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SINS OF A SOLAR EMPIRE

AN INDUSTRY IMPERATIVE TO ADDRESS UNETHICAL SOLAR PHOTOVOLTAIC MANUFACTURING IN XINJIANG

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EXECUTIVE SUMMARY

Over the past decade, much of the global silicon-based solar photovoltaic industry has slipped slowly into the path of a major human rights crisis. International actors have generally overlooked early warning signs of Chinese government oppression in the Xinjiang Uyghur Autonomous Region (XUAR; 新疆维吾尔自治区) while concentrating investment and business partnerships into solar manufacturing supply chains linked to the region. Now, extensive evidence of government-organized forced labor programs and numerous other crimes against humanity in the XUAR has come to light,[1,2] yet downstream solar photovoltaic companies remain hesitant to quickly and fully distance themselves from low-cost suppliers with operations in the region.

In addition to major advantages such as its modularity and near-zero variable and operating costs, much of the promise of clean solar energy stems from its affordability. The future of solar photovoltaic (PV) power looks bright precisely because it has attained stunning cost improvements over a relatively short period of time. To be clear, the lion's share of this progress has occurred thanks to legitimate technological advances and innovation in manufacturing. Chinese firms invested heavily in large, modern factories that have achieved high efficiencies of scale, aided by substantial regional then national government support in the form of direct subsidies, cheap land, and subsidized, affordable electricity.

But solar manufacturing plants that began operating in Xinjiang over a decade ago were attracted to industrial parks and coal mines established under regional political oppression that left Uyghur, Kazakh, and Kyrgyz peoples uniquely powerless—even by the political standards of authoritarian China—to object to local environmental and socioeconomic impacts. And in subsequent years, as regional authorities have intensified repressive policies targeting minoritized peoples, solar PV manufacturers have continued to expand in the region while directly participating in state-sponsored forced labor programs.

The Xinjiang region produces a significant quantity of some solar PV commodities, particularly solar-grade polysilicon. As such, the availability and price of solar PV products are currently quite sensitive to the region's manufacturing output, elevating the risk that efforts to truly divest the solar industry from dependence on Xinjiang could disrupt solar supply chains, at least until new, ethical production capacity is established elsewhere.

However, tackling this hurdle head-on is exactly the right choice for promoting a better, more innovative, and more socially responsible future for solar PV technology. An ethical and sustainable solar supply chain clearly cannot continue over the long term to rely upon current Xinjiang-dependent, coal-dependent manufacturing norms. Nor is this choice entirely up to solar industry actors alone. With the Uyghur Forced Labor Prevention Act having entered into effect in the United States[3] and with the European Union considering similar policies to prohibit imports produced using forced labor,[4] a failure to transition away from problematic solar equipment suppliers could hamper the industry's development. Having underprepared for addressing supply chain concerns over much of the past decade, solar PV companies, renewable energy developers, and investors would be well advised to rectify that error starting today.

Downstream manufacturers, solar installers, and project developers should move aggressively and unambiguously to avoid solar PV suppliers with any industrial capacity in Xinjiang. Companies that source solar PV commodities from firms with Xinjiang operations should face broad pressure to adopt similar measures—or face market exclusion as well. Upstream investors, suppliers, and researchers should likewise move to terminate business relationships with Xinjiang-based manufacturers. To accelerate and facilitate this process of supply chain diversification and support the important solar PV sector, policymakers globally must enact major public sector initiatives to help establish new large-scale manufacturing capacity outside of China.

This shift requires a more stringent standard than current ethical sourcing guidelines,[5] which have sought only to trace and exclude specific shipments of goods produced in the Xinjiang region.[6] Tracing allows companies operating factories in Xinjiang to sell sanitized streams of "Xinjiang-free" solar PV products on global markets while continuing to benefit separately from Xinjiang-based production. Furthermore, such tracing and certification protocols will likely prove ineffective due to lack of corporate and government transparency in China including in Xinjiang.

But what if supply chain reorganization threatens solar power's forward march and the speed of the global clean energy transition at large? This report explains how the current affordability of solar PV modules has historically resulted from technological advances, public-private investment, and industrial policy that can be replicated elsewhere. It is likely that enterprising companies with government support can establish new manufacturing pipelines outside of China at comparably low costs.

The door nevertheless remains open for Chinese firms and policymakers to address crimes against humanity in Xinjiang and assist in responsible solar PV sourcing by ending forced labor programs, restoring freedoms to persecuted minoritized groups, and adopting fair labor and environmental standards, among other necessary remedies and actions.

Responsible diversification of global solar PV manufacturing will benefit both the solar PV industry and the climate. Avoiding the reputational costs associated with companies operating in Xinjiang may well be worth a marginal and likely transient increase in the price of solar PV products. At the same time, alleviating the current overconcentration of the solar industry in China can help ensure a more stable and reliable supply of solar PV commodities, mitigating long-term risks to the solar industry in the event of supply chain disruptions. Alternative low-carbon solar PV manufacturing methods will also help displace the higher carbon and environmental costs of solar manufacturing inputs produced in Xinjiang, helping the solar PV industry improve its environmental record in a manner consistent with the spirit of long-term climate progress.

Ignoring the challenge at hand will only perpetuate the intertwining of solar supply chains with Chinese government repression, authoritarianism, and environmental injustice. At the same time, procrastination on supply chain reorganizations will suppress and postpone necessary evolutions in solar manufacturing that solar technologies need to truly—and justly—achieve global scale.

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THE CURRENT GLOBAL SOLAR MANUFACTURING LANDSCAPE

It is common knowledge that Chinese manufacturers dominate international solar supply chains and that dependence on Chinese suppliers is currently projected to grow. Suffice it to say that Chinese firms operate the overwhelming majority of manufacturing capacity at each step in the solar manufacturing supply chain, from solar-grade polysilicon feedstock to polysilicon ingots and wafers to solar cells and solar PV modules (Figure 1). The market share of Chinese manufacturers is largest for the production of monocrystalline silicon ingots and the slicing of those ingots into wafers for use in solar cells, with companies in China possessing essentially all existing industrial capacity (>95%) for these processes globally.[7] These companies also possess significant advantages in expertise and technology, utilizing some of the world's most cutting-edge equipment for solar cell manufacturing.

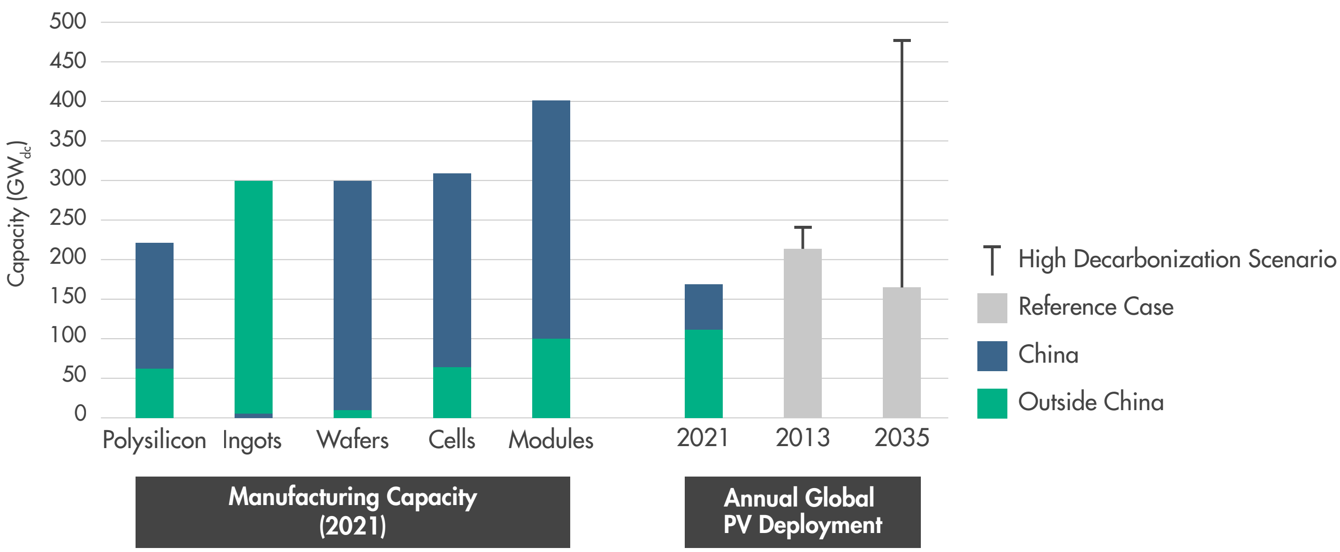


***Figure 1:** Current global solar PV manufacturing capacity inside and outside of China at major steps of the solar PV supply chain, relative to new installed solar capacity in 2021 and projected demand in future years. Figure originally published in* Solar Photovoltaics: Supply Chain Deep Dive Assessment*, a U.S. Department of Energy report.*[8]

At the key initial upstream steps in the current solar supply chain, manufacturing capacity has become highly concentrated in the Xinjiang region. In particular, the XUAR contains signifi-cant quartzite rock mining, metallurgical-grade silicon smelting, and solar-grade polysilicon production. This latter step—solar-grade polysilicon manufacturing—is the solar supply chain's most significant exposure to the Xinjiang region, with Chinese production based in Xinjiang operating a full 42% of global solar-grade polysilicon factory capacity in 2021.[9]

Chinese firms also dominate the subsequent steps in solar manufacturing: monocrystalline silicon ingot production, silicon wafer slicing, solar PV cell production, and solar PV module assembly (Figure 2). The Chinese solar sector's Xinjiang operations are much less extensive at these later steps of the supply chain, with a single known ingot and wafer factory owned by JinkoSolar Holdings Company (晶科能源控股有限公司) operating in the region.[10] Thus, the large majority of this production occurs in other provinces. For instance, over half (~180 GW) of Chinese ingot and wafer manufacturing capacity is located in Jiangsu, Yunnan, and Inner Mongolia,[11] compared with <4 GW capacity at JinkoSolar's Xinjiang facility.[12] Nevertheless, due to the large fraction of upstream solar manufacturing that takes place in the XUAR, many downstream operations are significantly exposed to Xinjiang production through their suppliers.

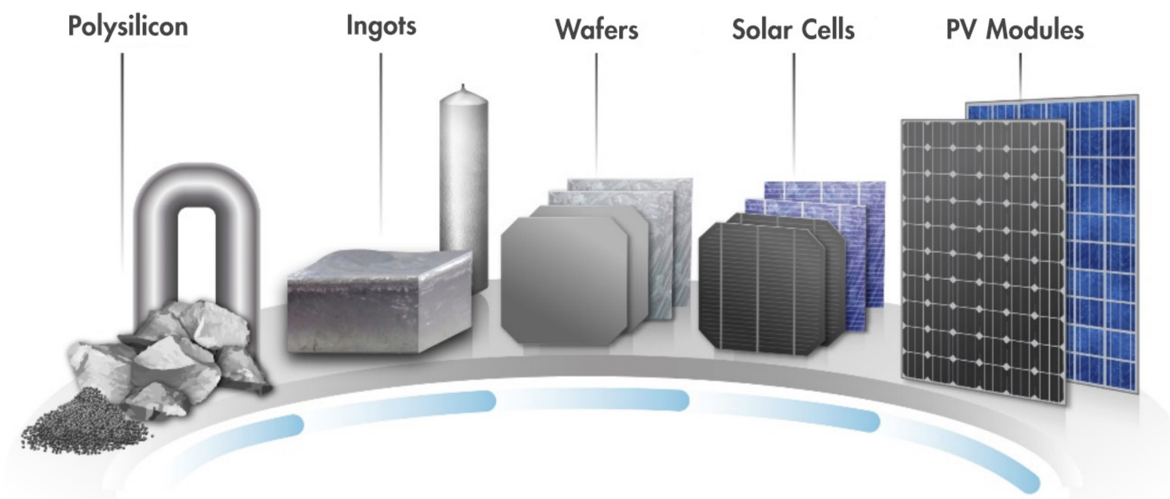


Figure 2: *The major steps in the modern manufacturing process for silicon-based solar photovoltaic modules. Figure originally published in* Crystalline Silicon Photovoltaic Module Manufacturing Costs and Sustainable Pricing*, an NREL report.*[13]

In addition to the solar manufacturing industry's high degree of geographic concentration in China, solar manufacturing is also highly concentrated in terms of manufacturing infrastructure, with individual large factories often representing a sizeable fraction of global production. This concentration of production in a few large-scale facilities is most evident in early steps of the solar supply chain such as solar-grade polysilicon. A recent special report from the International Energy Agency warned about the potential risks posed by such infrastructure overconcentration: "one out of every seven panels produced worldwide is manufactured by a single facility. This level of concentration in any global supply chain would represent a considerable vulnerability; solar PV is no exception."[14]

Overall, prospects for solar electricity today and in the foreseeable future—and the fate of much of current climate mitigation efforts—are currently sensitive to trends, policies, and events affecting the Chinese solar PV manufacturing industry.

Links to oppression in Xinjiang

At the same time, strong and intensifying human rights and environmental justice concerns associated with repressive Chinese government policies in Xinjiang carry significant ethical implications for solar industry activities in the region.

As discussed in this report, there is evidence that solar PV manufacturing companies and upstream raw material suppliers with operations in Xinjiang are complicit in the Chinese Communist Party's wider systematic campaign of oppression against Uyghurs, Kazakhs, Kyrgyz, and other minoritized peoples in the Xinjiang region. International corporations and investors outside China arguably share much of the blame for this crisis, having tacitly prioritized reductions in manufacturing costs at the expense of adequate moral accountability in light of increasingly alarming reporting from Xinjiang.

In 2014, under President Xi Jinping's administration, the ruling Chinese Communist Party commenced implementation of the "Strike Hard" campaign in the XUAR with the ostensible goal of curbing religious extremism throughout the Xinjiang region.[15] Under this campaign, Chinese authorities have dramatically intensified targeted persecution of Uyghurs and other Turkic Muslim peoples, seeking to suppress traditional cultural and religious expression while forcing minoritized peoples into alignment with the government's political and ideological agenda for the region.[16] Targeted Muslim groups have lost much of their freedom to travel within and outside China[17] and now live under intense, sweeping surveillance.[18] Meanwhile, the Chinese government has arbitrarily detained or imprisoned a shockingly high proportion of the XUAR's Uyghur population within a vast, brutal prison camp system. Detainees are often held or imprisoned for years for arbitrary reasons including minor expressions of religious faith,[19] experiencing physical and mental torture while living under abjectly inhumane conditions in detention or prison facilities.[20] Leaked government documents reveal standing orders that armed guards should shoot to kill if detainees attempt to escape.[21]

Within this broader landscape of intense oppression throughout Xinjiang, a major human rights issue associated with solar manufacturing is exposure to forced labor through state-sponsored labor transfer programs.[22] Numerous international organizations including labor and human rights groups,[23,24] academic researchers,[25] United Nations agencies,[26] and the European Union[27] have raised alarms about how such labor programs exhibit unacceptable patterns of discrimination and coercion. These initiatives enroll citizens from minoritized groups under the implicit threat of arrest and imprisonment[28] and employ them at farms, mines, workshops, and factories,[29] not only throughout the Xinjiang region but across China.[30] Often, laborers are separated from their families and children, relocated many hundreds of kilometers away from their hometowns, and denied the freedom to travel, to see or contact loved ones, or to terminate their work arrangements.[31] Transferred workers receive low, discriminatory pay, sometimes with living expenses deducted,[32] undergo mandatory political indoctrination, and work long hours under potentially hazardous conditions.[33] In many cases, Chinese authorities transfer detainees of the XUAR's prison camp system to labor programs after release as the next stage in their "re-education" process.[34]

Evidence of extensive participation in labor transfer programs throughout the upstream solar supply chain has already been widely and independently documented by researchers and journalists, including but not limited to analysts at Horizon Advisory[35] and S&P Global Market Intelligence,[36] as well as Bloomberg reporters[37] and human rights scholars Adrian Zenz[34] and Nyrola Elimä and Laura Murphy (see Table 1).[38] Forced labor risks are sufficiently serious that the United States has passed legislation to restrict imports of solar PV goods produced in Xinjiang,[39] while the European Union[40] and other countries like Australia[41] are now contemplating similar measures. Solar manufacturing is primarily exposed to forced labor risks at three key points: raw material production, coal mining and power, and solar-grade polysilicon manufacturing.

***Table 1:** Selected evidence of potential links to labor exchange programs by Xinjiang-based companies and entities within or adjacent to the solar PV manufacturing chain. This table is not a comprehensive accounting of companies with Xinjiang-based operations implicated in labor transfer initiatives or of the open-source documentation catalogued to date. Readers should refer to the* In Broad Daylight *report by Murphy and Elimä for more extensive records.*

Company	Key solar supply chain product(s) or supplied input(s)	Open-source evidence of links to state labor transfer programs with forced labor risks
GCL Technology Holdings Limited	Solar-grade polysilicon	Transferred laborers, as part of a larger transfer of 1,800 workers from Hotan, shown and described as participating in military-style training at GCL Tech.[42] A People's Daily article from 2018 mentions a transfer of 60 laborers from the region's south to GCL Tech.[43]
TBEA Co. & Xinte Energy Company (subsidiary)	Solar-grade polysilicon	TBEA CEO Zhang Xin delivered a speech before the National People's Congress detailing TBEA Co.'s collaborations with local government in supporting regional labor transfer initiatives.[44] TBEA Co.'s Tianchi Energy power station named as one of four recipients of a transfer of 139 workers.[45]
Daqo New Energy Corporation	Solar-grade polysilicon	Xinjiang Daqo's 2020 IPO prospectus alluded to potentially receiving subsidies for labor placement programs.[46] Daqo representatives have claimed in response that the company does not actually participate in labor transfer initiatives.[47] Direct raw material supply contracts with Xinjiang Western Hoshine Silicon Industry Co., Ltd, confirmed by written correspondence with Daqo.[48]
East Hope Group	Solar-grade polysilicon, aluminum	Ninety-five workers transferred from Hotan prefecture to nine companies including Xinjiang East Hope.[49] Labor transfer program workers from Hotan and Kashghar prefectures described and shown living in East Hope's southern dormitory complexes.[50]
Zhundong Economic and Technological Development Zone	Coal and coal-fired electricity	Report of 714 workers transferred from Hotan to work in the Zhundong Zone, with a coal power plant owned by TBEA described as accepting workers.[51] Following an investigation of villages aged 18-60, 139 workers transferred to companies in the Zhundong Zone.[52] Twenty-five "ethnic minority surplus laborers" transferred from Wuqia County to the Zhundong Zone.[53]

Company	Key solar supply chain product(s) or supplied input(s)	Open-source evidence of links to state labor transfer programs with forced labor risks
Xinjiang Western Hoshine Silicon Industry Co., Ltd.	Metallurgical-grade silicon, planned investments into solar PV cover glass	Close partnerships with the Turpan local government to specifically train large numbers of laborers for Hoshine.[54] Targeted recruitment of laborers in collaboration with local government of Dikan Township, accompanied by political indoctrination.[55] A 2018 transfer of 59 laborers identified a number of potential target companies, including Hoshine.[56,57]
JinkoSolar Holdings Company	Solar PV wafers, cells, and modules	Xinjiang JinkoSolar received 78 transferred laborers from the Xinyuan County government in early 2020.[58] A Xinyuan County government announcement from mid-2020 describes a subsequent transfer of 40 laborers from southern Xinjiang.[59]

Quartzite stone mining and metals companies in the XUAR utilize forced labor programs,[60] supplying solar-grade polysilicon factories in Xinjiang with metallurgical-grade silicon, the key raw material for solar polysilicon production. A 2021 report by researchers at Sheffield Hallam University found that three of the major solar-grade polysilicon producers with significant XUAR operations—GCL Technology Holdings Limited (协鑫科技控股有限公司; formerly GCL-Poly Energy Holdings Company, 保利协鑫能源控股有限公司), Xinte Energy Company (新特能源公司), and East Hope Group (东方希望)—themselves participate in forced labor exchange programs, while the fourth major producer, Daqo New Energy Corporation (大全新能源股份有限公司), is directly exposed to forced labor through its raw material suppliers.[61] Other materials of concern include quartz for use in solar cover glass and aluminum,[62] a common key input in solar module frames and in metallization employed in solar cell manufacture.[63]

Solar-grade polysilicon producers and other solar manufacturing activities in Xinjiang are additionally exposed to forced labor through the XUAR's coal energy network. Much of the Xinjiang region's coal mining and power generation takes place in vast state-sponsored industrial parks that extensively leverage labor transfer programs, with some solar-grade polysilicon factories located directly within these same industrial zones.[64]

XINJIANG'S ROLE IN CHINA'S SOLAR COMPARATIVE ADVANTAGE

The per-watt cost of a silicon-based solar PV module has plummeted rapidly over the past decade. The majority of this cost decline throughout the 2010s occurred thanks to genuine industry-wide technical progress, including technological standardization and improvements in manufacturing efficiency. Such real improvements are evidenced by how producers outside of China have achieved comparable cost declines over the same period. This is good news, as this history suggests that solar technology will largely remain as cheap as it is today even if the industry transitions away from unethical production in Xinjiang.

Likewise, many of China's cost advantages in solar manufacturing are relatively real. However, state industrial policies such as heavy state subsidies for industrial parks and special electricity discounts for solar manufacturing firms may still intersect with human rights and environmental justice issues, as they impact minoritized peoples in the XUAR who have no voice in the government's land use and environmental decision-making.

At the same time, even as the cost of solar modules has fallen, the relative importance of the cost advantages that unethical practices impart to Chinese firms has grown. This unethical component of the comparative advantages enjoyed by Chinese producers has helped drive international competitors out of solar manufacturing, contributing to current overconcentration of the global solar PV supply chain.

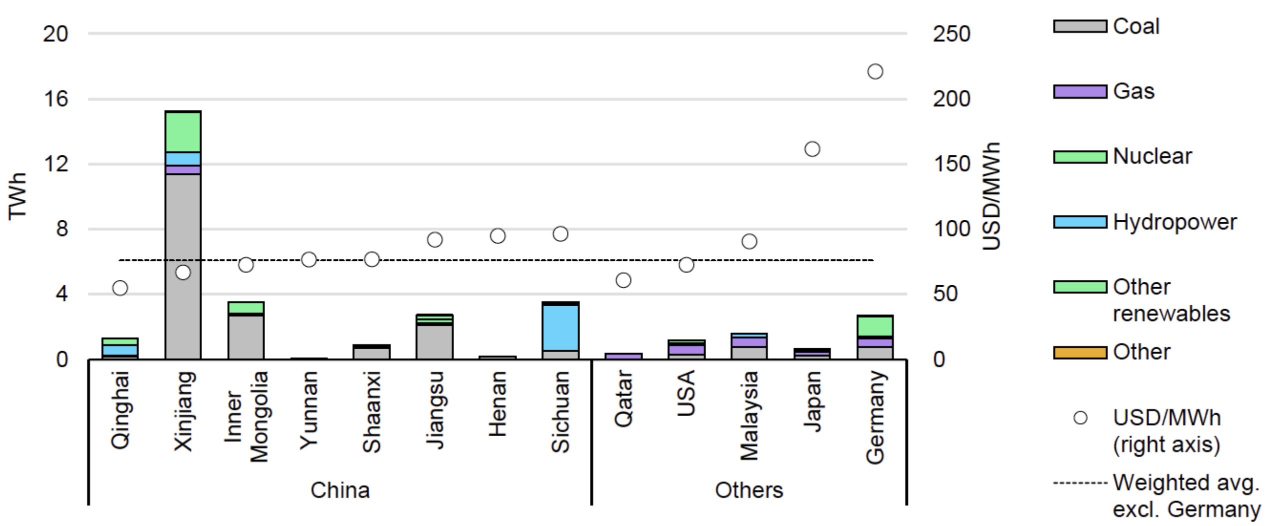
Electricity, energy, and polysilicon production

Cheap electricity is key to the competitive advantage of Xinjiang-based Chinese firms in solar-grade polysilicon production. Electricity represents more than 40% of the cost of manufacturing a unit of solar-grade polysilicon, an important input for a product with narrow profit margins.[65]

In the XUAR, solar-grade polysilicon factories benefit from low-cost coal-fired electricity. Across the province, coal power plants provide 70% of the region's electricity.[66] Xinjiang contains as much as 40% of China's total current coal reserves.[67] A recent IEA report on the solar manufacturing sector assessed electricity prices in the XUAR to be around $70/MWh, almost 30% lower than the global average industrial electricity price (Figure 3).[68] Relative to electricity prices prior to Russia's invasion of Ukraine, the IEA determined Xinjiang's electricity rates were approximately one-third that of rates in Germany, where the German firm Wacker Chemie is one of the only major international solar-grade polysilicon manufacturers outside of China (ranked fourth in production capacity in 2022).[69]

However, the IEA's assessment of XUAR electricity prices of $70/MWh is likely a significant overestimate. Recently published regulated pricing for large industrial customers in the XUAR lists rates that average $48-$58/MWh for time-of-day electricity sales.[70] Most solar-grade polysilicon production and metallurgical-grade silicon production also rely primarily upon dedicated on-site coal-fired power plants that directly serve the industrial facilities, as opposed to electricity purchased from the grid. These may offer functionally cheaper power. Additionally, posted electricity rates may not account for additional targeted direct subsidies.

Polysilicon Electricity Consumption by Region and Electricity Price, 2021



Sources: Electricity prices from IEA (2021g), World Energy Prices (database); BNEF (2022d), Power Prices. IEA.

Figure 3: *International comparison of electricity consumption for solar-grade polysilicon production by type and country (left y-axis). Comparison of average regional and national electricity prices (right y-axis). Original figure by IEA, Special Report on Solar PV Global Supply Chains.*[71]

Such use of coal-fired electricity to manufacture solar-grade polysilicon is the rule, not the exception. All four of the major facilities operated by polysilicon producers in Xinjiang either possess direct on-site coal power units or are located within 1-2 kilometers of large coal-fired power plants (Figures 4-7).

GCL Tech operates a large facility northeast of Ürümqi in the Zhundong Economic and Technological Development Zone (准东经济技术开发区) with an annual capacity of 40,000 tons/yr[72] representing a full 8.4% of China's total solar-grade polysilicon capacity.[73] This factory operates five on-site coal-fired generators in the northwest corner of the plant, while sitting just 4 kilometers from the lip of vast open-pit coal mines (Figure 4). To the southwest of GCL Tech's factory, the Xinte Energy Company's polysilicon plant is similarly conjoined with on-site coal power plants with six units (Figure 5). While Xinte's facility also operates two small solar PV farms along the western edges of the factory, this generation capacity is marginal relative to the plant's total energy demand. Daqo New Energy Corp. operates a large polysilicon plant north of the city of Shihezi, linked to several coal power plants a few kilometers to the north (Figure 6). Finally, East Hope Group's factory in the Zhundong Zone sources electricity from as many as 16 coal-fired generators scattered throughout the plant (Figure 7), with apparent preparations for on-site factory expansion underway as of February 2022.[74]

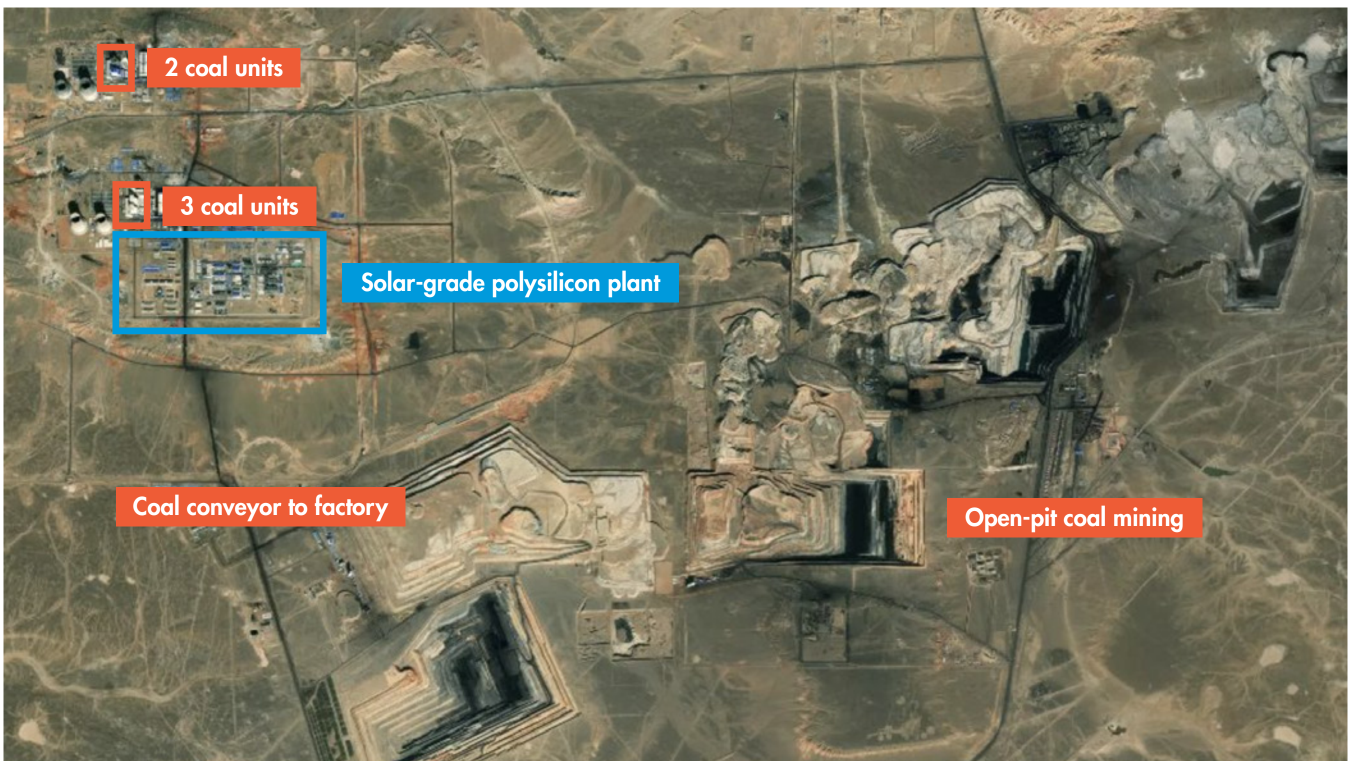


Figure 4: *This figure and the following three figures show satellite imagery of the four major solar-grade polysilicon manufacturing plants in Xinjiang. This image shows the factory operated by GCL Technology Holdings Limited in the Zhundong Economic and Technological Development Zone (44.54°N, 90.26°E). Visible coal power infrastructure is highlighted in red. Imagery is captured from the Mapbox satellite product (https://josm.openstreetmap.de/maps-view?entry=Mapbox%20Satellite), and dates from after 2018.*

Figure 5: *Satellite imagery of the solar-grade polysilicon plant operated by TBEA Co. & Xinte Energy Co. (44.13°N, 87.76°E) northeast of Ürümqi and co-located with aluminum production. Visible coal power infrastructure is highlighted in red. Imagery is captured from the Mapbox satellite product (https://josm.openstreetmap.de/mapsview?entry=Mapbox%20Satellite), and dates from after 2018.*

Figure 6: *Satellite imagery of the solar-grade polysilicon plant operated by East Hope Group (44.68°N, 89.10°E) in the Zhundong Economic and Technological Development Zone and co-located with aluminum production. Visible coal power infrastructure is highlighted in red. Imagery is captured from the Mapbox satellite product (https://josm.openstreetmap.de/mapsview?entry=Mapbox%20Satellite), and dates from after 2018.*

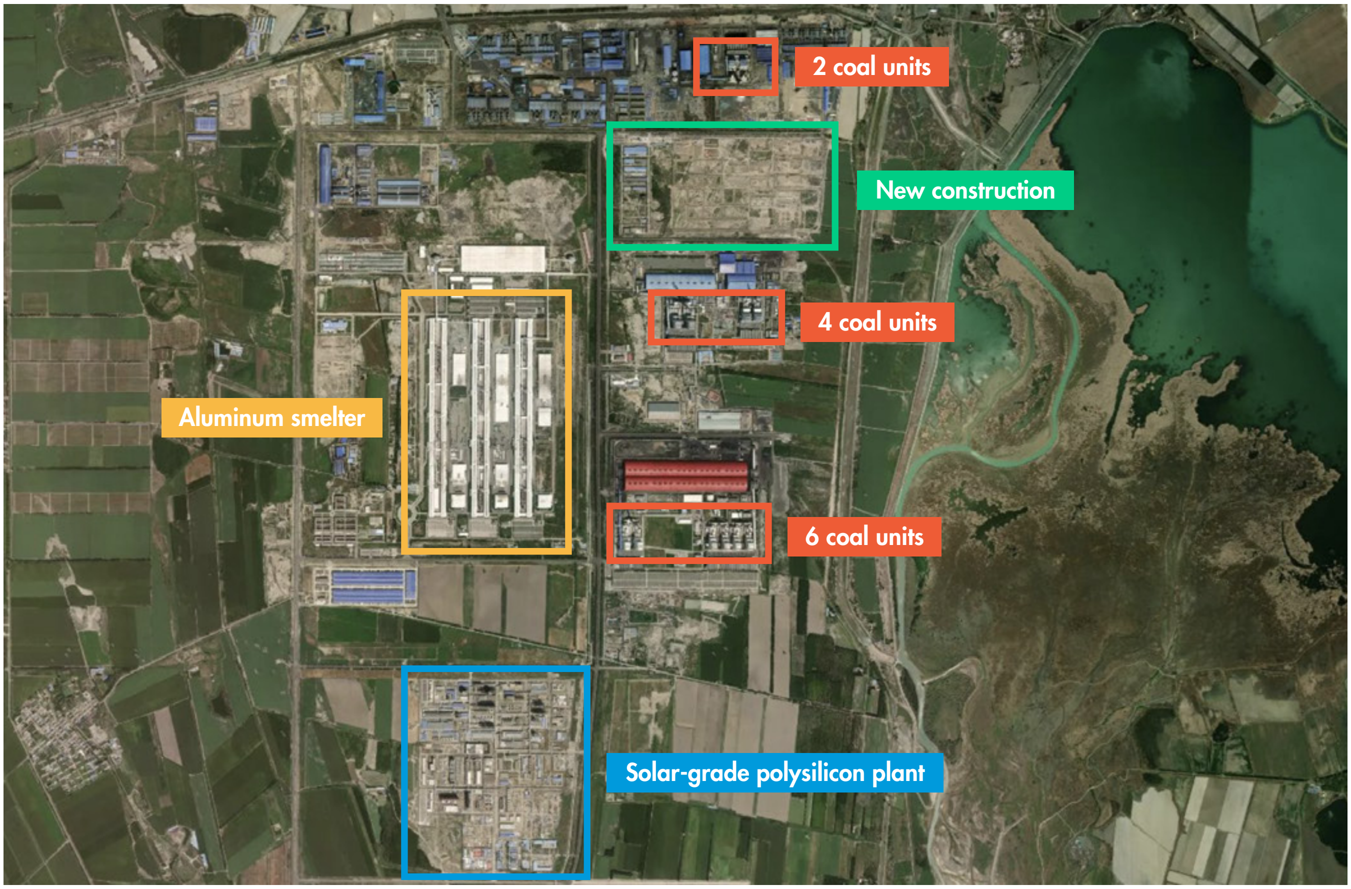


Figure 7: *Satellite imagery of the solar-grade polysilicon plant operated by Daqo New Energy Corporation (44.41°N, 86.08°E) north of Shihezi, co-located with aluminum production. Visible coal power infrastructure is highlighted in red. A new expansion site for silicone production is under construction for the north, still partially incomplete as of 2022. Note that Xinjiang Western Hoshine Silicon Industry Co., Ltd., operates a metallurgical-grade silicon factory directly adjacent and to the north of this construction site, powered by the two coal units pictured. Imagery is captured from the Mapbox satellite product (https://josm.openstreetmap.de/mapsview?entry=Mapbox%20Satellite), and dates from after 2018.*

Certainly, the use of coal energy in industrial applications is commonplace globally. However, coal-fired electricity in Xinjiang is strongly implicated in the region's record of human rights abuses. State media publications and industry documentation provide direct evidence that coal-fired power plants in the XUAR employ forced labor.[75] The Zhundong Economic and Technological Development Zone in particular makes extensive use of forced labor transfer programs,[76,77] while hosting GCL Tech and East Hope Group's large-scale solar-grade polysilicon plants within the same zone. As such, both coal mining activities and coal power facilities directly upstream of polysilicon production are likely taking advantage of unethical practices.

Public records suggest that power plants discriminate by employing Uyghurs and other minority workers in menial, undesirable roles such as cleaning accumulated coal dust from coal-fired boilers, while white-collar administrative roles are only open to Han Chinese.[78] Personal testimony also documents that Uyghurs employed via forced labor programs may be forced to pay for their own company-provided food and transportation, further reducing the low wage they purportedly receive.[79] Photographic evidence from other XUAR industrial facilities shows that workers often lack personal protective equipment required to shield them from injury and occupational exposure to harmful hazards.[80]

The region's four major solar-grade polysilicon producers—GCL Tech, Xinte, East Hope, and Daqo—also have their own suspected links to forced labor programs (Table 1).[81,82,83] Labor represents a small fraction of per-unit polysilicon production costs,[84] and the overall proportion of coerced labor within the larger workforce at XUAR solar-grade polysilicon plants is unclear. Official incentive programs may reward companies with subsidies for participating in labor transfer initiatives, suggesting that the economic appeal of low-cost labor alone may be insufficient to incentivize corporate participation.[85] At the same time, if the compounded effects of forced labor at upstream supply chain steps and relatively unrestricted exploitation of environmentally impactful coal energy are considered, solar-grade polysilicon production in Xinjiang arguably does enjoy some unethical economic advantages from repressive government policies in the region.

In summary, for the reasons discussed above, there is evidence that the solar manufacturing sector in Xinjiang exploits forced labor and benefits considerably from intensive vertical integration of dirty, cheap coal-fired energy with polysilicon production. Evidence also implicates the coal value chain in Xinjiang itself in forced labor abuses. Coal mining and power generation are admittedly machinery- and capital-intensive activities as opposed to labor-intensive industries, limiting the direct economic advantage obtained from exploited labor. However, the intense prioritization of industrial efficiency in Xinjiang's coal energy landscape results in part from political disenfranchisement of minoritized peoples throughout the region. The resulting sizable electricity cost advantages in turn help Chinese polysilicon producers maintain a lead over international competitors.

Raw materials sourcing

The solar manufacturing sector in Xinjiang also benefits from regional supply chains that provide important raw materials at low cost. These upstream inputs are heavily implicated in forced labor transfer programs, are promoted by repressive state-directed industrial policies, and depend upon the same coal mining and electricity generation activities mentioned above.

The chief input raw materials of concern are quartz rock and metallurgical-grade silicon (MGS), which are required upstream inputs for solar-grade polysilicon. Quarries mine quartz rock, while smelters crush this quartz and feed it into an electrode arc furnace where the silicon dioxide is reduced, yielding high-purity MGS.[86] Other materials of concern include aluminum, used in solar module frames and in minor quantities for metallization pastes used in solar cell production.[87] With a recently announced large-scale investment in a PV cover glass factory to be built in Xinjiang, a future risk is also emerging that the supply chain for solar cover glass could become increasingly linked to XUAR production.[88]

Open job listings discovered by researchers at Sheffield Hallam University indicate that, as of 2019-2020, MGS plants employ manual laborers to crush quartz rock and feed it into furnaces to be smelted. Hiring advertisements hint at systematic discrimination, specifying no ethnicity restrictions for manual work but requiring that office and laboratory workers be Han Chinese. Open-source analysis of publicly available industry documentation and news reporting shows that the region's largest MGS suppliers including Xinjiang Western Hoshine Silicon Industry Co., Ltd. (新疆西部合盛硅业有限公司), and Changji Jisheng New Building Materials Company (昌吉吉盛新型建材有限公司) participate in forced labor transfers.[89] As MGS production in electrode arc furnaces is highly electricity-intensive, the XUAR coal energy sector again plays a crucial role in upstream raw material production.[90] Finally, quartz rock quarries and MGS smelters are themselves often located within industrial parks affiliated with the Xinjiang Production and Construction Corps (新疆生产建设兵团), a unique state military-economic entity that helps operate the region's repressive detention camp system and labor transfer programs.[91]

Besides upstream solar-grade polysilicon inputs, XUAR industries also account for a sizeable fraction of other raw materials that may be employed in Chinese solar manufacturing. Primary aluminum factory capacity in Xinjiang represents 17% of total Chinese primary aluminum production and 11% of worldwide primary production.[92] As shown in Figures 5-7, large-scale aluminum smelters are often directly co-located adjacent to solar-grade polysilicon production in the region's industrial parks, exposing such operations to the same forced labor risks present in the solar PV polysilicon and coal energy value chains. One of the region's largest aluminum producers, Xinjiang East Hope Nonferrous Metals Co., Ltd., is also one of the top solar-grade polysilicon producers in the XUAR.[93] Indeed, a spring 2022 report by the consulting firm Horizon Advisory found evidence of forced labor program participation across numerous major aluminum companies in Xinjiang.[94] Aluminum produced in Xinjiang represents a sizable portion of domestic supply within China, and may consequently be incorporated into solar PV frames assembled by manufacturers across the country.

The extent to which quartz materials mined in Xinjiang currently support the solar PV cover glass industry is unknown. However, Hoshine Silicon Industry Co., Ltd., recently announced plans to expand its solar PV cover glass production capacity with a major new facility in Xinjiang that is coming online in summer 2023 with an annual manufacturing capacity of 3 million metric tons a year.[95] This quantity of solar PV cover glass is sufficient for ~43 GW/yr of finished monocrystalline silicon PV modules,[96] or approximately one-fourth of global solar deployment in 2021.[97] Hoshine Silicon was directly sanctioned in 2021 by the U.S. government, which banned all imports of silica-based products in response to forced labor concerns.[98] With a known supplier of concern imminently and significantly expanding Xinjiang-based solar cover glass production, human rights risks may soon extend to this component of the solar PV supply chain.

Downstream risks

Due to the prominent market share of Xinjiang-based suppliers at the upstream steps in the solar manufacturing chain, cost advantages and ethical risks associated with Xinjiang MGS, aluminum, and polysilicon production are subsequently passed onto solar manufacturing companies across China and the world. These highly uniform commodities may be blended or comingled with materials sourced from factories outside Xinjiang, complicating efforts to accurately trace relationships between customers and suppliers. With raw materials representing a sizable fraction of costs at each step in the solar supply chain,[99] cheap and unethical manufacturing of key inputs may confer an important competitive advantage to companies sourcing such materials.

While small relative to the scale of ingot, wafer, cell, and module production elsewhere in China, some ingot and wafer manufacturing capacity exists in Xinjiang. Researchers at the Australian Strategic Policy Institute have identified two suspected prison facilities within 1.5 miles of the monocrystalline silicon ingot and wafer factory operated by JinkoSolar Holdings Company in Xinjiang at 43.46°N, 83.25°E.[100] Open-source investigation has also uncovered evidence that JinkoSolar's Xinjiang operations have accepted workers via labor transfer programs.[101] This facility represented 42% of JinkoSolar's 8 GW ingot manufacturing capacity as of 2021,[102] with JinkoSolar as a whole ranking second among global solar PV module manufacturers and expecting to operate around 65 GW of PV module manufacturing capacity by the end of 2022.[103]

Finally, many other industries outside the solar sector may utilize MGS, aluminum, and high-purity polysilicon produced in Xinjiang factories. These multipurpose commodities are highly versatile and present in a dizzyingly wide range of products. For instance, media articles have touted the role of the XUAR's polysilicon industry in supplying the consumer electronics sector.[104] MGS and aluminum from Xinjiang may also be present in aluminum alloys used in car manufacturing.[105] Ultimately, these products represent just a portion of a larger crisis of unethical manufacturing across Xinjiang, with strong evidence of pervasive human rights and environmental abuses across numerous large-scale, globally traded supply chains from cotton and tomatoes to garments, pharmaceuticals, magnesium, batteries, and more.[106]

Industrial uses beyond the solar PV sector	
Quartz Rock (varying purity): • Glass and ceramics • Molds in metal casting • Industrial abrasives • Electronics (computers, GPS transmitters) • Watches and clocks	**Metallurgical-grade silicon:** • Hardener in aluminum alloy production • Smelting in industrial processes • Manufacturing of microprocessors • Production of silicones and silanes • Manufacturing of automotive parts

EXAMINING PAST PROGRESS IN SOLAR MANUFACTURING

It is nevertheless important not to overexaggerate the degree to which unethical practices and foul play have contributed to Chinese firms' overwhelming control over the global solar supply chain. Inflating the influence of such factors is to neglect real lessons from the historic improvement in solar technology costs and the rise of solar manufacturing in China. Unethical manufacturing may help solar companies keep solar commodity and module costs low today. However, the reduction in per-unit solar PV module costs over the last decade (Figure 8) also results from genuine technological improvements, large-scale targeted investments, and efficiencies of scale. This is welcome news, as the historical narrative demonstrates that the solar industry can likely reproduce many of these past cost improvements even while taking decisive steps to shun, pressure, and replace suppliers associated with human rights abuses.

Some commentators have attributed Chinese dominance in solar manufacturing largely to protectionist trade policies and market manipulation.[107,108,109] According to this narrative, the Chinese government propped up its domestic solar industry with favorable state subsidies while subjecting foreign competitors to heavy trade tariffs. At various times, policymakers[110] and industry figures[111] have alleged that Chinese firms conspire to dump manufactured products on international markets at prices lower than their cost of production.[112] These explanations are largely insufficient, inaccurate, or both.

The foundations for China's dominance in solar manufacturing predate the solar PV trade disputes that began in 2012 as well as the Chinese government's crackdown on the 2009 Ürümqi protests and its launch of the "Strike Hard" campaign of oppression starting in 2014. Rather, the nascent Chinese solar manufacturing industry emerged thanks to a combination of entrepreneurial initiative, public investment, international collaboration, and rapid nurturing of industry expertise throughout the late 1990s and early 2000s, accompanied by increasing international demand for solar products, particularly from Germany.[113]

In 1983, researchers led by Professor Martin Green at the University of New South Wales (UNSW) in Australia engineered the passivated emitter rear contact (PERC) solar cell, setting a new world record in the conversion efficiency of solar energy to electricity.[114] This and subsequent successes attracted a growing group of Chinese doctoral students and researchers to the Australian research group, many of whom would become executives and chief technical officers across the future Chinese solar industry.[115] UNSW researchers would expand collaboration with the nascent global solar industry and continue to pioneer record-breaking improvements to solar cell design over the next two decades.

Dr. Shi Zhengrong (施正荣), an alumnus of the UNSW group, returned to China in 2001 with the goal of establishing a solar manufacturing base in his home country.[116] With financial support from the local Wuxi municipal government and assistance in equipment procurement and workforce training from Australian colleagues, Shi Zhengrong founded Suntech Power (尚德电力控股有限公司) and opened its first 10 MW manufacturing plant in 2002 in the vicinity of Shanghai. Suntech's wildly successful IPO in 2005 raised 400 million in U.S. dollars,[117] igniting a fierce surge of interest in solar manufacturing among Chinese companies and international venture capitalists, and triggering successive waves of investment and market entry over the next several years.

Thus, Chinese firms and local policymakers perceived solar's market potential early on and rapidly placed a high priority on solar technology and manufacturing. At the same time, in 2000 the German government boosted global demand for solar PV by enacting a feed-in tariff subsidizing new solar PV projects, a program that would ultimately incentivize approximately 7.6 GW of solar PV installations nationwide in around a decade.[118] Beijing would enact its own Renewable Energy Law in 2005, implementing a feed-in tariff in 2011 that would fortuitously cushion the domestic industry following the 2008 global financial crisis.[119] As such, the establishment of a vibrant solar manufacturing sector in China occurred in large part thanks to close professional networks, fast and decisive industry development, and fortunate timing with supportive global, national, and local policy drivers.[120]

After rising PV startups in China established a successful business model and attracted growing investments in global capital markets, the national Chinese government began offering significant capital support in 2009, allowing for even more rapid expansion of the domestic industry.[121] This coincided near-perfectly with increasing global demand for solar PV modules. While competing governments similarly recognized the solar sector's future potential, they invested in new manufacturing capacity to a dramatically lesser magnitude.

By the early 2010s, many countries sought to support domestic solar manufacturing through tax incentives, public R&D support, or industrial policy, including the United States,[122] Taiwan,[123] and Japan.[124] As of 2011, East Hope and GCL-Poly had begun constructing new factory capacity in Xinjiang. However, expanding large-scale production across the solar supply chain was simultaneously driving a growing oversupply crisis. Solar module average selling prices, for instance, plummeted between the start of 2011 and the start of 2013 from $1.75 to less than $0.70/watt, while solar-grade polysilicon spot prices fell from $75/kg to $16/kg—all relative to a February 2008 peak of $475/kg just a few years prior.[125] While international competitors struggled to sell product and remain profitable, Chinese companies benefited from domestic experience competing in cheap manufacturing of globally traded goods with razor-thin profit margins. During this oversupply period, Chinese firms likely engaged in some dumping of solar PV commodities below cost to empty product inventories, keeping them in business while higher-cost firms abroad exited the market. Fierce domestic and international competition during this period drove aggressive further efforts to cut manufacturing costs, positioning the solar PV industry for a decade of cost improvements that would defy all expectations.

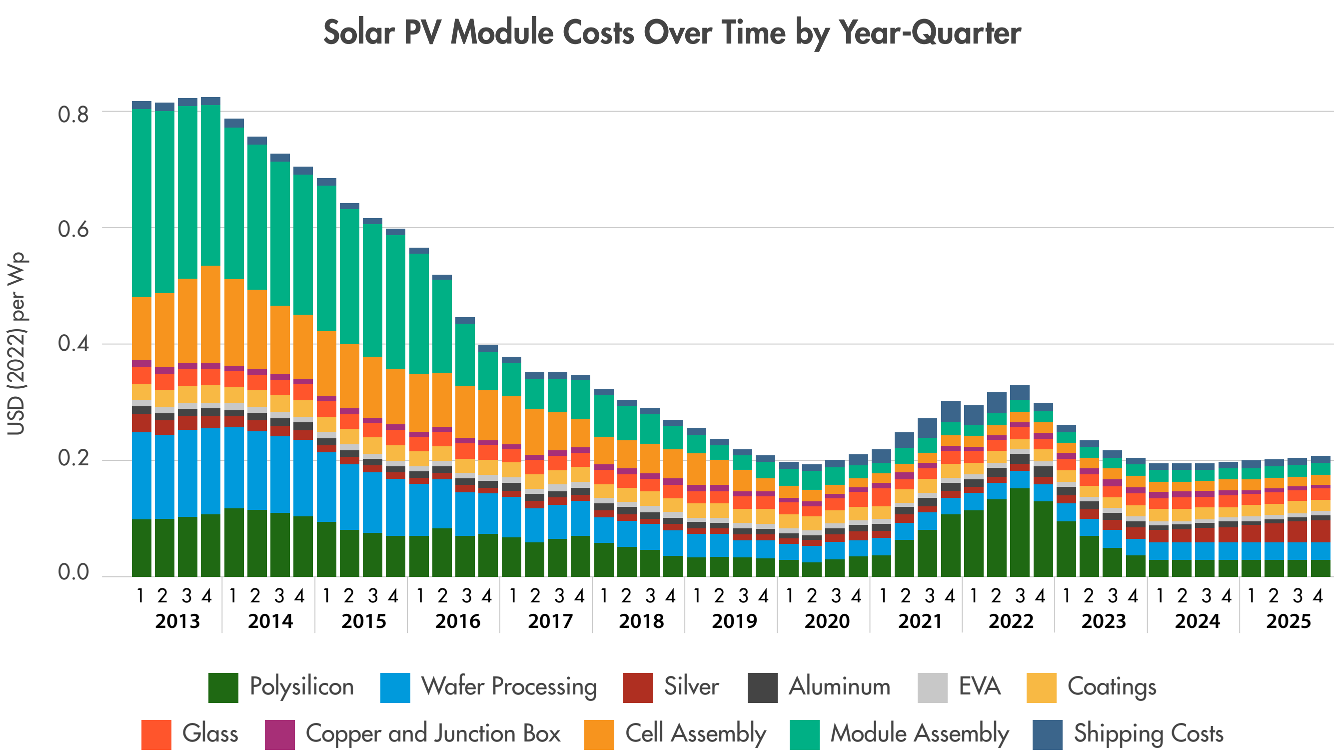


***Figure 8:** Historical changes in solar PV equipment costs and cost components since 2013 Q1, with projected future trends through the end of 2025 as estimated by Rystad Energy's SolarSupplierCube.*

In terms of mercantilist policies, the United States was actually the first country to enact tariffs on imported solar products from China, levying an anti-dumping duty in May 2012 that ranged from 18.3% to 249.96%.[126] Beijing policymakers responded in kind by imposing duties on imported solar goods from South Korea and the U.S.[127] and eventually implementing retaliatory tariffs on EU goods in other sectors.[128] European manufacturers ultimately negotiated to reduce these tariffs.[129] Yet the Chinese government has extended tariffs on American- and Korean-made polysilicon for the foreseeable future.[130]

In that period of the early 2010s, however, Chinese firms were already capturing global market share at a rapid pace, adding new factory capacity at scales that dwarfed competing efforts abroad.[131] Large-scale manufacturing capacity helped the Chinese industry attain substantial economies of scale. Simultaneously, solar PV industry standardization and optimization efforts in China and internationally gravitated toward selection of the monocrystalline silicon PERC solar cell, which offered high performance while also simplifying production.[132]

Solar photovoltaics have thus achieved the large majority of their cost declines over the past decade thanks to real technological innovations in manufacturing efficiency and module design. As a result of these factors, the cost per watt of a solar PV module fell by 75% between the start of 2013 and the start of 2020 (Figure 8),[133] while the global solar manufacturing sector continued to consolidate within China.

But while the Chinese solar manufacturing sector's birth and initial growth had little connection to Xinjiang, this same period saw the industry becoming increasingly tied to the region and to the Chinese government's oppressive policies. Labor transfer programs were already operating in the XUAR as solar-grade polysilicon factories first began local development around 2010.[134] Since 2014, when the Chinese Communist Party launched its "Strike Hard" campaign, and especially after 2017 when initial reports began to emerge of mass incarceration of Uyghurs and Kazakhs, successive waves of growth in the region's solar manufacturing sector have chronologically coincided with intensifying state repression of its minoritized peoples.

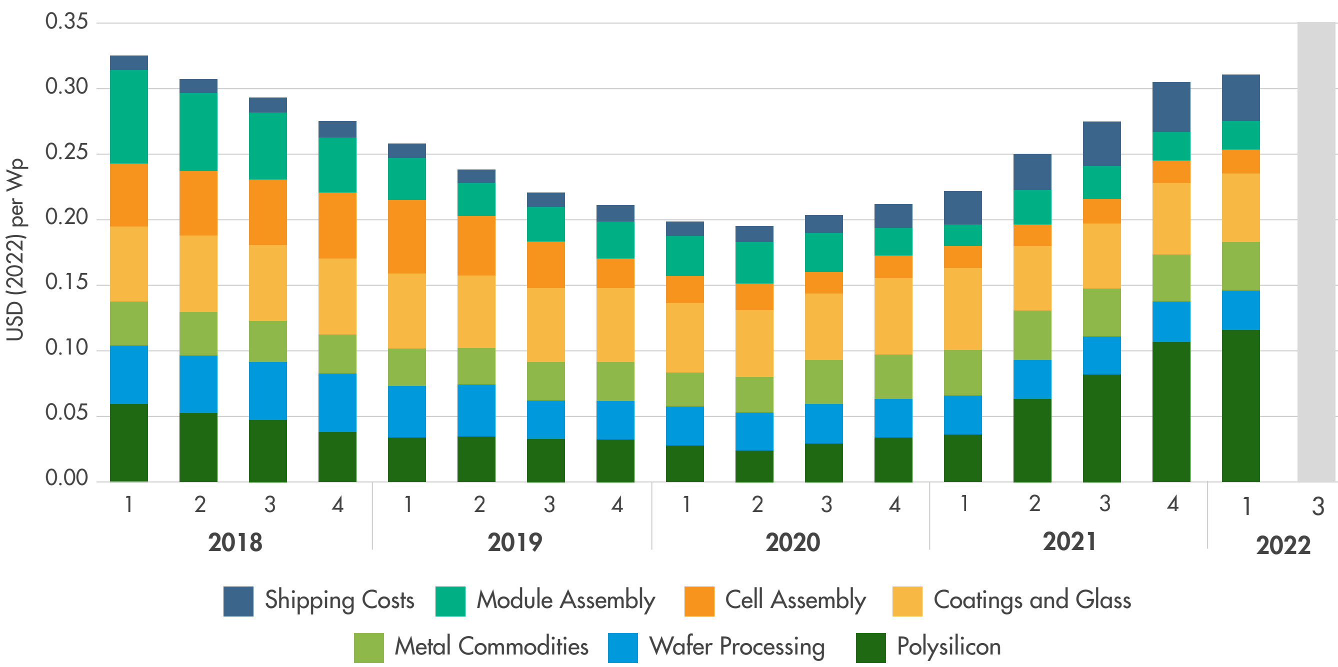
From its foundation of progress over the last 10 years, the solar industry now seems poised for a new explosive growth period on top of a decade of market performance that well exceeded most expectations. Yet like previous expansions of solar manufacturing capacity, this imminent growth phase threatens to tie the future of the global solar sector even more inextricably to unethical production in Xinjiang.

AN INDUSTRY SENSITIVE TO XINJIANG-BASED PRODUCTION

Recently, solar PV module costs have stopped falling. Since the start of the COVID-19 pandemic in early 2020, module costs increased by 50% between the second quarter of 2020 and the first quarter of 2022 (Figure 9).[135] A combination of increasing demand, global supply chain shocks, production pauses,[136,137] and industrial accidents[138] at polysilicon plants in China[139] have brought solar module costs back to levels last seen in early 2018.

As a result, the global solar sector is more sensitive to PV module prices now than it has been for years. Commodity price increases have driven rising costs, with PV module costs today tied almost directly to the cost and availability of solar-grade polysilicon. Industry experts now look more intently than ever to news and announcements from Chinese firms that dominate polysilicon production as an indicator of near-term future market trends.[140]

Solar PV Module Costs by Year and Quarter, 2018-2022*



*Forecast third-quarter values shown for 2022
Source: Rystad Energy SolarSupplier Cube

Figure 9: *Recent trends in solar PV module costs and cost components.*

While these recent fluctuations still leave solar as one of the most affordable unit-level electricity generation options in existence,[141] the rapidly changing economics of solar project development are subjecting the industry to some turmoil. Recent U.S. solar industry surveys conducted by the Solar Energy Industries Association suggest that many developers have postponed or shelved new projects due to heightened costs and shortages of solar PV components in addition to supply chain delays, COVID-19 disruptions, and the threat of import tariffs.[142] The U.S. solar sector's intense, organized opposition[143] to the Department of Commerce's investigation into allegations of industry circumvention of solar import tariffs demonstrates this general apprehension around supply chain sourcing. These organized efforts ultimately convinced the Biden administration to grant a two-year grace period protecting the U.S. solar sector from new tariffs.[144]

Yet the solar industry's fundamentals remain strong. Upstream manufacturers, particularly in China, are making large-scale new investments in industrial plant capacity as they prepare to meet anticipated future demand. It is reasonable to expect that, under the status quo, the solar sector's current supply chain anxieties will be transient, and the imminent future will produce a return to year-on-year solar PV module cost declines. But should the solar industry proceed blindly along a business-as-usual path, the next few years will only further deepen the solar sector's reliance on Chinese manufacturers.

As for the near future, a diverse array of projections anticipates sizable records in new solar power deployments in 2022 and beyond. This year, 190 GW of new solar capacity may be installed globally,[145] a 25% improvement over installed capacity in 2021. Worldwide deployment rates might grow to 250-266 GW per year by mid-decade.[146] At an assumed 2,930 tons of polysilicon per 1 GW of monocrystalline silicon solar capacity, that implies global production of 780,000 tons of polysilicon per year, with total global solar capacity reaching up to 2,500 GW by 2030.[147] Under a highly ambitious future scenario such as the IEA's net-zero emissions by 2050 pathway, solar capacity installed annually reaches 630 GW by 2030, implying annual manufacturing capacity in excess of 800 GW.[148] The IEA's 2050 net-zero pathway models a cumulative global installed capacity of 5,000 GW by 2030.

To meet this demand, Chinese firms have begun to rapidly expand solar manufacturing capacity at a record pace,[149] targeting multiple steps in the supply chain. The module manufacturer Longi is set to invest over $2 billion for a new facility in Erdos City, Inner Mongolia, with annual production capacity for 20 GW of ingots and wafers, 30 GW of solar cells, and 5 GW of modules.[150] Longi also has plans to build a 20 GW module factory in Wuhu, Anhui province.[151] Xinte Energy will be investing $2.8 billion to expand its polysilicon manufacturing capacity in Xinjiang by 200,000 tons/yr with a new factory to be built near Changji in two 100,000 ton/yr stages.[152]

Risen Energy is investing $7 billion for a new PV manufacturing facility in Inner Mongolia.[153] These are just a few of the massive expansion projects underway.

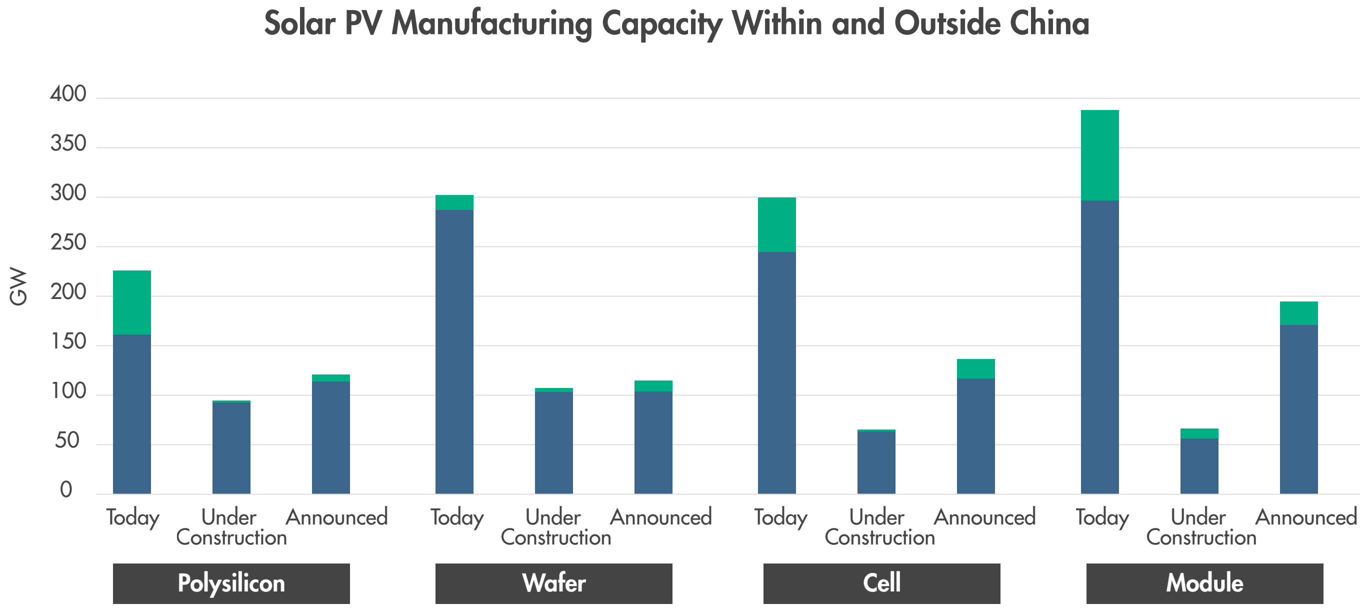


__Figure 10:__ Existing manufacturing capacity, new manufacturing capacity under construction, and new announced manufacturing capacity within China and outside China at major steps of the solar PV supply chain, as of July 2021.[154]

In total, as of a July 2021 survey, China has at least 300,000 tons of new annual polysilicon manufacturing capacity under construction and another 300,000 tons of new capacity announced.[155] Chinese firms have 100 GW of ingot and wafer factory capacity under construction, with a further 100 GW of capacity announced (Figure 10). Cell manufacturers in China are expanding production by at least 50 GW, with over 125 GW of additional capacity announced. Finally, factories conducting solar PV module assembly in China will grow by 50 GW in the near term, with over 125 GW of announced projects to follow.[156] These values are already a substantial undercounting, as many large new projects have been announced in the intervening year including several of the factory announcements detailed above. Recent research by Bloomberg analysts suggests that existing and announced polysilicon manufacturing capacity may attain 940 GW worth of annual production by 2025.[157]

Given increasing scrutiny and criticism of Chinese solar manufacturing in Xinjiang, such developments threaten to entangle the global solar industry in a culture where supply chain human rights and environmental concerns are too painful and inconvenient to confront. Further hesitancy will only intensify this challenge.

Without immediate action, not only may the future of solar energy become locked into complicity with the Chinese government's crimes against humanity, but inaction may prolong the solar industry's dependence on low-cost products that stifle innovation, contribute excessively to climate and environmental impacts, and increase long-term supply chain risks for the industry as a whole. In the following sections, we elaborate upon the moral and societal risks such dynamics pose to the solar sector and to the world community at large.

Moral complicity in forced labor

Outside of China, the environmental movement has rightly fought to ensure that climate change mitigation efforts do not inflict unjust, disproportionate harm on vulnerable peoples in the name of the greater global good. Whether advocating for the protection of communities in lithium mining regions of Chile, Bolivia, and Argentina[158] or when demanding strong policies to support coal miners through the clean energy transition,[159] policymakers and environmental advocates strive to protect groups that could bear unfair costs as the world seeks to reduce carbon emissions. Yet as evidence of the solar manufacturing sector's ties to crimes against humanity in Xinjiang continues to accumulate, activists, policymakers, and the clean energy industry have remained unusually silent.

A recent special report on the global solar PV supply chain by the International Energy Agency, for instance, conspicuously makes no mention of forced labor risks associated with Xinjiang-based manufacturers. And when a reporter at the COP26 international climate conference asked U.S. Special Climate Envoy John Kerry about solar energy, forced labor, and the Xinjiang region, he evasively replied that such concerns were "not my lane."[160] Numerous major international environmental advocacy organizations including the Natural Resources Defense Council, Greenpeace, and Friends of the Earth lack any mention of environmental or human rights issues in Xinjiang on their websites, with many of these groups declining to speak with reporters on such questions.[161]

Such silence and evasions are unconscionable. Environmental justice efforts should not stop at the borders claimed by the Chinese Communist Party, lest the climate movement wish to signal its willingness to tolerate inequitable sacrifice zones (geographic areas permanently impaired by heavy environmental damage) so long as they only affect Muslim or Asian peoples living under Chinese government authority. If the world is to truly prioritize climate justice, then the global community must take all necessary measures to eliminate forced labor risks throughout clean energy supply chains, no matter where such risks exist.

Some may counter that the true extent of forced labor and environmental injustice in the Xinjiang solar manufacturing chain is not only unknown, but likely small, while the Xinjiang industry is itself only a fraction of larger Chinese production.[162] For instance, the world's largest polysilicon producer is Tongwei Solar Company, which has no XUAR-based operations.[163] Many solar manufacturing activities such as solar-grade polysilicon production, ingot manufacturing, and wafer slicing are capital- and machinery-intensive as opposed to labor-intensive and likely rely heavily upon skilled and specialized workers to operate production lines. As such, use of forced labor in such facilities may not be as intensive and pervasive as it is in the XUAR's cotton, tomato, or garment industries.[164] Furthermore, labor represents a relatively small fraction of per-unit polysilicon costs.[165]

However, forced labor risks and any associated cost advantages for solar-grade polysilicon manufacturers are compounded thanks to upstream forced labor exploitation for inputs like coal energy and minerals. Upstream industries like quartzite rock mining and metallurgical-grade silicon smelting are likely to be more labor-intensive, with corporate and press documentation indicating regular use of manual labor at such sites in Xinjiang.[166] Even at polysilicon plants themselves, numerous supporting worker roles may not require skilled training or advanced technical expertise. The International Renewable Energy Agency assesses that, across the solar supply chain, 60% of the workforce requires only minimal training.[167] Indeed, records of Uyghur workers transferred to JinkoSolar in spring 2020 listed educational levels that ranged from junior high to undergraduate college.[168] Meanwhile, downstream customers that purchase a blended mix of commodities from XUAR- and non-XUAR-based facilities may indirectly benefit from XUAR-based production even if they do not directly operate in the region.

Given the tight profit margins under which the polysilicon industry operates, small changes in manufacturing and input commodity costs could deliver disproportionate benefits. Furthermore, direct labor force considerations may not reflect beneficial subsidies and treatment that manufacturers receive from official programs in consideration of their participation in state-sponsored labor transfer initiatives. At the same time, the existence of such subsidy programs may suggest that the competitive advantage of low-cost labor alone is insufficient to incentivize corporate involvement in labor transfer programs.

Initial efforts by solar industry actors to trace solar supply chains in response to forced labor concerns are disappointing. The Solar Energy Industries Association's guidance protocol for solar supply chain tracing, for instance, is focused on tracking and excluding specific batches of product manufactured with a risk of forced labor, instead of seeking to exclude upstream suppliers whose operations wholly or partially exploit forced labor programs.[169] SEIA's traceability protocol only covers the commodity chain between metallurgical-grade silicon and completed solar PV modules, omitting upstream sourcing of quartz rock as well as inputs like aluminum and solar PV cover glass. Even though unexpectedly strict enforcement of the Uyghur Forced Labor Prevention Act in the United States has, in particular, mandated documentation of quartz rock sourcing that solar PV importers did not anticipate,[170] SEIA's protocol has not been revised since its initial version was published in April 2021.

Current industry efforts, to the extent that they exist, are thus narrowly focused on avoiding individual shipments from Xinjiang-based factories. Such initiatives would permit purchase of "Xinjiang-free" material manufactured outside of the XUAR, even if the parent manufacturer is simultaneously operating factories within the XUAR. This narrow policy raises the risk of bifurcation, by allowing suppliers to cultivate a separate Xinjiang-free supply chain for more conscientious customers even while continuing to profit from Xinjiang-manufactured products sold separately.[171] Chinese manufacturers may already be shifting toward providing sanitized products to foreign markets while reserving forced-labor products for domestic or unscrupulous buyers.[172]

In addition, current tracing programs do not satisfactorily address concerns about access to reliable information. Similar efforts to trace or certify other undifferentiated commodities such as agricultural products have often fallen victim to widespread fraud, in which noncompliant products are comingled with compliant goods or are outright misrepresented as compliant with certification programs.[173] As scrutiny of XUAR-produced solar goods constrains their potential market while raising the desirability of Xinjiang-free commodities, temptation to profit from fraud may grow. Given the Chinese government's overall lack of transparency and its particularly tight control over information related to Xinjiang, supply chain tracing may be extraordinarily difficult if not impossible for auditors.[174] Chinese authorities in recent years have even moved to close local auditing partners that help international firms consult on labor issues.[175]

Rather, governments and customers should move aggressively, within the next couple of years, to adopt a zero-tolerance blanket policy toward Chinese solar manufacturers with operations in Xinjiang, as well as any downstream companies that source any product, regardless of origin, from those manufacturers. Responsible purchasers should not support suppliers that profit from forced labor and environmental injustice, regardless of whether a given shipment of product the supplier is offering for sale is purportedly free from such factors. Nor should the global finance sector or researchers continue to invest capital in or offer expertise to companies implicated in unethical solar manufacturing. These more stringent standards for ensuring ethical production will require a more significant reorganization of global solar manufacturing chains, but will enforce more meaningful accountability for producers.

Meanwhile, policymakers and the private sector should lend large-scale support to alternative solar PV manufacturers in order to ease the transition to more transparent and socially responsible supply chains.

Companies of Concern

In May 2021, researchers at Sheffield Hallam University published a full list of companies exposed to forced labor transfer programs in Xinjiang either directly or via supplier-customer relationships. This list is contained in Appendix A of the report In Broad Daylight: Uyghur Forced Labour and Global Solar Supply Chains.176

In Broad Daylight Report: Uyghur Forced Labour and Global Solar Supply Chains

Companies identified in the Sheffield Hallam University report to carry risks of forced labor exposure (direct and/or in immediate supply chain) are listed here. Downstream contracts are omitted.

Daqo New Energy Corp.; GCL Tech (formerly GCL-Poly); TBEA/Xinte; East Hope Group; Tongwei Solar Company; Asia Silicon (Qinghai) Company; JinkoSolar Holdings Company; LONGi Green Energy; Trina Solar Energy Company; JA Solar Holdings; Tianjin Zhonghuan Semiconductor; Qinghai Gaojing Solar Energy Company; Canadian Solar; Risen Solar; Astronergy/Chint Solar; Xinjiang Hoshine (Hesheng) Silicon Industry Co.; Xinjiang Sokesi New Material Co.; Changji Jisheng New Building Materials Co.; Xinjiang China Silicon Technology Co./Xinjiang Zhonggui; Xinjiang Jingweike New Energy Development Co.; Xinjiang Jingxin Silicon Industry Co.; Xinjiang Yusi Technology Co./Yu Silicon; Xinjiang Jiagesen New Energy Materials Co., Ltd.; Xinjiang Guopeng Technology Co.; Xinjiang Xintao Silicon Industry Co.; Beijing Dadi Zelin Silicon Industry Co.

Stifling of global solar innovation

Overreliance on unethical and dirty solar manufacturing with ties to repression in Xinjiang may in turn harm the global solar PV sector over the long term by suppressing innovation and competition within the industry. In contrast, coordinated pressure to hold low-cost manufacturers accountable for labor exploitation and pollution can drive large-scale improvements in energy efficiency, factory technology, and social responsibility.

Under the current status quo, prospective entrants to the sector seeking to establish new solar manufacturing capacity face competitors that benefit from cheap coal-fired electricity, generous subsidies, and a no-holds-barred polluting industrial landscape in Xinjiang constructed with Chinese government support. While supply throughout all stages of the solar manufacturing chain remains tight,[177] such that any new entrant would in theory be able to tap ample market demand, existing major producers in China enjoy cost advantages that help attract large-scale capital investment. And should the solar PV sector trend once more toward oversupply, high-cost competitors may be the first manufacturers forced out of the market, increasing perceived risks of entry.

This lopsided dynamic, partly enabled by unacceptable labor and environmental practices, constrains competition and reduces incentives to fund research and development of improved, more sustainable manufacturing techniques. For instance, production of high-purity polysilicon using fluidized bed reactor (FBR) technology is a well-understood and considerably more energy-efficient method for manufacturing solar-grade polysilicon, consuming just 10-20% of the electricity per kilogram of the current Siemens reactor approach used throughout Chinese industry.[178] However, the widespread availability of low-cost coal-fired electricity (and, admittedly, some facilities supported by hydroelectricity) has negated the market and sustainability advantages offered by the FBR method,[179] which continues to account for only a small fraction of global production.

Over the past decade, the increasing cost-efficiency of mass production of mono-PERC solar PV cells in China has also impacted the relative economic competitiveness of alternative solar technologies, such as thin-film solar cells.[180] Chinese firms' dominance of manufacturing has also heavily concentrated industry expertise and technical knowledge, imparting a further advantage in solar PV R&D while complicating any efforts to establish new large-scale manufacturing capacity outside of China.

Significantly, the solar industry's ties to Xinjiang have linked solar PV manufacturing to a human rights crisis that Chinese leaders consider politically taboo. International organizations, governments, corporations, and nongovernmental organizations cannot call attention to human rights concerns in the solar PV manufacturing chain without inviting harsh backlash from implicated companies and the Chinese government. As such, anxieties over provoking political controversy have slowed and muted the international community's reaction to an outright forced labor scandal. Similar political considerations possibly weigh upon domestic policymakers and industry leaders within China as well, given the potential consequences of appearing to contradict or disagree with the central government's policies in the XUAR.

Outside of China, the brewing controversy over the solar PV sector's links to oppression in Xinjiang also lends ammunition to political opponents of renewable energy technologies.[181,182] At the same time, policymakers face activist calls to place restrictions on suspect goods in accordance with international law and human rights norms,[183] while policy and consumer pressure in turn could increasingly force solar PV developers to scramble to source transparently procured, ethically produced solar PV products, delaying projects and raising development costs. Such political factors may collectively slow the rate of solar PV deployment, in turn impeding investment, technological learning, and industry growth.

Thus, while the global solar sector may be narrowly benefiting today from cost advantages associated with Xinjiang production, market distortions from unethical manufacturing may ultimately harm the solar industry in the foreseeable future. Global efforts to decouple from solar PV manufacturers implicated in Xinjiang operations will not only help fulfill the solar industry's ethical obligations, but could also help create a healthier global environment for innovation, investment, and accelerated solar deployment.

Climate and environmental impacts of Chinese production

Prolonged reliance on coal-intensive Xinjiang polysilicon production will also slow the rate at which the solar PV manufacturing sector itself decarbonizes over time, increasing the solar sector's own climate impact while continually harming Xinjiang residents from air pollution and coal mining.

While carbon intensity and environmental impacts are slowly improving in many areas of heavy industry,[184,185] the environmental record of solar PV manufacturing has likely remained carbon-intensive given the industry's increasing carbon footprint in Xinjiang. Life cycle assessment studies[186] have pointed conclusively to higher greenhouse gas and pollution impacts from coal-intensive solar PV manufacturing in China.[187] For instance, associated nitrogen oxide and sulfur dioxide emissions are on average 9-13% higher for solar modules manufactured in China than those produced in Europe.[188] A solar PV panel made using polysilicon sourced from coal-heavy Xinjiang in turn carries considerably higher life cycle environmental impacts than the industry-wide average in China.

With a 25-30 year lifetime, even a coal-intensive solar PV module will eventually pay back its carbon cost of production several times over, yielding a strong net climate benefit. But the increased carbon footprint of solar-grade polysilicon produced from coal does significantly affect the climate impact of a solar PV module. Conversely, improved energy efficiency and use of cleaner energy in the manufacturing chain can significantly strengthen solar PV technology's contribution to emission reductions.

If a module produced with coal-intensive manufacturing is exported and installed in a region like California or Germany with an electricity grid that is already fairly clean, that module carries a higher carbon footprint while providing a lower marginal benefit in terms of avoided fossil power generation, significantly increasing the time required for the module to "pay back" its embodied carbon emissions. A simplistic back-of-the-envelope calculation demonstrates this effect (Table 2):

California case:
Panel is installed in California, a region with an average grid CO_2 intensity of 200 g CO_2eq/kWh.

China case:
Panel is installed in China, a region with an average grid CO_2 intensity of 620 g CO_2eq/kWh.

For these two scenarios, one can evaluate a range of life cycle CO_2 emissions for a ground-mounted mono-PERC solar PV installation[189] based on two cases:

- **High case:** 433 kg CO_2eq/m^2 with parts mostly manufactured using coal-fired energy in China.[190]
- **Low case:** 114 kg CO_2eq/m^2 with parts mostly manufactured with cleaner energy in Europe.[191]

Table 2: *Greenhouse gas payback time required to negate life cycle emissions for a monocrystalline PERC solar PV installation with different life cycle CO_2 intensities, installed in either California or China.*

	CO2 payback time for panel installed in California	CO2 payback time for panel installed in China
High CO2 intensity solar PV	9.8 years	3.2 years
Low CO2 intensity solar PV	2.6 years	0.8 years

Scenario assumes one square meter of ground-mounted mono-PERC solar PV cells with 19.79% efficiency, with 1391 kWh/m2/yr192 of solar irradiation and a performance ratio of 0.80.193 These values yield 220 kWh of electricity in a year with zero CO_2 emissions, avoiding 44.0 kg CO_2eq in power sector emissions per year in California and 136.4 kg CO_2eq of power sector emissions per year in China.

Calculation details: Solar PV carbon payback period analysis

This is an illustrative calculation that significantly oversimplifies many operational factors. Actual avoided CO_2 emissions, for instance, will vary seasonally and over the course of the day due to time-evolving utilization of various generation technologies. True material and energy usage data for recent solar PV manufacturing is difficult to obtain, as such information is often proprietary and closely guarded. Nevertheless, this example demonstrates how a carbon-intensive solar PV module installed in a relatively clean electricity grid may require significant added time to pay back its higher life cycle emissions associated with manufacturing. In contrast, a solar PV module manufactured with clean energy and installed in a power grid dominated by fossil fuels will rapidly pay back its life cycle emissions.

While greenhouse gas impacts are felt globally, albeit unequally, pollution from coal mined and burned in Xinjiang to power solar manufacturing plants disproportionately affects local communities living close to such facilities. Solar-grade polysilicon facilities in Xinjiang draw power from at least 39 on-site and nearby coal-fired power units, accounting for close to one-fifth of the 203 coal-fired boilers operating across the entire province.[194]

Chinese cities already experience some of the highest air pollution rates in the world,[195] yet the XUAR bears a disproportionately high pollution burden even by Chinese standards.[196] Ürümqi, Xinjiang's capital, ranks as one of the most polluted cities in China, with Xinjiang ranking fifth worst out of 30 provinces on the basis of environmental and health conditions. At least 33 coal-fired boilers ranging from 100 MW to 330 MW generating capacity operate within a 30-mile (48 km) radius of downtown Ürümqi, of which six units are co-located with Xinte New Energy Company's polysilicon factory northeast of the city.[197]

Figure 11: *Open-pit coal mines, coal-fired power plants, and industrial water impoundments in the Zhundong Economic and Technological Development Zone at approximately 44.80°N, 89.17°E. East Hope Group's aluminum smelter and polysilicon factory in the region are located just out of frame to the south. The TBEA Tianchi Energy Zhundong Wucaiwan power station is visible along the upper edge of the image.*

This coal fleet in turn relies upon a vast network of coal mines throughout the region. Many large pit mines scar the ecologically delicate Gobi Desert northeast of Ürümqi, with successive coal pits stretching for up to several kilometers in some mining complexes. Based on satellite imagery, piles of tailings and spoils appear uncontrolled, creating high risks of hazardous dust emissions and environmental contamination. Large man-made water impoundments dot this landscape at the margins of mines, power plants, and factories, indicating heavy industrial water use in one of the most arid regions on the continent of Asia (Figure 11).

The XUAR solar-grade polysilicon industry is thus directly tied to a highly coal-intensive energy system that is causing immense harm to public health and the environment, turning much of the region's northeast into a textbook example of a sacrifice zone. Coal mining and pollution will likely leave local minoritized communities unfairly saddled with long-term damage to air and water quality, public health, and natural ecosystems, while economic benefits predominantly accrue to Han Chinese persons and state-supported corporations. Uyghur, Kazakh, and Kyrgyz individuals are not only coerced into laboring within this system, but they have no opportunity to oppose these damaging impacts of the Chinese state's economic and land use policies. Upstream solar manufacturing in Xinjiang bears a significant fraction of the responsibility for these harms, which could scarcely present a clearer example of environmental injustice and race-to-the-bottom forms of industrial production.

Increasing supply chain risks

Many industry commentators have downplayed the challenges associated with avoiding solar PV goods sourced from Xinjiang, pointing to significant investments in new factories elsewhere in China and arguing that Chinese firms will soon establish sufficient supply outside Xinjiang to meet projected demand for Xinjiang-free products in international markets.[198]

However, the solar PV industry would be wise to view mounting alarm over forced labor in the solar supply chain as a broad lesson about the general risks associated with growing overconcentration of manufacturing capacity in China, particularly given the likelihood that new manufacturing plants will fail to address forced labor concerns in the first place.

Chinese firms are indeed constructing considerable new factory capacity outside of the XUAR, particularly in the provinces of Sichuan and Inner Mongolia, significantly reducing the likelihood that such plants will participate in forced labor exchange programs. The regional electricity mix in Sichuan also boasts a higher proportion of clean energy generation, reducing the carbon footprint of manufactured solar goods relative to products made with power supplied by Xinjiang's coal-heavy grid.[199]

But changing the distribution of solar PV manufacturing within China will not guarantee an increase in the true availability of Xinjiang-free solar PV goods, given the possibility that downstream manufacturers may blend input materials purchased from XUAR-based and non-XUAR-based suppliers. In addition, such reshuffling fails to address bifurcation, in which a solar manufacturing firm could market some of its products as Xinjiang-free while continuing to benefit from separate supply chains that involve Xinjiang-based operations or suppliers.

Furthermore, while new announced plant capacity in China will mostly operate in other provinces, Chinese firms are also planning to construct new manufacturing plants in Xinjiang. Earlier this year, Hoshine announced a new polysilicon plant in Ürümqi City that will boast 200,000 tons of annual capacity.[200] A month later, Xinte announced its own new plant, a 200,000-ton operation to be built in Changji county.[201] In April, Hoshine declared that it would also seek to establish a large factory for solar PV cover glass in Xinjiang.[202] Such projects signal that Chinese solar industry actors are not completely avoiding investment in large new manufacturing facilities in the XUAR. Without pressure to the contrary, the risk exists that future waves of factory expansion will once again shift toward Xinjiang.

In contrast, more sincere efforts to diversify global solar PV manufacturing outside of China will not only more reliably limit exposure to forced labor but also reduce industry-wide risks associated with excessive concentration of manufacturing capacity in China. The International Energy Agency's recent report on the solar PV supply chain cautioned that, at some steps of manufacturing, the solar PV sector relies on production that has consolidated within not just a single country, but within a small handful of large plants—a level of vulnerability that would raise concerns within any industry.[203]

In projections based on the status quo, a vast majority of future solar PV manufacturing would remain sensitive to any economic or policy shifts within China. Chinese government policy decisions that could impact the solar PV sector are not just limited to official policies governing Xinjiang, but could include cross-strait tensions with Taiwan or geopolitical disputes with India or Japan, in addition to revisions to energy, trade, and industrial policy. In particular, as the central government remains determined to uphold its domestic zero-COVID pandemic response, authorities may continue to impose quarantines on key cities and regions. Reciprocally, other countries may implement bilateral policies that impact trade or manufacturing in China.

And as the past few years of global events have made abundantly clear, large-scale economic disruptions may occur for reasons largely unrelated to human factors. An outbreak of disease, a shipping blockage in a major channel or port, a natural disaster, or extreme weather all carry the potential to impact a regionally concentrated industry to a far greater degree than a more broadly distributed supply chain. Major industrial accidents have already caused previous short-term disruptions to the solar-grade polysilicon industry.[204]

Solar project developers around the world have faced significant disruptions as a result of such incidents coupled with shifts in trade policies, causing shipping delays, cost escalations, and project postponements and cancellations.[205] A more globally distributed solar PV manufacturing sector will not only be more accountable to high labor and environmental standards, but will provide the industry with a more predictable supply of goods at a more stable cost.

Promising models for public sector policies to support diversification of global solar PV supply chains already exist. The recently passed Inflation Reduction Act in the United States, for example, grants manufacturing tax credits to companies that produce solar PV commodities domestically: 4¢ per watt for solar PV cells, $12/m² for wafers, $3/kg of solar-grade polysilicon, 40¢/m² of solar backsheet, and 7¢ per watt for solar PV modules.[206] The act further grants a 10% bonus to applicable clean energy investment tax credits and production tax credits for projects that utilize domestic components beyond defined domestic content thresholds.

This legislation has already prompted numerous new solar manufacturing announcements in the United States.[207] Similar public policies enacted by other governments to expand solar manufacturing in their countries and expand the global solar manufacturing sector beyond China could help accelerate global solar PV deployment. Meanwhile, continued complacency in the face of volatile industry overconcentration could very well act to impede solar PV technology's future.

How much more would solar PV sourced from an alternative supply chain cost?

An assessment of the challenges associated with diversifying solar manufacturing should evaluate the potential that such efforts could lead to somewhat higher costs for manufacturers and customers than the solar PV industry is currently accustomed to, at least temporarily. Given high exposure to Xinjiang-based operations in the first steps of the solar PV manufacturing chain and difficulties in reliably tracing commodities traded between Chinese solar PV companies, an overhaul of global solar PV supply chains may necessitate the establishment of nearly if not fully integrated manufacturing pipelines outside of China. Setting aside the efforts required to establish new large-scale manufacturing plants, what might the market price of non-Chinese solar PV commodities be relative to low-cost Chinese products?

A 2019 NREL modeling study[208] estimated that the minimum sustainable price (MSP) for a monocrystalline PERC solar PV module manufactured using a largely U.S.-based supply chain could be 1.41 times more expensive than a module produced by lowest-cost manufacturers in China ($0.48/watt versus $0.34/watt in 2018 dollars). This estimate, however, assumed that both the U.S. and Chinese supply chains would leverage uniformly priced, globally blended polysilicon, largely produced in China. Using the NREL study's modeled price for U.S.-made polysilicon and propagating this cost through NREL's calculations to assume a fully decoupled supply chain, we estimate that the MSP of entirely U.S.-produced solar modules implied by NREL's study could be 1.47 times that of lowest-cost Chinese producers (Figure 12; $0.51/watt versus $0.34/watt in 2018 dollars).

Note that this estimate of U.S.-produced solar PV modules at a cost of $0.51/watt still retains the overwhelming majority of the historical cost improvements in solar PV module costs over the past decade, which began with solar PV module costs at $1.70 to $1.90/watt in 2010-2011.[209] This assessment should increase confidence in the conclusion that other countries could establish large-scale solar PV production outside of China that could achieve comparably low costs.

How much more would solar PV sourced from an alternative supply chain cost?

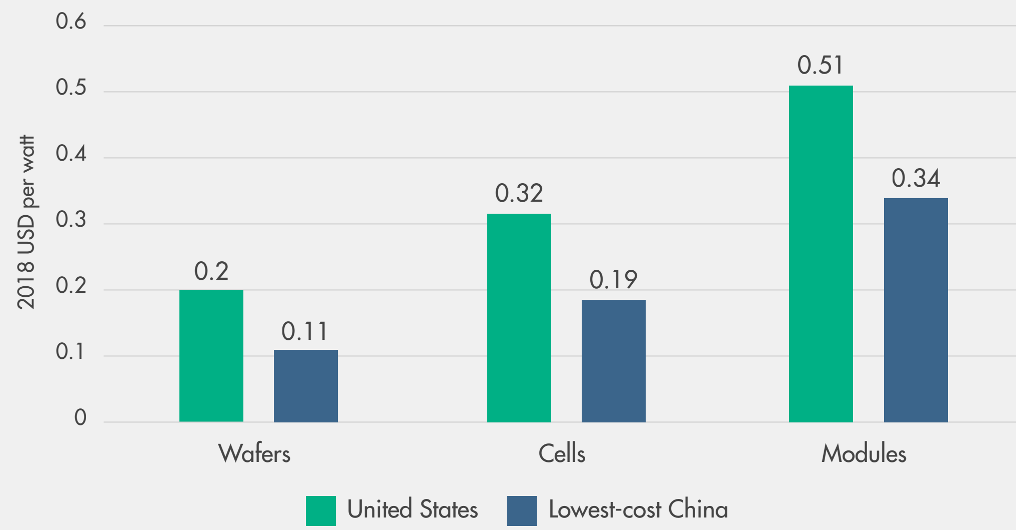


***Figure 12:** Market price difference between entirely U.S.-sourced solar PV commodities and lowest-cost manufacturing in China, adapted from a 2019 NREL modeling study. To convert between prices per wafer and per watt of different solar commodities as originally presented by NREL, this report assumed a 295 Wp solar module with 60 x M0 156.75 mm wafers.*

Admittedly, this NREL analysis and our derived estimate are both subject to large assumptions and convey only a general, relative assessment of cost differences between Chinese manufacturers and a hypothetical, nationally integrated, U.S.-based supply chain. The solar PV sector continues to rapidly evolve, affecting NREL's choice of methodology. For instance, the assumed industry-standard solar PV module has changed over time, with the solar PV industry having moved toward larger modules with 120 cells each, using M6 166 mm wafers, just in the few years since the NREL report's publication. In the future, industry standards are likely to shift toward even larger wafers of 182 mm and beyond.[210]

On the other hand, there is no express need for a diversified solar PV supply chain to be entirely integrated within a single country or even based in a high-income advanced economy like the United States at all. Alternatively, integrated configurations of the global solar PV industry, with fair and ethical solar manufacturing capacity increasingly established in emerging economies, could potentially bring products to market at more intermediate price points.

CONCLUSION: A MORAL CROSSROADS FOR THE GLOBAL SOLAR SECTOR

Given its status as a leading technology of the clean energy transition, the solar photovoltaic industry must strive to achieve the highest ethical standards. Failure to uphold responsible business practices carries the real, demonstrated potential to impact the short-term perception and long-term reputation of solar PV technology around the world, in turn affecting market demand, deployment, and technological progress.

Unfortunately, the solar PV sector's failure to scrutinize its growing supply chain links to forced labor and state-sponsored oppression in Xinjiang is already producing significant consequences. The United States has implemented stringent policies to restrict the import of goods sourced from Xinjiang, and the European Union may soon follow suit.[209]

Solar industry actors have begun to respond to concerns over ethical sourcing of solar PV commodities. However, many tracing and certification efforts underway are half measures that at best seek narrowly to avoid batches of goods produced wholly or in part within the boundaries of the XUAR, instead of targeting the Chinese companies themselves that are complicit in forced labor and environmental injustice. Such ineffective responses threaten to deepen both the global solar PV sector's complicity in and dependence upon unethical production.

In contrast, a more decisive stance by solar companies and developers will help galvanize private sector momentum toward action. Indeed, industry leaders and policymakers should move within a couple of years to exclude all goods originating from solar manufacturers with any operations in Xinjiang and from any downstream companies that source any product from those manufacturers.

Governments must support such efforts with policies that incentivize large-scale investments in new manufacturing industries elsewhere and should reward procurement of solar components from socially and environmentally responsible producers. The U.S. Inflation Reduction Act[210] provides a promising example for other countries to follow, while further public-private investment and incentives could further speed the pace of supply chain diversification. In a subsequent memo, we plan to outline policy and industry recommendations to accelerate international diversification of solar PV manufacturing.

Only stringent policies will send a sufficiently strong signal to Chinese solar PV manufacturers that the international market will not tolerate forced labor in solar PV supply chains. Shunning culpable producers entirely will also more effectively counteract their ability to market a portion of their products as Xinjiang-free (bifurcation) and to obscure the origin of shipments and production batches through fraud or blending of input materials (Figure 13).

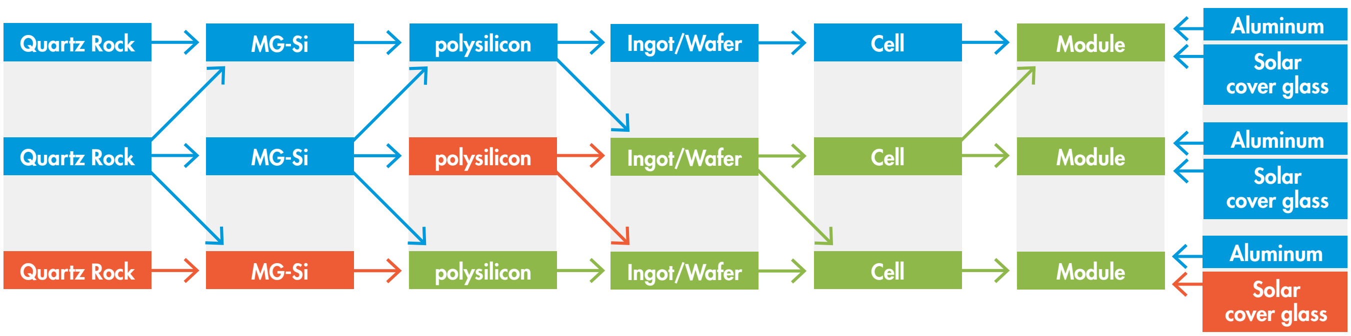


Figure 13: *Conceptual diagram illustrating how a tracing and certification program may allow some solar PV manufacturers (in green) to represent some fraction of product as free of forced labor risks in Xinjiang while still benefiting from supply contracts with upstream partners operating in Xinjiang (red). Blue font and arrows indicate companies with no direct or indirect links to Xinjiang. Note that many preliminary tracing protocols do not scrutinize sourcing of non-silicon materials such as aluminum or solar PV cover glass.*

Such a decisive stance by the solar PV industry would be consistent with long-standing demands from Uyghur, Kazakh, Kyrgyz, and other minoritized activists in exile who have called for broad boycotts of products from Xinjiang and businesses that trade in them.[211] Strong policies to bar products from solar PV manufacturers with links to Xinjiang and Xinjiang-based suppliers will also target corporate support for labor exchange programs, potentially helping to erode demand for one of Beijing's key instruments of oppression in the XUAR.

Bold action from the solar energy sector on supply chain justice[212] is all the more necessary given growing concerns that other areas of clean technology manufacturing could become more active in Xinjiang within the next few years. Recent reporting points to upcoming efforts by electric vehicle battery manufacturers to establish new factory capacity[213] and lithium mines[214] in the region. Broadly, the XUAR contains many potentially valuable mineral deposits for clean technology efforts, including nickel,[215] copper,[216] and graphite.[217] Without a clear and strong signal from the international community, the risk that other major manufacturing chains needed for the clean energy transition will become increasingly intertwined with Chinese government oppression in Xinjiang will only grow.

Moving forward, the industry must exercise the utmost vigilance to ensure that similar patterns of injustice are not repeated elsewhere in new centers of solar manufacturing. Efforts such as the Responsible Mining Index Framework[218] or the Ultra-Low-Carbon Solar Alliance[219] serve as promising examples of proactive approaches to ensure broad alignment of industry-wide practices.[220] Public policies and industry standards should stand broadly against forced labor, exploitative dispossession, and irresponsible environmental practices everywhere, not just in China. Any standards that seek to promote greater sustainability and fairer economic terms in the solar PV supply chain should strive to be international and universal in scope.

The door remains open for Chinese corporations and policymakers to enable a more rapid and efficient transition to ethical solar PV module production. Workers, employees, and officials can begin this process by opposing injustice in Xinjiang and calling for policy changes. Ultimately, firms should end participation in forced labor programs, lobby the central Chinese government to change its policies in Xinjiang, implement fair hiring and labor terms, establish ambitious clean energy goals, and commit to strong international industry environmental standards and best practices. Businesses can also apply pressure on upstream partners like coal mining zones, coal power plants, and other suppliers to follow suit. Companies that take meaningful, verifiable steps to adopt these approaches could then regain full access to the solar PV market.

Meanwhile, Chinese government leaders can start to reverse their policies in Xinjiang by not only ending labor transfer initiatives but by broadly restoring the personal freedoms of minoritized peoples and creating mechanisms to compensate victims of its policies and incorporate democratic input on the region's economic and political future. Throughout this reform process, companies and policymakers should invite international auditors and journalists to Xinjiang and give them unrestricted access to observe changing practices and policies in the region.

From a pragmatic perspective, however, particularly given the recent human rights track record of the Chinese government, the global solar PV industry should proceed under the assumption that such desirable corporate and governmental reforms in China are unlikely to take place. In time, one can only hope that combined pressure from the solar, garment, automotive, agricultural, and other sectors in conjunction with international criticism can persuade Chinese leaders to reconsider policies in Xinjiang that amount to crimes against humanity. However, given the need for global climate progress, the continued rise of solar photovoltaics cannot afford to wait for Beijing.

Greater pressure to accomplish ethical and sustainable solar manufacturing now, rather than later, will deliver climate and industry-wide benefits of its own. In addition to avoiding emissions, a well-executed shift away from Xinjiang-sourced production will promote greater innovation in manufacturing and could help expand global manufacturing capacity more rapidly. Diversification of the solar PV supply chain will help insulate worldwide solar deployment from disruption and promote a more stable, predictable supply of solar PV products. Finally, given the central role that clean solar energy will undoubtedly play in future decarbonized energy markets, early and bold efforts to establish new solar manufacturing facilities will undoubtedly reap large economic rewards for participating workers, governments, and companies.

In looking ahead, the solar sector should take faith from the last decade of extraordinary progress in solar photovoltaic technology. Particularly in conjunction with strong public sector support, the solar industry can not only achieve the same success in expanding solar PV manufacturing and deployment, but surpass it—all while maintaining strong commitments to ethical and environmentally responsible production.

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