global supply chains.[19] Technological change, including the growing importance of electronics in engine control and safety equipment, has made auto manufacturers dependent on collaboration with suppliers which offer expertise that automakers historically did not possess. These changes have only accelerated in the transition to electric vehicles, which introduced new components, including batteries and electric drivetrains. The division of labor in the electric vehicle sector now bears some resemblance to what I have outlined in the renewable energy sectors, as Chinese firms have applied their capabilities in manufacturing to focus on scale-up and mass production. Relying on the same state resources that buoyed aspiring wind and solar manufacturers, Chinese firms now control more than two-thirds of the global production capacity for lithium-ion batteries while rapidly reducing the associated costs.[20]

3. U.S.-China Competition

China has historically set an uneven playing field in its domestic market in favor of Chinese firms, and in some sectors, such as wind energy, foreign firms have been systematically pushed out of China's market through discriminatory government procurement policies.[21] Even though local content requirements for wind turbines were removed in 2009 and no formal nationality requirements were part of China's feed-in tariffs, foreign wind turbine manufacturers complained about being systematically excluded from government tenders and undercut by local competitors.[22] Despite having established local manufacturing facilities in China, foreign manufacturers argued that central and subnational governments were making use of the government procurement clauses included in the indigenous innovation legislation to purchase from domestic firms.[23] Many foreign firms ceased to participate in public tenders and subsequently scaled down planned investments in China-based manufacturing facilities. In other industries, such as the auto sector, foreign firms have until recently been forced to share IP and profits with Chinese partners in order to gain market access. Although forced partnerships have often failed to produce serious Chinese competitors, such policies did not create an inviting environment for collaboration. Allowing foreign firms fair access to its domestic market is one step China should take to level the playing field for foreign firms.

In some areas the situation is improving. In 2018, the central government announced it would remove the joint venture requirement for electric vehicle manufacturers so that foreign firms could wholly own their enterprises in China, and this ruling will extend to all auto manufacturers in 2020. Tesla was one of the first foreign manufacturers to build its own manufacturing facility in China as a result of these changes, much to the chagrin of local competitors who complained about the subsidies it received from the Shanghai government.[24] 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 the cases in the Beijing and Shanghai courts have ruled in favor of foreign plaintiffs against Chinese infringers. Damages paid to foreign plaintiffs were on average three times greater than those paid to domestic victims of IP theft. Nonetheless, domestic firms are increasingly making use of the courts to protect their IP. In 2015, 88.5 percent of the roughly 11,000 patent cases involved a Chinese plaintiff and Chinese defendant.[25]

China has announced ambitious plans to use standard-setting as an industrial policy tool in the future, including in new energy industries that will be critical to addressing global emissions. Although such plans are, for now, just plans, they dovetail with broader goals to become a key producer and exporter of climate-related technologies. Technical standards could eventually become a way of controlling global markets for new energy technologies and leverage China's dominant position for the production of such technologies for political and economic purposes. China's "Standards 2035" project and the related National Standardization Development document outline future goals, even if China is not currently dominating standard-setting for current new energy technologies.[26]

As China began to dominate global supply chains for an array of key clean energy technologies, the U.S. responded with a series of trade barriers against Chinese imports. Initially targeting Chinese wind turbine towers, tariffs were expanded to Chinese solar panels under the Obama

administration. Tariffs were renewed in 2018 under the Trump administration, again targeting Chinese solar cells despite vocal opposition from the domestic solar industry which feared the impact of rising prices in the large U.S. solar installation and maintenance industry.[27]

Despite the justification of trade barriers across both Democratic and Republican administrations, manufacturing has not "come back" to the United States. Tariffs have instead led to relocation of production capacity to other Asian economies, including to Vietnam and Malaysia, but they did not forge a reorganization of the solar industry in the United States or promote the expansion of domestic manufacturing capacity. China continues to account for roughly two-thirds of global production capacity in the solar sector and most US panels are imported.[28]

More recently, the Biden administration launched a broad investigation into gaps in domestic supply chains from both economic and security perspectives in the context of China's dominance in key industrial sectors. But the administration has thus far continued to primarily rely on tariffs implemented under previous administrations as its main tool to improve the competitiveness of domestic firms.[29] The Strategic Competition Act, which seeks authorization to assist U.S. companies with supply chain diversification away from China, proposes new investments in domestic infrastructure to compete with China and emphasizes the need to build alliances to counteract China's growing international influence. Yet, for now, it remains stalled in Congress.[30] The Infrastructure and Investment Jobs Act, which passed in November 2021 with bipartisan support, includes investments in the domestic grid and EV-related infrastructure, but does not directly address the competitiveness of domestic clean energy technology firms.[31]

4. The Way Forward for the United States

Historically, the United States has been the largest investor in clean energy research and development and continues to lead in many areas critical for fixing the climate crisis. U.S. companies are at the forefront of developing next-generation technologies that could make decarbonization cheaper and more efficient, including next-generation solar technologies, advanced battery chemistries, new building materials, smart grid technologies, and software to manage complex energy systems.[32]

Yet the United States risks losing its leadership position, particularly as other economies, including the European Union, have made strengths in clean energy sectors a priority. From offshore wind turbines to hydrogen and battery technologies, Europe has combined economic and climate objectives in its recovery plans. China, meanwhile, is closing the gap in research and development expenditure, including in the area of new energy technologies.[33] In both Europe and China, climate policy is taking on an economic imperative, as governments seek to expand market shares for domestic firms in growing markets for clean energy technologies.[34]

Addressing grand challenges like climate change will require fundamental advances in technology, where the United States is uniquely equipped to be at the global frontier. In United States, this means continuing to support the core strengths of U.S. firms and universities—the invention of new technologies—through investments in basic and applied research. Particularly on climate-related technologies, the United States should rapidly accelerate its research and development

investments to defend its technological lead.[35] The technologies that emerge from these efforts must eventually be scaled and deployed, and for now, few alternatives exist to Chinese supply chains to move new technologies to market.[36]

To change this, the United States needs to improve conditions for segments of clean energy supply chains that are currently not well-supported domestically. This means investing in domestic manufacturing capabilities as part of a national strategy for technological innovation. The creation of a government-controlled industrial finance corporation that could finance domestic manufacturing projects that the U.S. financial system has been unwilling to fund, renewed investments in vocational training and technical colleges, and a stable regulatory framework to support domestic markets for clean energy technologies are needed to improve national competitiveness in clean energy technology sectors. Even then, it is unlikely that entire value chains for complex energy technologies would lie entirely within national boundaries. European economic recovery strategies offer instructive lessons on how strategic policy intervention can improve national competitiveness in clean energy industries, while maintaining open trade relationships with China that are necessary to meet climate goals in the short-term.

The United States should also not lose sight of the substantial domestic economic benefits from investments in clean energy industries, even if a share of these technologies is, for now, manufactured abroad, including in China. Investments in clean energy infrastructure, upgrades to the grid, sustainable transit solutions, renewable energy installations—including offshore wind—and energy efficient building retrofits create local jobs in construction, installation and maintenance, and related service industries, regardless of where these products are manufactured. Even aggressive investments in clean energy sectors will need to be complemented by stable regulatory measures to create domestic clean technology markets if the goals is to create domestic industrial sectors that develop, commercialize, and produce such technologies in the United States.[37]

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