FEBRUARY 2021

Industrial Policy, Trade, and Clean Energy Supply Chains

AUTHORS
Sarah Ladislaw
Ethan Zindler
Nikos Tsafos
Logan Goldie-Scot
Lachlan Carey
Pol Lezcano
Jane Nakano
Jenny Chase

A Report of the CSIS Energy Security and Climate Change Program & BloombergNEF

CSIS | CENTER FOR STRATEGIC & INTERNATIONAL STUDIES

BloombergNEF

FEBRUARY 2021

Industrial Policy, Trade, and Clean Energy Supply Chains

AUTHORS
Sarah Ladislaw
Ethan Zindler
Nikos Tsafos
Logan Goldie-Scot
Lachlan Carey
Pol Lezcano
Jane Nakano
Jenny Chase

A Report of the CSIS Energy Security and Climate Change Program & BloombergNEF

CSIS | CENTER FOR STRATEGIC & INTERNATIONAL STUDIES

BloombergNEF

About CSIS

The Center for Strategic and International Studies (CSIS) is a bipartisan, nonprofit policy research organization dedicated to advancing practical ideas to address the world's greatest challenges.

Thomas J. Pritzker was named chairman of the CSIS Board of Trustees in 2015, succeeding former U.S. senator Sam Nunn (D-GA). Founded in 1962, CSIS is led by John J. Hamre, who has served as president and chief executive officer since 2000.

CSIS's purpose is to define the future of national security. We are guided by a distinct set of values—nonpartisanship, independent thought, innovative thinking, cross-disciplinary scholarship, integrity and professionalism, and talent development. CSIS's values work in concert toward the goal of making real-world impact.

CSIS scholars bring their policy expertise, judgment, and robust networks to their research, analysis, and recommendations. We organize conferences, publish, lecture, and make media appearances that aim to increase the knowledge, awareness, and salience of policy issues with relevant stakeholders and the interested public.

CSIS has impact when our research helps to inform the decisionmaking of key policymakers and the thinking of key influencers. We work toward a vision of a safer and more prosperous world.

CSIS is ranked the number one think tank in the United States as well as the defense and national security center of excellence for 2016-2018 by the University of Pennsylvania's "Global Go To Think Tank Index."

About BloombergNEF

BloombergNEF (BNEF) is a strategic research provider covering global commodity markets and the disruptive technologies driving the transition to a low-carbon economy. Our expert coverage assesses pathways for the power, transport, industry, buildings, and agriculture sectors to adapt to the energy transition. We help commodity trading, corporate strategy, finance, and policy professionals navigate change and generate opportunities.

© 2021 by the Center for Strategic and International Studies and BloombergNEF. All rights reserved.

Center for Strategic & International Studies
1616 Rhode Island Avenue, NW
Washington, D.C. 20036
202-887-0200 | www.csis.org

BloombergNEF
731 Lexington Avenue
New York, NY 10022
www.bnef.com

Acknowledgments

The report is made possible by the Climate Imperative Foundation and general support to the CSIS Energy Security & Climate Change Program.

Contents

1

Introduction

Over the last two decades, clean energy technologies like solar photovoltaics (PV), wind turbines, and lithium-ion batteries have gone from relatively expensive technologies produced and deployed by a small number of countries to cost-competitive technologies produced and deployed all over the world. Due to these cost declines, improved performance, and greater public and private sector support for renewable energy, the market for clean energy technology is positioned to grow even faster over the next couple of decades.

In the United States alone, solar and wind installed capacity is forecast to rise from 180 gigawatts (GW) today to 1,329 GW by 2050 (under the Economic Transition Scenario in BloombergNEF's New Energy Outlook). Combined, solar and wind are likely to make up 56 percent of 2050 U.S. installed power generation capacity, up from approximately 14 percent today. President Joe Biden has an even more ambitious plan to make the power sector carbon-free by 2035. In that case, significantly more wind, solar, and energy storage would be built over the next 15 years.

Similarly, electric vehicles (EVs) will be cost-competitive with conventional internal-combustion engine vehicles by the middle of this decade. Once this important crossover point arrives, EV sales will accelerate, and by 2040, pure battery-electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs) will account for the majority of new cars sold and 42 percent of the cars on roads in the United States. Over the next decade, this will represent a potential $67 billion market for battery sales in passenger EVs in the United States.

Which companies will produce the equipment that powers the transition? Which countries will be the manufacturing powerhouses that reap the economic benefits? What strategies should be pursued to take advantage of these opportunities? In an atmosphere of intense competition and increasing protectionism, could trade conflicts hinder the development of these growing markets?

This report is the first part of a multi-phase study conducted by BloombergNEF and the CSIS Energy Security and Climate Change Program. It traces the history of clean energy manufacturing and trade over the last 15 years, focusing on the supply chains of solar PV, wind, and lithium-ion batteries used in EVs and chronicling how these technologies have been scaled up and matured.

The history of clean energy markets has been characterized by frequent use of tariff barriers and other policies specifically intended to protect and grow nascent industries. As demand for solar PV, wind, and lithium-ion batteries expanded, supply chains shifted to new countries but are now less diverse overall with the advent of China's dominance as a manufacturer across the sector. China has played a critically important role in driving down the cost of these technologies and making them more accessible to a greater number of countries overall.

While there is nothing inherently wrong with China having a large role in clean energy supply chains, countries around the world have grown less trusting and accommodative of China's role in those markets and are increasingly looking to create more domestic value from their own clean energy policies.

Countries have tried to promote and protect domestic manufacturers of clean energy technologies with limited success, as two case studies in this report will highlight. Even China, the country that has experienced the greatest success cultivating a manufacturing base for these technologies, did so at a tremendous cost not likely to be borne by many other countries.

U.S. policymakers have shown interest in improving U.S. competitiveness in clean energy manufacturing and innovation. Manufacturing scale, intellectual property, and expertise dictate the performance and cost competitiveness in each sector. Major technological changes are also underway in each sector. Any effort to establish a foothold in manufacturing in solar, wind, or storage requires a clear understanding of the current best-in-class technology, where the industry is moving, and at what pace. In wind, for instance, the market share for direct-drive turbines that employ permanent magnet generators is rising in the offshore market. This has implications for rare earth use in the sector.

U.S. policymakers are also concerned about reliance on China for strategically important technologies. The analysis in this report shows, in terms of overall reliance on foreign companies and overseas manufacturing, the United States is most exposed in the solar sector, followed by energy storage and then wind. However, choke points within each sector differ considerably. There are no rare or hard-to-access raw materials used in the production of most PV modules, whereas certain wind turbines rely on rare earths, and the battery industry relies on a combination of nickel, cobalt, and lithium.

Clean energy technologies are now critically important to the future of all countries seeking to rapidly decarbonize their economies. As a result, the strategic value of clean energy supply chains has never been higher. As we document in this first phase of our report, many nations clearly recognize this. We also explore frictions that have emerged to date between countries and the policies that prompted those disagreements.

As the energy system evolves, so too should our thinking about what energy security and competitiveness mean in this new world and what policies are best suited to safeguard them. The next phase of our report will explore in greater depth the future landscape of potential trade and security concerns related to clean energy technology development and trade. In this report, we highlight the anticipated growth in clean energy markets, examine China's evolving role in clean energy markets and supply chains, explore individual countries' responses to China's growing competitiveness, and offer several overarching lessons from those experiences.

2

The Booming Clean Energy Market

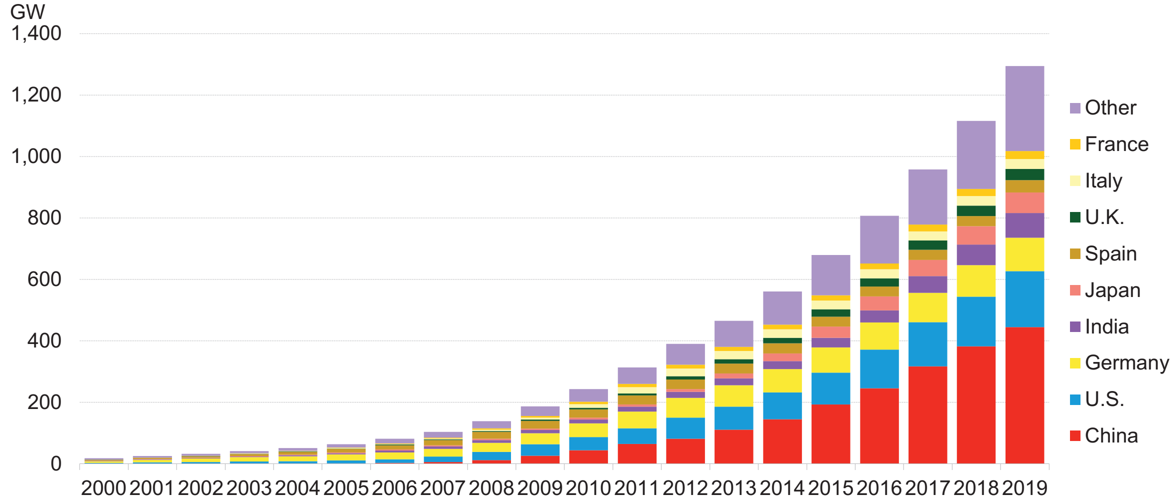
In a decade and a half, renewable power and electric vehicles have gone from the fringes of the energy and transportation world to its epicenter. Once termed “alternative,” these technologies comprise an ever-growing share of energy sector investment and an even bigger share of the strategic direction of some of the world’s largest energy companies. In 2005, global new capital invested in clean energy technologies totaled $60.5 billion. Five years later, it grew to $235 billion, and by 2020, it was at $501 billion. In all, over $4 trillion cumulatively has been invested in clean energy technologies since BloombergNEF first began tracking this sector 16 years ago. The bulk of new power generation capacity worldwide comes from renewable energy sources.

Global Outlook

With greater investment has come mass deployment. Global solar power-generating capacity, which stood at 5.5 GW in 2005, totaled 651 GW at the start of 2020. Wind capacity has jumped from 58GW to 643GW in that same period. EVs, which were virtually non-existent a decade ago, neared 10 million as of year-end 2020, and EV sales grew by an estimated 33 percent globally in 2020 from the year prior—even during an unprecedented economic crisis. Each of these technologies occupies a relatively small share of total power sector and vehicle deployment, but all have grown quickly and show no sign of abating.

As of year-end 2019, China accounted for just over a third of the total installed capacity for wind and solar, with a fifth installed in the United States. Another 45 percent was spread across Germany, Spain, Italy, France, and the United Kingdom. India and Japan are the other large markets outside Europe. Solar and wind power account for the vast majority of all renewable capacity built in the past two decades.

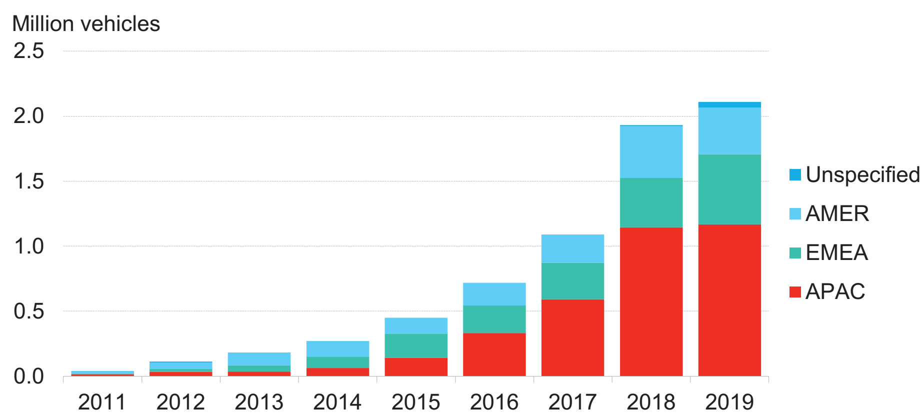
Figure 1: Cumulative Worldwide Installed Wind and Solar Power-Generating Capacity



Source: BloombergNEF

China has been the largest EV market since 2015, and well over half of total annual sales in both 2018 and 2019 were across the Asia Pacific region (Figure 5). Through the first three quarters of 2020, an additional 1.75 million EVs were sold, with APAC accounting for 711,000 units. Sales in the Europe, Middle East, and Africa regions have surged as higher emissions standards have gone into effect in the European Union.

Figure 2: Passenger Electric Vehicle Sales



Note: Commercial and low-speed electric vehicles not included. Source: BloombergNEF, Marklines, vehicle registration agencies.

Each of these three technologies has developed at its own pace and has been affected by different factors. But broadly speaking, all three have gone through two phases of development: pre-cost-competitive and cost-competitive.

During the pre-cost-competitive phase, technology is more expensive to deploy than incumbent solutions. Governments then respond through subsidies or other support with the goal of helping the new technology achieve scale and reduce its per-unit costs to the point where it is cost-competitive with incumbent technologies. At that point, market forces take over, and technology proliferates without substantial additional government intervention.

Solar and wind power have largely achieved cost-competitive status in many parts of the world—they can be the first additional megawatt of capacity added to a power grid, regardless of the availability of government support. This largely explains their explosive recent growth. EVs have yet to achieve unsubsidized cost parity in most places. However, that threshold is now in sight, thanks to a 90 percent decline in prices for lithium-ion (li-ion) batteries over the last decade. BloombergNEF projects EVs will start to underprice conventional internal-combustion engine (ICE) vehicles on a "sticker-price" basis in many countries, including the United States as soon as 2023. That is, after comparing the upfront prices of an EV vs. an ICE, a consumer will be able to choose the EV based strictly on it being lower cost—without any subsidy taken into account. At that point, we can expect consumer adoption to increase at a faster rate.

U.S. Outlook

The deployment of these technologies is bound to grow over time. Even in the absence of additional policy support, BloombergNEF expects $1.7 trillion to be invested in U.S. power-generating and power-storage assets in the United States through 2050, with another $2.4 trillion required for grid infrastructure. In transportation, BloombergNEF expects that EVs will account for 42 percent of U.S. vehicles by 2040, representing 60 percent of new sales annually. The EV market more than doubled from $8 billion in 2016 to $16.5 billion in 2019. Between 2020 and 2030, about $67 billion in passenger EV batteries will be sold in the United States.

Already, both subsidized and unsubsidized renewable energy can underprice new gas-fired power on a $/MWh basis across most of the United States. In recent years, wind and solar plants have struck fixed-price power-purchase agreements as low as $13/MWh and $23/MWh with an average 51 percent drop in wind PPA prices and 57 percent in solar in the last five years alone. While these contracts are aided by current U.S. tax-credit subsidies, wind and solar can compete with their fossil rivals on a new-build, unsubsidized basis as well.

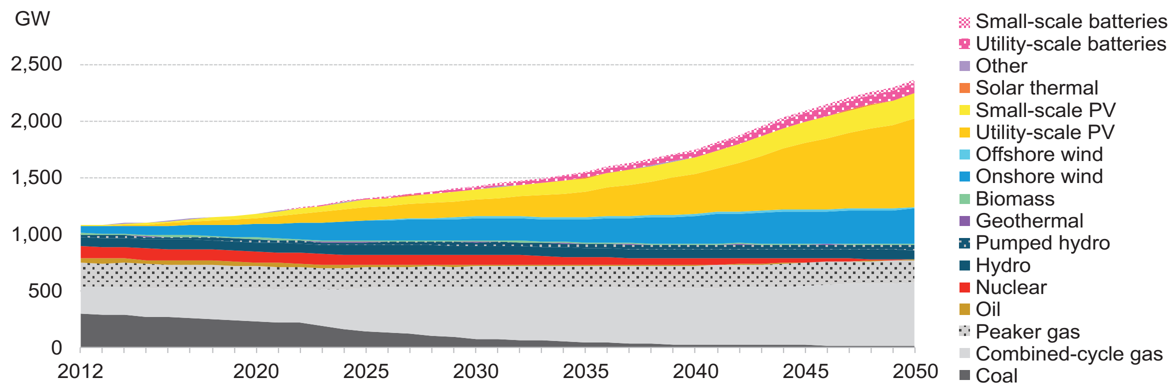
By the late 2020s, BloombergNEF projects new-build renewables should also be able to out-compete existing gas plants as solar, wind, and battery costs continue to decline. The timing of this "tipping point" varies regionally—happening sooner in places with excellent renewable resources and higher gas prices, such as California, and later where renewable resources are weaker, and gas is cheaper, such as the PJM market, which encompasses the mid-Atlantic and Midwestern states.

As renewables get cheaper and gas prices slowly rise, utility-scale solar and onshore wind will increasingly dominate new-build, accounting for 39 percent and 19 percent of capacity additions in the United States, respectively, through 2050. By 2050, there will be 323 GW of wind and 1,006 GW of PV, making up 13 percent and 43 percent of installed capacity (Figure 12).

Between now and 2050, BloombergNEF estimates investment in solar and wind power-generating assets will total $1.1 trillion. Batteries should attract an additional $106 billion. Meanwhile, at least 2.9 million miles of new transmission and distribution will be required. Globally, roughly one-third will likely run underground.[1]

1 All of this is detailed in BloombergNEF's New Energy Outlook's Energy Transitions Scenario, which employs a combination of near-term market analysis, least-cost modeling, consumer uptake, and trend-based analysis— yet makes no assumptions

Figure 3: Cumulative Installed Capacity in the United States

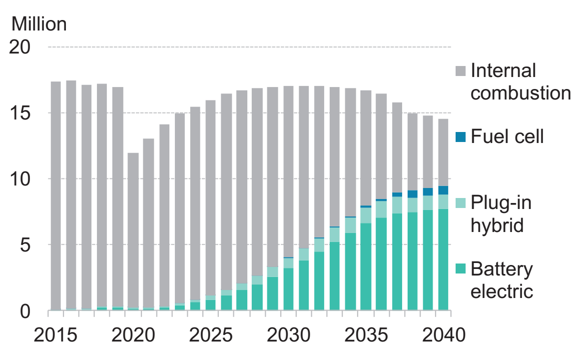


Note: This is based on the New Energy Outlook Energy Transitions Scenario. Source: BloombergNEF.

EVs today remain unaffordable to many consumers, particularly when current vehicle-purchase subsidies are taken out of the equation. Still, EV sales have accelerated over the past five years, rising from 0.7 percent of total U.S. car sales in 2015 to 1.9 percent in 2019.

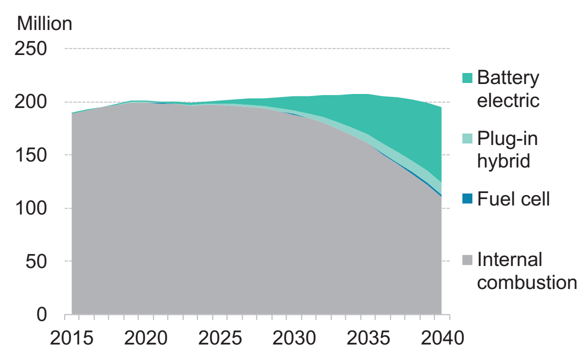
However, that is expected to change soon. Thanks to rapidly declining battery costs, EVs will be entirely cost-competitive with conventional internal-combustion engine vehicles on a sticker-price basis by approximately 2025, BloombergNEF estimates in its long-term Electric Vehicle Outlook. Once this important cross-over point arrives, EV sales will start to accelerate at a fast clip. By 2040, pure battery-electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs) will account for the majority of new cars sold and 42 percent of the cars on U.S. roads (Figure 4, Figure 5).

Figure 4: U.S. Annual Passenger Vehicles Sales by Drivetrain



Source: BloombergNEF, Long-term Electric Vehicle Outlook.

Figure 5: U.S. Annual Passenger Vehicles Fleet by Drivetrain



Source: BloombergNEF, Long-term Electric Vehicle Outlook.

about explicitly supportive policies for clean technologies. In fact, additional state or federal policies favoring clean power could dramatically boost demand for wind, solar, and storage in the United States and create even further economic opportunities.

Similarly, BloombergNEF expects sales of electric U.S. short-haul delivery vehicles and buses to rise in coming years as battery prices decline. Already, major delivery companies such as Amazon and UPS are moving to convert their fleets while municipalities seek to add electric school buses.

The power and transportation sectors of the U.S. economy have begun to undergo profound transformation, thanks to technological advancements and economies of scale. Not only will change continue in coming years it will substantially accelerate—creating trillions of dollars in economic opportunity along the way. What is less clear is which companies will exploit these opportunities and what efforts U.S. policymakers might make to ensure that U.S. companies supply a U.S. market.

3

China Leads in Clean Energy Manufacturing

Humans have sought to harness the power of the sun and wind for centuries. Expanded use of today's most common and modern technologies, however, only kicked off approximately 20 years ago—first in western Europe, followed by the United States, Japan, India, China, and Brazil, and finally to almost every corner of the world. In the 2000s, the growth of PV and wind was driven almost entirely by demand-side policies. The earliest policy mechanisms included feed-in tariffs (FiTs), renewable portfolio standards (RPS), government-backed loan guarantees, and tax credits. For EVs, subsidies included tax breaks for manufacturing plants to produce lithium-ion batteries, higher vehicle-emissions requirements, or direct tax credits for EV purchasers.

Germany was among the very first nations to offer FiTs both to solar and wind projects operating in the country and was soon followed by Spain, the Czech Republic, and Japan. For its part, the United States subsidized project developers through its tax code, in the form of the Production Tax Credit for wind and the Investment Tax Credit for solar projects. These countries implemented such policies under the assumption that the equipment that would be used to outfit new projects would largely be manufactured locally, or at least manufactured by nations with which they had trade alliances. In the earliest years, this was largely true with manufacturers such as Vestas, Acciona, and General Electric serving the Danish, Spanish and U.S. wind markets and firms such as Q-Cells, Sharp, and SunPower serving the German, Japanese, and U.S. solar markets.

For many policymakers in the 2000s, climate change or other environmental concerns were top of mind when they introduced initial subsidies and other supports for clean energy technologies. Policymakers were certainly aware of the potential economic and energy security benefits that would come by fostering such industries, but they mostly emphasized the "green" attributes these new technologies offered.

After all, these policies were crafted against a very different geopolitical backdrop than the one we face today. Debates over the merits of an interconnected global economy took place, for sure, but were either far more muted or occurred far from the political mainstream. After a mostly peaceful and prosperous 1990s, the default assumption in many developed nations was that free trade was a force for good that could lift nearly all economic boats.

Meanwhile, the discourse over China was different in the 2000s than it is today. The country's economic growth was certainly recognized as an opportunity to bring a large, emerging economy into the fold of a neoliberal economic and rules-based multilateral order. Large, multinational corporations were intrigued by the possibility of growing sales to China's expanding middle class. To many, China's rise as a genuine strategic competitor, as opposed to a mere economic powerhouse, seemed relatively far off into the future.

Rhetorically, Western policymakers recognized the enormous economic opportunities presented by the potential to dominate the supply chains for solar, wind, and EV technologies. But in reality, many of these decisionmakers were free-trade proponents or environmentalists who wanted to drive down the cost of these technologies as quickly as possible for rapid dissemination. As a result, the earliest policies to spur demand for clean power and EVs in the United States, the European Union, and other developed nations rarely included measures to ensure the needed equipment would be made at home.

This paved the way for China to grow its footprint in these industries. China's initial growth came from policies that subsidized both domestic demand and supply. The country implemented generous FiTs similar to those adopted in Western nations. On the supply side, Chinese development finance institutions made virtually unlimited credit available to new solar and wind equipment makers, while massive state-owned entities entered the market by tapping their balance sheets. These efforts were undertaken not just with an eye on serving the domestic market but with the goal of exporting to Western Europe, Japan, the United States, and other developed countries.

By the early 2010s, the boom in Chinese manufacturing of solar and wind equipment was well underway (lithium-ion battery and EV production would come a few years later). In the solar market, in particular, Chinese exports began to saturate a global market that just a few years earlier had seen a supply squeeze. As PV prices plummeted, Chinese exports to the European Union, the United States, Japan, and other OECD nations surged.

Few manufacturers and policymakers in the West immediately recognized the threats posed by China and were thus surprised when Chinese-made PV equipment flooded across borders. Hubris no doubt played some role in this lack of preparedness. China was widely, but wrongly, regarded as being good only at the mass production of low-value goods—not sophisticated equipment such as high-efficiency PV modules or utility-scale wind turbines. This view was not entirely without merit. In its earliest days of PV manufacturing, Chinese firms lacked key capital equipment to produce components contained in PV modules and were forced to import these from foreign firms such as GT Solar of New Hampshire. The earliest Chinese-made wind turbines were plagued by gearbox malfunctions.

It did not take long for Chinese firms to catch up, however, and by the early 2010s, firms such as Yingli and Suntech were making major inroads in overseas markets with modules of sufficient quality at below-market prices. On the wind side, Chinese firms experienced a good deal less success exporting complete, assembled turbines, due to high transport costs, concerns over equipment reliability, Western banks' unwillingness to finance purchases of their equipment, and the strong positions of incumbents such as GE. Undeterred, Chinese firms began successfully exporting less sophisticated wind components such as steel towers.

China and the Lithium-Ion Battery Supply Chain

The lithium-ion value chain begins with the extraction of raw materials, the most significant of which are lithium, cobalt, and nickel, which are then refined for further processing. More than 90 percent of the world's lithium is produced in five countries: Australia, Chile, Argentina, Bolivia, and China. China is the largest refiner of lithium, accounting for 61 percent of total capacity, followed by Chile (30 percent) and Argentina (9 percent). The concentration is even greater in cobalt, where the Democratic Republic of Congo accounts for over three-quarters of the world's output and operational mining capacity (most cobalt is produced as a byproduct of either copper or nickel). China accounts for a similarly high share of cobalt refining capacity, at 72 percent, with the balance being largely in Europe. Nickel production is geographically dispersed, with Russia, the largest producer, accounting for 20 percent of global nameplate mining capacity (this refers to Class 1 nickel). A similar dispersion is visible in refining: in this market, China's share is just 16 percent.

These refined materials, alongside others, are turned into components, the most important of which are cathodes, anodes, separators, and electrolytes. The processing capacity for these components is largely concentrated in China, Japan, and Korea, mainly due to the legacy of established battery manufacturers for consumer products. Among these Asian producers, however, it is China that holds the largest market share: 52 percent for cathodes, which is the most important component and can account for half the cost of a manufactured cell, 78 percent for anodes, 66 percent for separators, and 62 percent for electrolytes. The United States only has a meaningful presence in electrolytes with 8 percent of processing capacity, largely because electrolytes are liquid, hard to transport, and therefore often produced near cell-manufacturing facilities. The country's footprint in the other components is largely non-existent.

These components are then turned into cells, which can then be assembled into modules, packs, or racks depending on the end use. Around 78 percent of the world's cell manufacturing capacity is located in China, with some modest capacity in Europe and the United States. Looking ahead, there is far more planned capacity additions in China and in Europe than in the United States—even if every project went ahead, the United States would still only have about one-tenth of China's cell manufacturing capacity by 2025.

China and the Solar PV Supply Chain

The solar PV manufacturing value chain can be broken down into five main components: polysilicon, ingots, wafers, cells, and modules. The upstream parts of the value chain—polysilicon and wafers—are technically challenging, capital intensive, and with high barriers to entry. They are also highly consolidated: the top ten firms supplied 83 percent (polysilicon) and 95 percent (wafers) of the market (most ingot capacity exists within wafer plants and is not reported separately) in 2019.

The Chinese presence in the polysilicon market has grown over time. Since 2017, 91 percent of the new polysilicon processing capacity in the world has been built in China, and by 2019, two-thirds of the world's polysilicon manufacturing capacity was owned by Chinese firms (regardless of factory location). At the high end of the market sits a German manufacturer, Wacker-Chemie, and major Korean players are still important in the market, although some major producers have gone out of business recently.

The story is even starker when it comes to wafer manufacturing. More than 90 percent of the world's capacity is in China, and having control over this part of the value chain has been essential to the country's dominance of the PV supply chain. Wafer factories are expensive and technically challenging to build. As major buyers of upstream materials in the value chain, wafer manufacturers can use their bargaining power to negotiate favorable supply terms, making it even harder for newcomers to break into the market.

The market for solar cells is far less concentrated; in 2019, the top ten cell producers supplied 59 percent of the market. Leading cell makers are vertically integrated companies that own wafer and/or module manufacturing as well. This allows them to exert better cost control and manage output certainty. Companies have found it relatively easy to shift production facilities in this segment of the value chain in response to trade barriers. When the United States imposed tariffs on Chinese solar cells, for instance, large manufacturers built both cell and module assembly plants across Southeast Asia—thus skirting U.S. tariffs. Meanwhile, domestic manufacturing in the United States received no noticeable boost, while the exports from Southeast Asia still came from Chinese firms.

A similar dynamic is visible in module manufacturing. Here too, the upfront cost and complexity is lower than in the upstream parts of the supply chain, but vertical integration confers an advantage to existing producers, thus benefiting China. Chinese companies own about 72 percent of the world's module manufacturing capacity (regardless of factory location), a share that has stayed the same since 2016.

China and the Wind Supply Chain

The wind supply chain is both local and global. Onshore wind turbines are largely made of concrete (by weight), while steel makes up most of the weight for offshore turbines. As the industry pursues larger projects to drive down costs, the components become larger too, making them costlier to ship. That alone encourages supply chains to grow near demand centers. Of the 39 countries that make utility-scale wind equipment, only China, India, Spain, Germany, and the United States can produce all six major components: nacelles, blades, towers, generators, gearboxes, and bearings. This too produces some concentration: the top 10 firms supplied 84 percent of the wind turbine market in 2019, up from 74 percent in 2014.

China accounts for 58 percent of the nacelle market by plant location and 42 percent of the market based on company ownership. Other major producing countries are the United States, India, Germany, and Denmark. (Together, these countries made up 92 percent of world nacelle capacity.) Blades are largely produced by wind turbine manufacturers except in China, where there remains a market for independent suppliers. In 2019, 59 percent of the world's plants were in China (by count, not capacity). For wind towers, almost half the world's manufacturing plants are in China, with Spain a distant second. Turbine manufacturing is more dispersed: almost 40 percent of the plants are located in China, but outside of China, the market is dominated largely by European manufacturers. The gearbox market is far more global since gearboxes are comparably easy to ship; roughly half of the world's plants are in China.

Bearings used in wind turbines must be designed to precise specifications, which create barriers to entry in their production. China has an established production base but relies on German, Swedish, Japanese, and U.S. manufacturers for high-end, large-diameter bearings. Since other sectors use bearings, demand for wind is not usually the overriding driver of plant capacity.

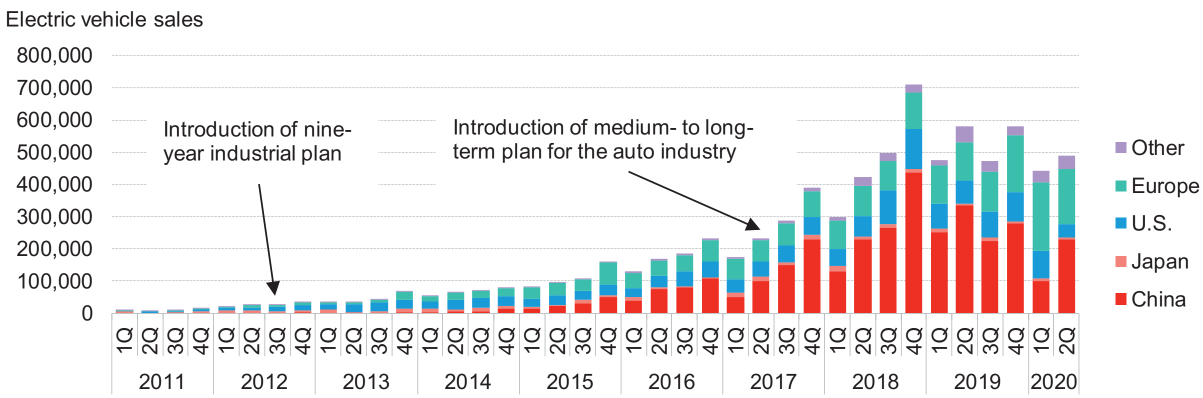
Case Study in Industrial Policy: Batteries and Electric Vehicles in China

In 2012, China published its Energy-Efficient and New-Energy Vehicles Industrial Plan, the central government's official intention to develop a domestic EV and battery industries. Lagging behind in internal combustion engine vehicle technologies, the hope was to better position China for the era of EVs and make the most of its comparative advantages in low-cost manufacturing. Less than a decade later, China is by far the largest single-country market, has a dominant presence in every component of the upstream supply chain for battery technologies, and is a growing force in the EV and battery innovation race.

China's EV plan included all the classic features of industrial policy: demand and supply incentives, public procurement, clear targets, R&D funding, and government guarantees. It began with the rollout of conventional hybrids and more efficient gasoline vehicles, but by 2015 the focus shifted to the mass rollout of EVs. Unlike Western leaders in EV sales like Norway, China focused on expanding local manufacturing capacity in every phase of EV production, rather than overall sales numbers.

Today, China is the largest EV market in the world, and there has been no single policy responsible for its significant EV sales and battery manufacturing capacity. However, even as it dominates the upstream EV supply chain, China's automotive industry has yet to become internationally competitive, with few, if any, recognizable brands in global markets. This may well change as its indigenous R&D efforts bear fruit, manufacturers benefit from further economies of scale, and global consumers become more comfortable with EV technology.

Figure 6: Electric Vehicle Sales



Source: BloombergNEF, Marklines.

PROGRAM DESIGN, IMPLEMENTATION AND IMPACT

In 2011, only 40,000 EVs were sold globally, and the industry was almost exclusively found in the United States, Japan, and Europe. Just 1,000 EVs were sold in China that year. While China was not a leading EV producer in 2011, it did have a foothold in the consumer battery industry, which served as a foundation for leading EV and stationary storage battery manufacturers.

After several failed attempts, the Chinese government adopted a new approach in April 2012 with the publication of its Energy-Efficient and New-Energy Vehicles Industrial Plan 2012–2020. The nine-year plan set a more sensible pace than previous efforts. Its near-term focus was the rollout of conventional hybrids and more efficient gasoline vehicles while research and development work continued on EVs. Beyond 2015, the focus shifted to the mass rollout of EVs.

The plan had several components and targets. First, it aimed to increase research and development in key EV and energy-efficient vehicle technologies. This was perhaps the most important development area for the Chinese EV industry. It envisaged a ramp-up in public R&D funding delivered through national research labs, universities, and companies throughout the supply chain. A key developmental target was cost and the battery life cycle. Second, the plan sought to improve industry planning. To avoid overcapacity issues seen in the PV industry and in the early EV battery market, the government aimed to develop two to three leading companies in each stage of the value chain with primary attention paid to batteries, battery materials, motors, and transmissions. Third, the plan sought to accelerate vehicle demonstration and rollout. The government would more closely monitor the 25 demonstration cities in its "Ten Cities, Thousand Vehicles" plan to ensure public purchases of EVs actually occurred. It would also use average corporate fuel consumption targets to encourage uptake. Fourth, it called for another plan to be designed specifically for charging infrastructure to address questions of technology choice, standards, regulation, and business models. Lack of clarity on these points had stymied consumer uptake of EVs in the country. And fifth, the plan called for investment in recycling and reuse of electric vehicle batteries. The government committed to drafting regulations on how to recycle and which companies would be responsible for doing the recycling.

The overall strategy had three target areas. First, it was to lower battery costs and improve performance. Battery modules should cost less than CNY 2000/kWh ($314/kWh) and have a life of more than 2000 cycles or 10 calendar years by 2015 and should cost less than CNY 1500/kWh ($235/kWh) by 2020. This was later updated with a target of doubling average battery pack energy density from 2016 levels by 2020 and lowering battery pack prices to $150/kWh by 2020. Second, it aimed to boost vehicle sales. By 2015, cumulative sales of BEVs and PHEVs should reach 0.5m; by 2020, cumulative sales should reach five million, and annual production capacity should reach two million. The plan was updated in 2017 to a seven million target by 2025, and the latest plan aims for BEVs to make up the majority of sales by 2035. And third, the strategy sought to improve average fuel efficiency. Passenger vehicles manufactured in 2015 would have an average fuel efficiency of at most 6.9 liters per 100km with energy-efficient passenger vehicles reaching an average fuel efficiency of at most 5.0 liters per 100km; by 2020, these targets ratcheted to 5.0 liters per 100km for passenger vehicles and 4.5 liters per 100km for energy-efficient ones.

The Chinese government used a combination of demand and supply-side policies to further its high-level goals. Local governments also provided additional, but narrower support. Direct purchase subsidies for EVs were key to boosting sales. The specific criteria have been amended a number of times over the last few years as costs of the program ballooned, but the principle has remained consistent, using incentives for both production and consumer adoption. Of the $60 billion the Chinese government is estimated to have spent on the EV industry between 2009 and 2017, around 60 percent or $37 billion was in consumer subsidies. There were fewer demand-side policies to support the battery industry in China, but the EV subsidy scheme boosted demand for batteries which in turn benefitted local companies. The push to improve energy density and battery performance also forced Chinese battery manufacturers to focus on technology development.

On the supply side, China introduced a New Energy Vehicle (NEV) credit program in 2012. Similar to California's Zero Emissions Vehicle (ZEV) mandate, China's system forces automakers to sell an escalating percentage of EVs each year. As with the direct subsidy program, the policy differentiated between performance characteristics of different technologies. There are also three multipliers—range, battery energy density, and vehicle efficiency—that are applied to the baseline NEV credits.

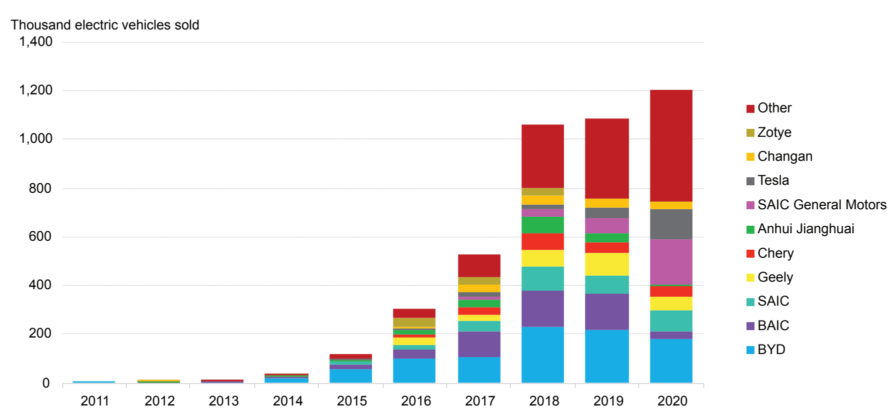
The Chinese government also introduced foreign investment restrictions to benefit local automakers and battery suppliers. In 2015, the National Development and Reform Commission (NDRC) and Ministry of Industry and Information Technology (MIIT) jointly issued the *New Investment Electrified Vehicles Corporation Management Regulation*, which served as the basis for EV production permits. Securing a permit was the first step for automakers seeking to sell EVs and receive government subsidies. Foreign automakers were also required to set up joint ventures with 50:50 stakes in the country. This restriction was lifted for EV manufacturing in 2018 and for commercial vehicles in 2020, and it is scheduled to be lifted for all vehicles in 2022.

DID THE PROGRAM SUCCEED?

The combination of a clear national strategy to develop EVs and batteries, and specific policies and financial support to sustain it, has boosted EV uptake significantly. China's share of total EVs sold globally rose from 3 percent in 2011 to 26 percent in 2015 and exceeded 50 percent in both 2018 and 2019. China is and will continue to be the world's largest country market for the next decade or more based on annual sales and fleet size for both passenger and commercial vehicles. The combination of policies ensured that Chinese automakers and battery manufacturers were able to scale.

As overall EV sales have surged in China, domestic automakers have reaped the benefits. Among the top 10 manufacturers serving the market from 2011–2019, just two were not entirely Chinese-owned: California-based Tesla Motors and a SAIC-General Motors joint venture. Shenzhen-based BYD topped the list, followed by Beijing-based BAIC. The combination of national and local policies has also led to Chinese battery manufacturers establishing themselves as top-tier suppliers. China's CATL was the world's largest supplier of batteries for EVs and for stationary storage in 2019.

Figure 7: Electric Vehicle Sales in China by Manufacturer



Source: BloombergNEF, Marklines.

4

Responding to China's Growing Clean Energy Dominance

As Chinese-made equipment, particularly PV modules, began to be exported, policymakers started to react, chiefly by looking at erecting trade barriers, but they moved slowly. In some cases, inaction was deliberate as China's growing presence served to depress prices, which was seen as good news because it helped to lower costs and accelerate decarbonization. Lower prices also allowed policymakers to dial back the generosity of FiTs, or even eliminate them, thus easing the burden on taxpayers in countries such as Germany, Spain, and the Czech Republic who had heavily subsidized clean energy's initial growth.

What policymakers failed to recognize was that global clean energy manufacturing was becoming a zero-sum game in which manufacturers that achieved greatest scale could underprice and ultimately bankrupt their smaller competitors. China's rise in clean energy equipment manufacturing had the potential to spell local manufacturers' demise.

Policymakers scrambled to respond. The United States undertook a series of actions to curtail imports of both Chinese-made solar and wind equipment. It imposed tariffs on PV imports. It blocked the development of at least one wind project that planned to use Chinese-made wind equipment and the sale of a U.S.-based battery technology firm to a Chinese firm, both on national security grounds. Meanwhile, in Europe generally and in Germany specifically, local equipment manufacturers lobbied loudly for protections.

Brazil and India launched their clean energy support programs with policies specifically intended to support domestic manufacturing—in line with past efforts to stimulate domestic industry. Almost from the start, India imposed "domestic content rules" that mandated that certain portions of new PV equipment installed in the country would be manufactured locally for projects to secure power-delivery contracts to state-owned utilities. The country has long regarded China as a geopolitical rival, and it sought to exclude Chinese-made PV equipment while supporting local manufacturers. In Brazil, national development bank BNDES made financing contingent on wind projects sourcing equipment locally. As BNDES is effectively the sole provider of low-priced capital for infrastructure projects in Brazil, the bank's policy (undertaken in full cooperation with the country's policymakers) effectively required all new wind projects be outfitted with equipment at least partially manufactured in the country.

Western nations had largely skipped such provisions in the rollouts of FiTs, tax credits, or other supports. Now, they sought to take direct actions to block imports. In March 2012, the United States imposed tariffs on Chinese-made PV equipment, and in July 2012, imposed tariffs of up to 73 percent on Chinese-made towers and 60 percent on Vietnamese towers. The United States also stepped-up efforts to slow Chinese development or ownership of certain assets, citing national security concerns. In September 2012, the Committee on Foreign Investment in the United States (CFIUS) blocked the development of a wind farm planned near a military base in Oregon that had planned to use Chinese-made wind turbines. CFIUS later considered blocking the sale of a Massachusetts-based battery technology developer, A123 Systems, to the Chinese firm Wanxiang. In May 2013, China determined that U.S. and EU producers were dumping solar-grade polysilicon into the Chinese market to bankrupt nascent Chinese producers and said it was considering imposing tariffs.

To date, tariff-related responses to China's growing dominance of clean energy supply chains have done little to stem China's progress but forced clean energy supply chains to adapt. Most policy efforts intended to curtail flows of least-cost equipment from China or other developing nations such as Mexico or Thailand have proven futile. Today, the vast majority of the world's PV equipment is produced in China or Southeast Asia and exported to Western nations. While the wind and li-ion supply chains are a good deal more geographically diverse, China is the top producer of equipment for both technologies. What was once a relatively diversified set of niche clean energy supply chains made up of countries using myriad supports to grow fledgling industries is now a much larger and sprawling complex of industrial players selling cost-competitive technologies now largely dominated by China. It should be noted, however, that the trade disputes listed above occurred before the worsening trade relations between the United States and China over the last several years. Our next report will outline the ways in which trade and security concerns could potentially impact clean energy trade going forward.

Case Study in Industrial Policy: India's Solar Mission

Concerned over growing imports of Chinese-made PV equipment and hoping to build its own thriving industry, India launched its National Solar Mission in 2009. The scheme sought to vastly expand local PV power-generating capacity from approximately zero to 20 GW by 2022 while ensuring a substantial portion of equipment deployed was made in India. To achieve this latter goal, India implemented a local-content rule mandating projects use certain volumes of Indian-made PV, such as a 30 percent local content minimum for solar thermal auctions.

India has, in fact, seen an explosion in installed solar capacity, vastly exceeding its original 20 GW goal, with 43 GW already installed. However, the country still lacks almost any manufacturing capacity in higher-value segments further up the value chain. It has virtually no polysilicon, ingot, or wafer production capacity. Further, upon closing a loophole that had allowed U.S.-manufactured "thin-film" PV modules to bypass local content restrictions, U.S. manufacturers brought an official complaint against the Solar Mission to the WTO in 2013. Three years later, the WTO ruled in the United States' favor. India abandoned the rules but continues to support local manufacturers, primarily through public procurement, which is exempt from WTO rules.

PROGRAM DESIGN, IMPLEMENTATION AND IMPACT

To improve their chances in winning a tender, developers had to demonstrate their projects would use certain volumes of domestically made equipment. During the first phase of the program from 2010–2012, the local content rules only applied to crystalline-silicon (c-Si) technologies. The program sought to work up the c-Si value chain, starting with the segment deemed easiest to fulfill domestically—the assembly of finished PV modules. During the first "batch" (tender), projects needed only to use locally made modules; the cells contained in those modules could be imported. In the second batch of Phase 1, developers had to use both modules and cells made in India. Importantly, none of the Phase 1 rules applied to projects that used thin-film modules, which are made from cadmium telluride, not c-Si.

In Phase II, which included four more batches, the rules tightened while also giving developers the flexibility to choose between closed and open auctions. Developers participating in a closed or "domestic-content requirement" (DCR) segment of the tender process had to source both their modules and cells locally. Alternatively, they could take part in the "Open" category where local-content rules did not apply, and developers were free to choose any equipment, regardless of where it was manufactured. Or they could take part in both by submitting separate bids. For the first time, projects seeking to use thin-film modules were subject to local-content requirements as well, significantly impacting U.S. manufacturers. By 2017, the last year DCR auctions could take place after the WTO ruling, almost twice much capacity was auctioned off in the closed than the open auctions.

The program also had explicit targets that it hoped would help India achieve its long-term installed power-generating capacity goals. The government hoped that Phase I would result in 1-2 GW of new build, followed by 4-10 GW in Phase II. A later, Phase III from 2017-2022 would add another 20 GW. Below each of these headline objectives were carve-out objectives for off-grid solar to boost energy access rates in the country.

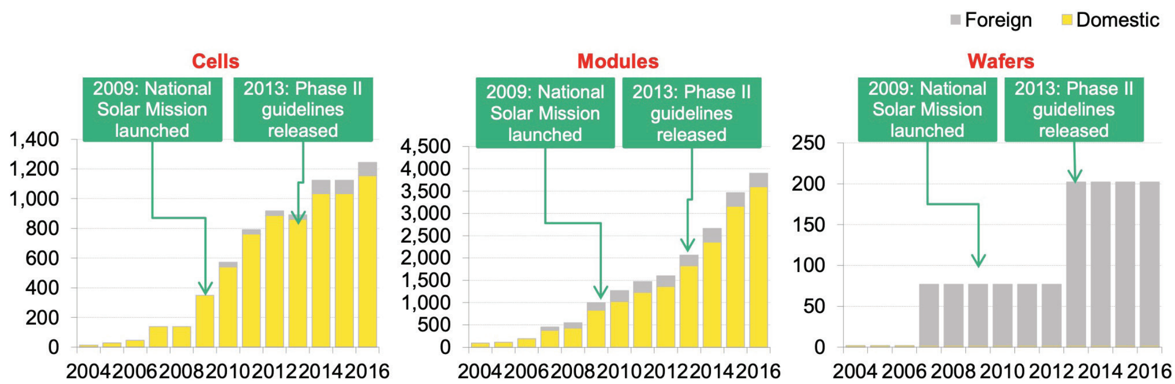
When the auctions kicked off, the local content rules in Phase I essentially favored thin-film products as they were exempt from the requirements, tended to be cheaper, and could be procured with low-cost international financing. Thin-film modules offered lower capacity factors than c-Si equipment but were considerably less expensive on a dollar-per-Watt basis. They are also quite suitable to regions with particularly strong sun, including many parts of India.

Arizona-based First Solar, the world's largest manufacturer of thin-film equipment, saw an opportunity in India and leveraged support from the U.S. Export-Import Bank and the U.S. Overseas Private Investment Corporation. The two U.S. credit agencies offered cut-rate loans to Indian developers to buy First Solar equipment for the projects. The interest rate was reportedly three percent and denominated in dollars. By comparison, local banks were offering developers rates as high as 14 percent on loans issued in rupees. In 2010–11, U.S. Ex-Im lent $248m to Indian companies to buy thin-film modules.

India had only a tiny volume of domestic thin-film module manufacturing at the time. Those plants did not enjoy the same economies of scale as the First Solar plants, and developers using that equipment could not access U.S. Ex-Im financing. As a result, half of the installations in Phase I Batch I used thin-film modules. That rose to 59 percent in the following batch. By comparison, the share of thin-film in solar plants developed globally during those years was around 14 percent.

In Phase II, however, the thin-film loophole was closed to better support local manufacturers. Now subject to the same local content rules as other manufacturers, the United States filed a complaint in February 2013, invoking the General Agreement on Tariffs and Trade to press the case that India's domestic content requirements granted Indian manufacturers "certain benefits and advantages, including subsidies through guaranteed, long-term tariffs for electricity, contingent on their purchase and use of solar cells and modules of domestic origin." In February 2016, the WTO sided with the United States, ruling that India's local content requirements under Phase I and II (Batch I) unfairly discriminated against imported cells and modules. India said it would implement the WTO's findings but would not revisit contracts awarded to earlier projects.

Figure 8: India Crystalline-Silicon PV Manufacturing Capacity (MW per annum)



Source: BloombergNEF.

DID THE PROGRAM SUCCEED?

The Mission and accompanying local-content rules spurred growth in India's solar manufacturing; today, the country has a significant presence in the production of finished PV modules and, to a lesser degree, in the manufacturing of PV cells. These represent the last two segments of the PV manufacturing value chain. However, the country still lacks almost any manufacturing capacity in higher-value segments further up the value chain. It has virtually no polysilicon, ingot, or wafer production capacity.

Significantly, empirical analyses suggest the price of solar panels was higher thanks to the local content rules, adding as much as $69–88 million per installed GW of solar PV[2]. Potential benefits included an increase in Indian solar PV innovation—as measured in patent applications—and a steady decline in the price of locally manufactured PV modules. Any damage to the U.S.-India relationship thanks to the WTO complaint is harder to quantify.

While India has made some progress expanding its supply chain for PV modules, the country was a net importer of $160 million of equipment during 1H 2020, with China accounting for 78 percent of the $220 million in imports. The Indian government has voiced concern that local projects remain reliant on foreign equipment and has come to aid local manufacturers through manufacturing linked solar

2 B Probst et al., "The short-term costs of local content requirements in the Indian solar auctions," *Nat Energy* 5 (2020): 842–850, https://doi.org/10.1038/s41560-020-0677-7.

tenders and government procurement rules that may offer preferential treatment to projects that use local equipment.

Figure 9: India 1H 2020 Imports by Supplier Country

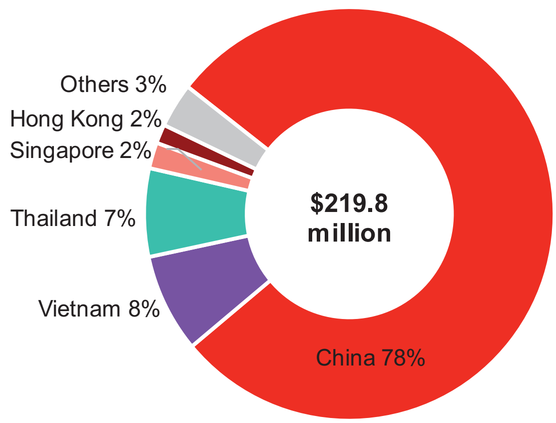
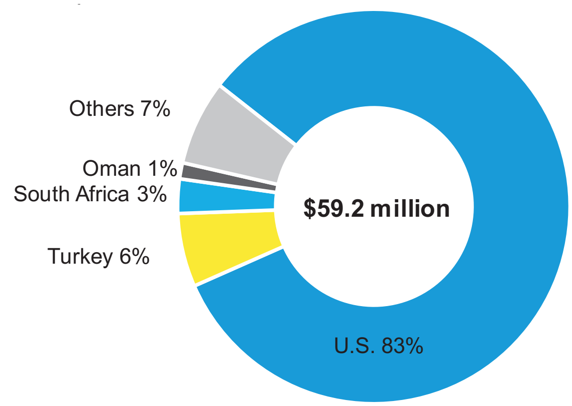


Figure 10: India 1H 2020 Exports by Destination Country



Note: Data includes both modules and cells imported and exported from January to June 2020 under HS Code 85414011.
Source: BloombergNEF, Long-term Electric Vehicle Outlook.

In mid-2018, the Indian government changed course and put in place a "safeguard duty," set initially at 25 percent on imported cells and modules, with an eye toward making local manufacturing more competitive. The explicit target was on countries the Indian government deemed to be "developed," a category which included China and Malaysia.

The safeguard duty provided only limited protection to Indian manufacturers for several reasons. First, projects that signed contracts under tenders held pre-2018 were able to pass through the tariff cost to their original offtaker and thus maintained the contracts they had signed with foreign equipment suppliers. Second, some projects simply turned to Vietnam and Thailand for equipment since both nations were exempt from the tariff. Third, and perhaps most importantly, the tariffs were largely offset by the continuing rapid decline in equipment prices overall. The decline allowed Chinese equipment to be cost-competitive, even after taking the tariff into account. In addition, Indian manufacturers complained that because the tariff was of limited duration and scheduled to expire after just two years, it did not prompt developers to fundamentally reconsider their relationships with existing overseas suppliers fundamentally.

The safeguard tariff duty expired at the end of July 2020 as scheduled. In response to local manufacturers, the government moved to extend it an additional year and added Thailand and Vietnam to the list of countries subject to the tariffs. However, the tariff is set at 14.9 percent through July 2021, well below what domestic manufacturers would like.

The government is now contemplating additional steps that may help support domestic production. One possible move would be to impose a "basic customs duty" that would impose higher tariffs on a longer-term basis. Indian manufacturers are petitioning for the new tariff to be set at 50 percent while developers, understandably, are staunchly opposed. The government is also contemplating more direct support for manufacturers, potentially in the form of cut-rate loans that would allow equipment makers to scale production and move up the value chain at a lower cost.

With the Indian market poised for further growth yet still far from achieving the Modi government's target of 100 GW PV installed, further policy action seems likely as the original goals of India's Solar Mission have yet to be fully achieved. In fact, Delhi may raise its sights even higher; there is now discussion that the government will up India's 2030 solar target to 280GW by 2030, though this has not yet been announced.

Case Study in Industrial Policy: Germany's 2004 Renewable Energy Law

Germany's 2004 Renewable Energy Law (Erneuerbare Energien Gesetz, or EEG) is the single most important piece of legislation supporting solar development implemented in the last two decades. It established an ambitious program, which sparked the creation of the world's first major market for ground-mounted PV projects and kicked off a global boom in PV equipment manufacturing, briefly in Germany and then longer term in China.

PROGRAM DESIGN, IMPLEMENTATION AND IMPACT

Germany offered a fixed FiT of at least 457 euros per MWh for 20 years to all solar power plants, roughly three times the average price of electricity for consumers at the time. The German development bank KfW also extended relatively low-interest loans to households and businesses through local banks, easing financing for these projects. The FiTs were funded through surcharges on German power bills (this surcharge covers the spread between the FiT and the spot power price, so if the spot power price rises, the surcharge falls). The goal was to boost installed capacity from 440 MW in 2003 to 52,000 MW in 2020, helping to meet the country's goal to generate 39 percent of its electricity from renewable energy sources by 2020. At the time, solar installed capacity stood at 2,970 MW globally, so the German target was very ambitious.

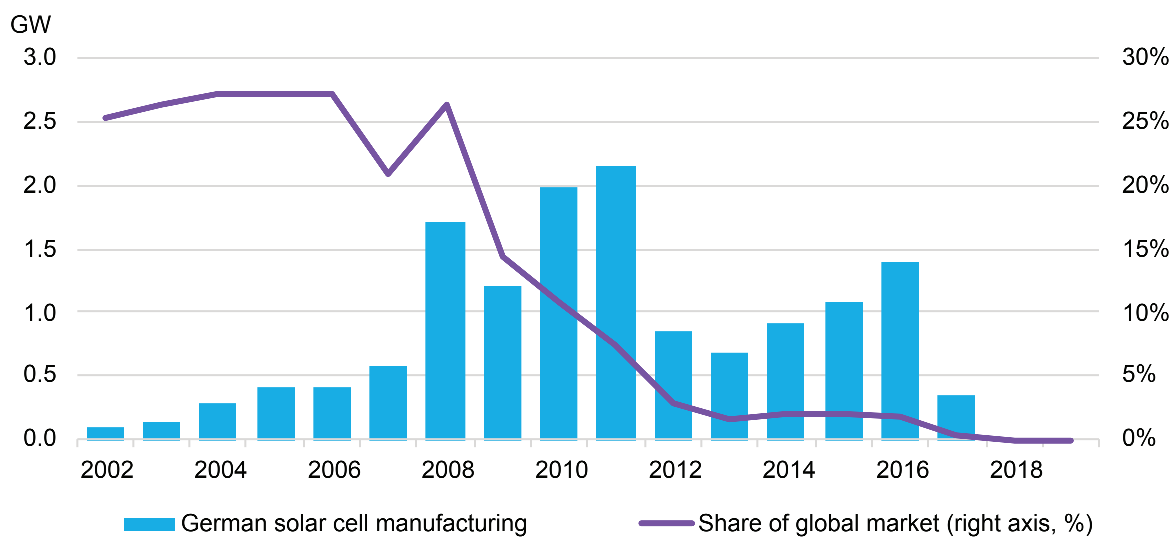
The FiTs supercharged the country's solar development. Germany accounted for nearly two-thirds of global PV module demand in 2004 and 2005. During this period, the only restraint on even faster growth was a global shortage of processed polysilicon and a dearth of factories to produce it (polysilicon prices spiked to over $400/kg in 2005 from approximately $25/kg in 2000–2004). Under the law, solar FiTs were to be reviewed annually and reduced by no more than 10 percent. However, as volumes installed grew far faster than anticipated, the government scrambled to adjust. From April 2012, Germany began ratcheting the tariffs down monthly by using installation rates over the trailing six months as a guide. In 2017, it decided to cut the costs of new capacity further by holding auctions to build new solar and wind capacity and removing feed-in tariffs for solar systems bigger than 750 kW on roofs or 100 kW on the ground. These auctions have been a success, attracting competition and allowing larger projects to be built at prices below the former feed-in tariffs.

The policy contained no provisions to grow German equipment production. The German government generally supports free trade and did not set barriers on foreign firms entering the German market. There was hope, however, that growing domestic demand would foster local manufacturing. The country was home to companies with technological expertise in PV, such as Schmid GmbH, which made the manufacturing equipment to produce solar panels, and PV equipment makers Solarworld, Solar Fabrik, Conergy, Aleo Solar, and Q-Cells.

German solar cell and module manufacturers supplied over 25 percent of the global market in 2004, with Japanese manufacturers dominating the rest. As local and global demand grew, German firms scaled up, but Chinese solar companies like Suntech and Trina Solar expanded faster, gaining market share. In the early years of the boom, German firms thrived because they had secured polysilicon feedstock under long-term contracts with manufacturers at attractive prices. Chinese firms, by contrast, were limited in their ability to source polysilicon. The situation was not sustainable, however, as new polysilicon factories were ramping up worldwide and prices for the key commodity would soon plummet.

In April 2012, German giant Q-Cells went bankrupt for the first time, partly because it had secured polysilicon at long-term contracted prices above $50/kg, which had seemed competitive in 2004–2008 but was by then well above market rates. In 2012, Q-Cells was competing with Chinese competitors who not only had newer factories with more modern (often German-made) machines and cheaper labor but were also paying the spot price for polysilicon, which was below $30/kg.

Figure 11: Germany's Solar Cell Production



Note: Some appointments and estimates have been made by BloombergNEF as there is no single consistent data source over this period.
Source: BloombergNEF, European Commission PV Status Report using PV News data.

In the third quarter of 2012, a group of European solar cell and module manufacturers called EU ProSun brought anti-dumping (AD) and anti-subsidy (AS) complaints to the European Commission, which can set compensating measures across the European Union. The Commission initiated investigations into anti-dumping and anti-subsidy complaints in September and November 2012, respectively. European installers and project developers—representing a strong majority of European solar jobs—set up an opposing lobbying group called the Alliance for Affordable Solar Energy (AFASE). The German government is also understood to have taken a position against the imposition of anti-dumping and anti-subsidy tariffs, but on such matters is bound by the judgment of the European Commission.

Starting in March 2013, Chinese products (including modules assembled in a third country using Chinese cells or wafers) had to be registered upon import to the European Union, raising the possibility that duties would apply retroactively. In June 2013, provisional tariffs were published in response to the anti-dumping (AD) investigation. The initial level of 11.8 percent for the first two months was significantly lower than had been anticipated, but the average duty then rose 47.6 percent, with a range of 37.2 percent to 67.9 percent depending on the individual company.

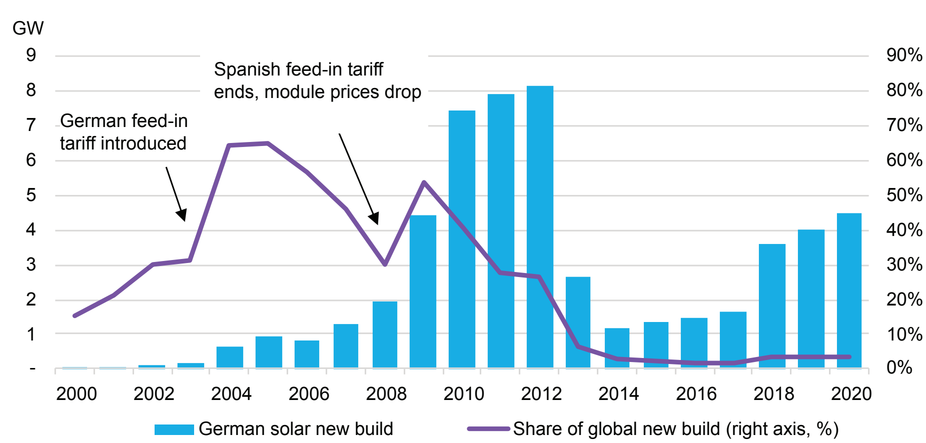
In July 2013, the Commission announced that it had reached a settlement (or "undertaking") with China, whereby no import tariffs would be applied to the first 7 GW of Chinese module entering the European Union at a minimum price of 56 euro-cents ($0.74) per Watt—roughly the spot price at the time—for two and a half years. The minimum price was adjusted regularly based on BloombergNEF's monthly price survey.

A result of the negotiated undertaking on cells and modules was that German polysilicon maker Wacker obtained a similar settlement when China retaliated with import duties on polysilicon in late 2012. Consequently, Wacker has done better than its U.S. peers REC Silicon and Hemlock Semiconductor, which have suffered badly from Chinese retaliatory tariffs on U.S. polysilicon after the United States set import tariffs on Chinese modules.

In March 2017, duties were extended an additional 18 months. However, SolarWorld's German subsidiaries filed for insolvency in May 2017. They were then re-bought in August 2017 by SolarWorld founder Frank Asbeck and Qatar Solar Technologies, a new investment firm. The new SolarWorld Industries GmbH filed for insolvency again in March 2018. Several other EU ProSun's 30 manufacturers have since been identified. These small and obscure players have not continued the legal fight.

In August 2018, the European Commission decided not to extend tariffs on Chinese PV products on the basis that companies were no longer lobbying for them. In September 2018, the tariffs expired. As of November 2020, Germany still has a few small module manufacturers, such as Heckert Solar and Sonnenstrom Fabrik. These firms mainly use Chinese cells to make bespoke module designs and custom modules as replacements for older models in established solar projects. However, the country is no longer a major global supplier of PV cells or modules.

Figure 12: Build of New PV Power-Generating Capacity in Germany



Note: Data includes both modules and cells imported and exported from January to June 2020 under HS Code 85414011.
Source: BloombergNEF, Long-term Electric Vehicle Outlook.

DID THE PROGRAM SUCCEED?

Germany has exceeded the goal it set for itself in 2004 for installed solar capacity and renewables generation in 2020. The EEG achieved its stated goals, and the German government appears to regard it as a success, and a key steppingstone in the "Energiewende" or energy turnaround, with which Germany aims to prove that major economies can run on renewable energy.

Germany is also home to industry-leading engineering, procurement, and construction contractors such as juwi GmbH and Enerparc AG, which win business regularly outside Germany. While the country's residents pay some of the highest power prices in Europe thanks to the costs associated with the feed-in tariffs, there is no debating that Germany's Renewable Energy Law did spur a major scale-up in installed capacity.

On the manufacturing side of the equation, the story is murkier. At the top of the PV value chain, German polysilicon producer Wacker-Chemie (Frankfurt:WCH) benefited greatly from Germany's generous feed-in tariffs and the ensuing explosion of global PV demand. Similarly, SMA Solar Technologie (Frankfurt: SMA), which makes inverters that enable PV systems, has fared well. Both firms remain major international suppliers.

However, Germany's once-thriving PV wafer, cell, and module manufacturers are now largely gone. All have been outcompeted and driven into bankruptcy by the rapid cost reductions achieved by foreign firms. As of year-end 2019, the solar and storage industry employed about 26,400 people in Germany, versus 60,000 in 2008.[3] Most solar jobs continue to be in the installation, project development, and design segments of the industry.

3 Based on data from EuPD Research. EUPD Research, "50,000 new jobs through photovoltaics and storage technology," press release, May 12, 2019, https://www.solarwirtschaft.de/en/2019/12/05/50000-new-jobs-through-photovoltaics-and-storage-technology/.

5

Conclusions

The brief history of clean energy trade frictions in this report offers a rudimentary lesson on smart clean energy trade policymaking. When seeking to seed, grow, or protect a domestic clean energy manufacturing sector, it is critical to consider policies that both spur demand for clean energy goods *and* lower their cost of production.

"Demand-side" policies were critical to kicking off the era of industrial clean energy growth in the 2000s. Well into the 2010s, such policies successfully boosted sales of clean energy products, whether for PV systems in Japan, or EVs in the U.S. state of Georgia, thanks to a $5,000-per-vehicle EV tax credit offered on top of a $7,500 federal credit. Time and again, where generous demand-side policies have been implemented, consumers have responded, and demand has flourished.

The influence of supply-side policies is considerably more difficult to pinpoint. Efforts such as domestic-content rules, tax credits to incentivize manufacturers to build plants in certain locations, or the provision of below market-rate loans for manufacturers have all yielded mixed results. Brazil instituted a domestic-content requirement to access debt from its state-backed development bank BNDES and successfully developed a local wind turbine manufacturing supply chain, for instance. India instituted a similar rule for solar manufacturing but has struggled to keep PV imports at bay.

In the United States, the federal government sought to offset the cost of building new manufacturing plants to produce clean energy equipment by offering a 30 percent Capex-based tax credit under the 2009 American Recovery and Reinvestment Act (ARRA) but fell well short of its manufacturing capacity build-out goals as manufacturers lacked confidence in local market demand. In China, by contrast, the China Development Bank helped bankroll spectacular growth in PV manufacturing capacity.

Given its general success to date, China can potentially offer important lessons for other nations about how to cultivate a clean energy economy then grow it to massive scale. From the outset, policymakers there provided strong signals that they were committed to these industries. These were manifested in both substantial demand- and supply-side policies offered simultaneously. Both consumers and suppliers recognized these signals and reacted accordingly.

Is this a model other nations can emulate? Perhaps, but only to a degree. Because of China's sheer size, manufacturers there had confidence they would have a massive market to serve at home before launching serious attempts to export. With the massive backing of both state and private funds, manufacturers had the wherewithal to make long-term, multi-billion-dollar investments in some of the largest plants the world has ever known. Such sums of capital only get deployed when funders have full confidence that policy commitments are serious, long-term, and durable. Unlike fluid democracies, the Chinese system of governance tends to instill confidence that promises made publicly and loudly by leaders tend to be promises kept.

It should be noted that China's industrial strategy of supporting both the demand and supply of clean energy has hardly been an unqualified win for all manufacturers or their financial backers. The country's "flood the zone" strategy contributed to periods of major over-capacity in equipment manufacturing. The government's inevitable response was to cull the herd, allowing some number of former high-flyers to go broke. Billions of dollars in value were destroyed in the process.

Furthermore, the inefficiency of China's approach to cultivating an industry would generate substantial opprobrium to the point of impracticality in the Western democratic context. In the United States, for instance, a single, poorly timed federal investment into Solyndra under the Obama administration's ARRA generated months of negative headlines after that California-based PV equipment maker went bust. A decade later, Solyndra is still invoked as an example of government decision-making run amuck. (Never mind that the same government effort to back clean energy underwrote the growth of Tesla, which today one of the world's most valuable companies employing over 48,000 workers.) Nonetheless, as discussed, China's strategy did ultimately create an industry that as a whole is succeeding globally today.

The three case studies in this report illustrate the benefits and shortcomings of countries' efforts to use policies, including trade measures, to grow their domestic clean energy markets and manufacturing capability. India relied predominantly on aggressive national build targets to expand domestic solar power-generating capacity, but it achieved less success in ensuring domestic manufacturers supplied the equipment installed locally. Its history suggests ongoing efforts to restrict imports of Chinese and other foreign-made solar PV panels might have to be structured differently if they are to succeed. Germany has shown its willingness to alter its support for renewable energy deployment as the market matures and, thus far, to focus on areas of the global supply chain where its has a supportable comparative advantage. China, however, stands in stark contrast to other countries for the sheer size and comprehensive nature of its support for clean energy technologies and persistence in moving up the supply chain to both fulfill domestic demand and build a globally competitive industry.

About the Authors

Sarah Ladislaw is senior vice president and director and senior fellow of the Energy Security and Climate Change Program, where she leads CSIS's work in energy policy, geopolitics, and technology analysis. She is an expert in U.S. energy policy, global energy trends, and climate change. Ladislaw has spearheaded new work at CSIS on climate change and foreign policy, deep decarbonization, and just transitions. She has authored numerous publications on the geopolitics of energy, energy security and climate change, and the energy transition. Ladislaw formerly worked in the Office of the Americas in the Department of Energy's Office of Policy and International Affairs, where she covered a range of economic, political, and energy issues in the Western Hemisphere. While at the Department, she also worked on comparative investment frameworks and trade issues as well as biofuels development and use both in the Western Hemisphere and around the world. In addition, she spent a short period of time working Statoil as its senior director for international affairs in the Washington office.

Ladislaw is a member of the National Renewable Energy Laboratory's Strategic Analysis Technical Review Panel, the Strategic Advisory Council for Georgia Tech's Strategic Energy Initiative, and the University of California, Davis Institute of Transportation Studies Board of Advisors. She has taught graduate courses on energy security as an adjunct professor at the George Washington University and is a frequent guest lecturer at other universities. She also testifies before Congress and comments frequently in print, radio, and television media outlets. Ladislaw received her bachelor's degree in international affairs/East Asian studies and Japanese from the George Washington University and her master's degree in international affairs/international security from the George Washington University as part of the Presidential Administrative Fellows Program.

Ethan Zindler is a senior associate (non-resident) with the CSIS Energy Security and Climate Change Program. Ethan is head of Americas at Bloomberg NEF, a provider of insight, data and news on clean energy, advanced transport, commodities, and emerging technologies. In that capacity, Zindler manages the company's analyst and commercial teams in New York, Washington, San Francisco, and Sao Paulo. Ethan also oversees Climatescope, a project to profile clean energy investment conditions in emerging market countries underwritten by the UK and U.S. governments. Zindler serves as BNEF's primary spokesperson in North America, has been quoted widely in the media, and testified before two U.S. Senate committees and elsewhere. Previously, Zindler oversaw BNEF's coverage of clean energy policy developments globally and served as BNEF's head of North American research. Zindler's prior experience includes stints at the White House, MTV, and as a freelance journalist covering two World Cup soccer tournaments.

Nikos Tsafos is a deputy director and senior fellow with the CSIS Energy Security and Climate Change Program. His research interests include natural gas, the geopolitics of energy, the future of mobility, and the energy transition more broadly, especially the interplay between energy consumption, economic growth, and greenhouse gas emissions. Nikos has advised companies and governments in over 30 countries on some of the world's most complex energy projects, and his experience includes market analysis, strategy formulation, due diligence, and support for commercial negotiations and project development.

Nikos led PFC Energy's (now IHS Markit) global gas consulting practice and was responsible for the firm's research agenda on global gas. He then spent 3.5 years as a commercial adviser to the Alaska State Legislature, focused largely on the $43 billion Alaska liquefied natural gas project. He was also an adjunct lecturer for four years at the Johns Hopkins School of Advanced International Studies (SAIS), where he taught a graduate-level course on natural gas. Nikos has published extensively on natural gas, and on energy and economics more broadly. He is the author of *Beyond Debt: The Greek Crisis in Context* (2013); numerous articles in publications like *Foreign Affairs*, the *National Interest*, EURACTIV, the *Australian Financial Review*, and others; research reports and commentaries for CSIS, the German Marshall Fund of the United States, and the National Bureau of Asian Research. His views appear frequently in print media, including the Financial Times, the New York Times, Axios, Bloomberg, and elsewhere. Nikos is passionate about data analysis and visualization—and is forever honing his skills in R, Python, D3.js, HTML, CSS, and JavaScript. He holds a BA in international relations and economics, with a minor in statistics, from Boston University, and an MA in international relations from Johns Hopkins SAIS.

Logan Goldie-Scot is global head of Clean Power research at BloombergNEF. He oversees BNEF's solar, wind, storage, and decentralized energy research divisions. Prior to this, he was manager of the Energy Storage insight team at BloombergNEF. He also runs BNEF's Supply Chain focus area, a cross-company effort to provide insights on supply chain resilience, regionalization, trade, manufacturing and sustainability.

He advises utilities, technology companies, investors and policymakers across these fields. He has authored numerous research papers and regularly speaks at international conferences and in the mainstream media.

Lachlan Carey is an associate fellow with the CSIS Energy Security and Climate Change Program. His research interests include the geopolitics of energy, climate change policy, and international trade. Mr. Carey was previously a consultant with the World Economic Forum and before that worked in the Australian Treasury Department in Canberra. He holds a master's in public affairs from the

Woodrow Wilson School at Princeton University and a Bachelor of Commerce (liberal studies) from Sydney University.

Pol Lezcano is a solar analyst at BloombergNEF, where he covers the U.S. distributed solar market and solar value chains. He advises utilities, energy companies and investors on the U.S. market prospects for small-scale solar. Pol also looks at the solar supply chain and manufacturing to provide insights on trade, risks and technology bankability.

He has authored and co-authored research papers on U.S. solar and storage, corporate sustainability, hydrogen, PV module pricing and U.S. solar supply chains. Prior to his role at BloombergNEF, Pol worked as an investment analyst financing commercial solar projects in the United States and early-stage clean technologies.

Jane Nakano is a senior fellow with the CSIS Energy Security and Climate Change. Her research interests include U.S. energy policy; global market and policy developments concerning natural gas, nuclear energy, and critical minerals; and energy security and climate issues in the Asia-Pacific region. She frequently writes and speaks on these issues at domestic and international conferences and to media around the world. She has also testified before Congress on U.S. liquefied natural gas (LNG) exports and before the U.S.-China Economic and Security Review Commission on U.S.-China nuclear energy cooperation. Prior to joining CSIS in 2010, Nakano worked in the Office of Policy and International Affairs in the U.S. Department of Energy, where she covered a host of energy, economic, and political issues in Asia. From 2001 to 2002, she served at the U.S. embassy in Tokyo as special assistant to the energy attaché. Nakano graduated from Georgetown University's School of Foreign Service and holds a master's degree from Columbia University's School of International and Public Affairs.

Jenny Chase is the manager of BloombergNEF's global Solar Insight Service. She joined BNEF mid-2005 and launched the Solar Insight Service in early 2006, and now runs the team from Bloomberg's Zurich office.

The team conducts regular and rigorous surveys across the PV value chain, detailed and timely analysis of policy and its implications for the solar sector, and extensive technology and economic analysis of PV and solar thermal electricity generation. Jenny is the author of BNEF's quarterly PV Market Outlook, which draws together updates and output of proprietary models to give a detailed account of demand, supply, price, margins, and investment activity in the PV industry.

Jenny is the author of a book, Solar Power Finance Without the Jargon, published by World Scientific Publishing in 2019. She holds a BA in physical sciences and an MSci in physics from the University of Cambridge, England, and breeds award-winning West of England geese. She is on Twitter as @solar_chase.

COVER PHOTO LOU BENOIST/AFP/GETTY IMAGES

CSIS | CENTER FOR STRATEGIC & INTERNATIONAL STUDIES

1616 Rhode Island Avenue NW
Washington, DC 20036
202 887 0200 | **www.csis.org**

BloombergNEF

731 Lexington Avenue
New York, NY 10022
www.bnef.com