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Analysis of Supply Chain Challenges in the U.S. Solar Industry: Focus on Build America, Buy America Act and Inverter Supply Issues

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Changing the World's Energy Future

Idaho National Laboratory

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Securing Solar for the Grid (S2G)

1. Introduction

The United States (U.S.) solar industry has been undergoing significant transformation, driven largely by meeting U.S. climate goals while simultaneously maintaining national security. At the forefront of this movement is the Inflation Reduction Act (IRA) and the Build America, Buy America (BABA) Act. The IRA has driven investment in clean energy generation deployments while the BABA Act, enacted under Division G, Title IX of the Infrastructure Investment and Jobs Act (IIJA) establishes domestic content procurement preference for all federal financial assistance obligated for infrastructure projects. [1,2] While these pieces of legislation aim to reduce reliance on foreign-made solar components and increase domestic production, the sector continues to face notable supply chain challenges. These are particularly pronounced with inverters, a critical component in solar photovoltaic (PV) systems. This report explores the current state of these supply chain challenges, with a specific focus on the impact of the BABA requirements and the associated complexities in inverter manufacturing and supply.

This document focuses on inverters in part because of their remote connectivity and associated potential to be misused by malicious threat actors, it is important to note that inverters are not the only components within a solar PV system that have the capability for remote connectivity and digital control. Other components that may have this capability include energy storage power conversion systems (PCS), monitoring systems (data loggers and gateways), solar trackers and environmental monitors, smart meters, and more. With that being said, many of the components mentioned above share components or manufacturers, and the supply chain challenges across this space are similar.

2. Raw Material & Semiconductor Constraints

Access to raw materials and semiconductors is a key constraint limiting domestic manufacturing of solar PV systems. Solar inverters depend on various critical materials, including copper, aluminum, and semiconductors. PV cells depend on silicon mining, and China produces over 10 times more silicon than the next-highest producer, Russia. [3] The global semiconductor shortage has created bottlenecks in the solar inverter supply chain. Domestic sources of these materials remain limited, and the current semiconductor industry is dominated by manufacturing facilities in Asia. [4] Efforts to address these shortages in the U.S. will require substantial time and investment. The Creating Helpful Incentives to Produce Semiconductors (CHIPS) Act provides funding and creates incentives to produce more semiconductors in the U.S., but seeing the results from this investment takes time. [5]

3. Key Solar Inverter Suppliers by Inverter Type

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There are three main types of inverters used in solar PV systems, microinverters, string inverters, and central inverters. [6] Each type has its own use case and comes in different power capacities depending on the system requirements. However, they all require some form of remote communications or remote access for operations and maintenance.

Micro inverters, the smallest of the three, are compact inverters installed on each individual solar panel. These inverters are commonly seen in residential and small-scale commercial installations. Key Micro inverter manufacturers include Enphase (U.S.), APsystems (US), SMA Solar Technology (Germany), Hoymiles (China), and Chilicon Power (U.S.). [6-8]

String inverters are bigger than micro inverters yet smaller than central inverters. These inverters are ideal for small to medium-sized installations with distributed power conversion. Key string inverter manufacturers include SMA Solar Technology (Germany), Huawei (China), Fronius (Australia), Solar Edge (Isreal), and Yaskawa Solectria Solar (U.S.). [6-8]

Central inverters, the biggest of the three, are typically used on large-scale utility farms. Key centralized inverter manufacturers include SMA Solar Technology (Germany), ABB/Hitachi Energy (Switzerland), Huawei (China), Sungrow (China), and Alencon Systems (U.S.). [6-8]

Although there are many global companies leading these markets headquartered in countries around the world, most of the manufacturing is done in China and other parts of Asia. In fact, 66% of solar inverter capacity manufactured in 2020 was from companies headquartered in China. [9] Broken down by component, the U.S. lags significantly behind Europe and Asia in terms of known locations capable of assembling power blocks and only manufactures 1% of passive components (e.g. cathode, wire, die, terminals), while China manufactures 43% and elsewhere in Asia accounts for another 33%. A small number of companies have vertical integration from the component level to the inverter level, most inverter components (i.e. the power electronics, passive components, and semiconductors) are bought then assembled separately. What this means is that most inverters, regardless of their size, are built with at least some key components designed or manufactured in China.

4. Domestic Manufacturing Capacity

Current U.S. production facilities do not have the infrastructure to meet the increased demand for domestically sourced inverters, causing a significant number of inverters to be imported. It is estimated that around 80% of solar inverters used in U.S. installations are imported from countries such as China and Germany. [8] U.S. inverter manufacturing capacity fell dramatically between the second half of 2020 and 2021, largely due to continued price declines for imported utility-scale inverters. [9] However, solar module (not inverter) manufacturing capacity has increased since the passage of the IRA in 2022, and

grew dramatically in Q1 of 2024, though manufacturing capacity still lags significantly behind installation capacity in the same time periods. Additionally, in Q3 of 2024, the U.S. began solar cell manufacturing for the first time since 2019. [10] Though not nearly as dramatic as solar module manufacturing capacity, U.S. inverter manufacturing has increased since 2022 too, with 7 GW of inverter manufacturing capacity across four facilities manufacturing hybrid inverters (serving PV and batteries, two facilities manufacturing microinverters, and one manufacturing string inverters. [11,12]

This high reliance on imports is due to several factors, including the established global production infrastructure of key manufacturers, lower production costs abroad, and the technical expertise that these international companies bring to the market. Passage of the Bipartisan Infrastructure Law (BIL) and other federal incentives appear to be highly correlated to an increase in domestic manufacturing capacity, noting that domestic manufacturing still involves purchase and assembly of key sub-components manufactured abroad.

5. The Risk of Relying on a Global Supply Chain

While importing from a global supply chain has benefits such as cost efficiency and the availability of resources to meet increasing demands, there are some geopolitical security and cybersecurity concerns that should not be overlooked. In general, security considerations from an unsecured supply chain may include hardware or software that could introduce backdoors or security flaws, counterfeit components in the manufacturing process, poor quality components that have potential for digital failure, lack of transparency regarding components and their origins, and weak vendor security practices. The concern is exacerbated when dealing with a foreign entity of concern (FEOC), such as China, Russia, Iran, and North Korea[1]. The Peoples Republic of China (PRC) dominates the solar inverter supply chain, causing the U.S. to be vulnerable to supply chain disruptions and creating national security risk. The PRC government has been known to appoint government officials to key positions within Chinese manufacturing facilities, giving them access to proprietary information and influence over critical business decisions. Company oversight is not the only way that the PRC can use private companies to their advantage, they also have federal laws that require all Chinese businesses, and foreign companies operating in China to report any vulnerability findings within 2 days of discovery. [14] Vulnerabilities that are disclosed to the PRC government can then be saved and used as a zero-day vulnerability to be exploited at an opportune time. Additionally, PRC government oversight could lead to the addition of

[1] A foreign entity of concern is defined in the Bipartisan Infrastructure Law if it is “owned by, controlled by, or subject to the jurisdiction of a government of a foreign country that is a covered nation.” As defined in 10 U.S.C. 3872(d)(2), covered nations include the People’s Republic of China, the Russian Federation, the Democratic People’s Republic of North Korea, and the Islamic Republic of Iran. [13]

hardcoded passwords and other backdoors placed in solar PV components, making them increasingly susceptible to cyber-attacks.

6. BABA and IRA Requirements

BABA and the IRA are government actions taken to help bolster domestic manufacturing capabilities. BABA mandates that federally funded projects must use domestically manufactured materials and components wherever possible or obtain waivers if these are not reasonably available. The IRA incentivizes private companies with tax credits for meeting domestic content requirements. These policies impact solar inverter procurement by requiring compliance with domestic content criteria or justifying reliance on imports through the waiver process. Under the IRA's investment tax credit (ITC) for clean energy, companies can be eligible to receive up to 10% bonus tax credit for meeting domestic content requirements. Both the project owner and U.S. manufacturer are eligible for the ITC.
Eligibility for IRA credits and adherence to BABA mandates requires the following:

- 100% of steel and iron products must be U.S. made. This applies to PV module racks, rebar in foundations or concrete pads, and ground screws.
- Before the year 2025, 40% of manufactured products must be domestically sourced to be eligible for the full 10% bonus. The percentage requirement of domestic content will then increase to 45% in 2025, 50% in 2026, and 55% after 2026. Manufactured products in a solar PV system may include PV modules, inverters, PV trackers, and other manufactured components.

One method for calculating the domestic content is as follows:

Domestic materials* ($) = *A*
Foreign Materials ($) = *B*
Domestic Labor* ($) = *C*
$\frac{A+C}{A+B+C}$ = Domestic Content %
*Direct costs, excludes all overhead on materials and labor.

For each component of this calculation, the cost used includes the total cost for the system (e.g. PV module, inverter, and PV tracker costs are all added up).

Another way to calculate domestic content can be found using the guidelines issued by the U.S. Treasury in *Notice 2024-41, New Elective Safe Harbor to Determine Cost Percentage for Adjusted Percentage Rule*. [15] In this method, the manufactured product is broken down into components, and each component is assigned a percentage of the full system that it represents based on cost[2]. Each individual

[2] Note that cost does not necessarily represent criticality to the system. Some digital components may have far greater impact on the security system but may be outweighed in cost by "dumb" components in this calculation.

manufactured product component (MPC) is either produced domestically or not. If the MPC is domestically manufactured, then the percentage it was assigned can be included in the overall domestic manufacture percentage. See the template for this calculation in the Table below.

Applicable project components (APC)	Subcomponents (MPCs)	Domestic?	MPC % of the total system (example)	APC % of the total system (example)	Domestic content percentage
APC 1 (e.g. PV module)	MPC 1 (e.g. PV cells)	No	55%	65%	$A = (0x0.55 + 1x0.05 + 0x0.05) = 0.10$
	MPC 2 (e.g. mount)	Yes	5%		
	APC 1 Production*	Yes	5%		
APC 2 (e.g. inverter)	MPC 3 (e.g. PCBAs)	No	2%	10%	$B = (0x0.02 + 0x0.01 + 1x0.04 + 1x0.02 + 1x0.03) = 0.06$
	MPC 4 (e.g. electrical parts)	No	2%		
	MPC 5 (e.g. climate control)	Yes	4%		
	MPC 6 (e.g. enclosure)	Yes	2%		
	APC 2 Production*	No	3%		
APC 3 (e.g. PV tracker)	MPC 7	Yes	10%	25%	$C = (1x0.10 + 1x0.07 + 1x0.08) = 0.25$
	MPC 8	Yes	7%		
	APC 3 Production*	Yes	8%		
TOTAL					$A + B + C = 41\%$

* Using this methodology, the Production category for each APC can only be claimed if all MPCs are 100% domestic content.

Proof of compliance with BABA requires that prime recipients must maintain certifications or equivalent documentation for proof of compliance that those articles, materials, and supplies that are consumed in, incorporated into, affixed to, or otherwise used in the infrastructure project, not covered by a DOE waiver or exemption, are produced in the United States. [2] The certification or proof of compliance must be provided by the suppliers or manufacturers of the iron, steel, manufactured products and construction materials and flow up from all sub-awardees, contractors and vendors to the prime recipient. Prime Recipients must keep these certifications with the award/project files and be able to produce them upon request from DOE, auditors or Office of Inspector General. The prime recipient is responsible for flowing the Buy America Requirement down to all sub-awards, all contracts, subcontracts, and purchase orders for work performed under the proposed infrastructure project, including to For-Profit Entities when the For-Profit Entity is a sub-recipient or sub-awardee.

BABA waivers may be granted if the item is not reasonably available or if U.S. sources would increase the overall project cost by more than 25%. [2] Requests to waive the application of the Buy America Requirement in an award must be submitted by the Prime Recipient in writing to the DOE Contracting Officer or Grants Officer in accordance with the terms and conditions of the award. The process could take up to 90 days and includes a public comment period of no less than 15 days.

Although waivers are available and may be applicable for certain parts of solar PV systems, it is important for organizations to understand all requirements that may apply to them. For example, defense-serving entities may have different requirements. It is recommended to review the National Defense Authorization Act (NDAA) language. Section 154 of FY24 NDAA describes the prohibition of availability of funds for procurement of certain batteries. [16] Additionally, state and local guidelines may impose additional restrictions or instructions. Even if domestic content is not required, tax credits may still be available for voluntary compliance.

7. Impact of the Build America, Buy America Act

Although the IRA and BABA are well intentioned policies, they have had both positive and negative impacts on the solar industry. On the positive side, they have driven a surge in domestic production of solar PV components. By prioritizing U.S.-made products for federal projects, the IRA has incentivized investments in American manufacturing facilities. This has led to new manufacturing plants which in turn has created more jobs in the U.S.. By fostering a robust domestic supply chain for solar PV components, the U.S. has reduced its reliance on imported components, mitigating risks associated with international trade tensions and logistical challenges.

However, BABA has also led to higher labor and operational costs compared to countries with lower production expenses. These costs are often passed on to consumers, making solar projects more expensive. BABA has also led to supply chain bottlenecks. The rapid scaling up of domestic manufacturing has caused some short-term bottlenecks, such as shortages of raw materials or skilled labor, and further driving up costs.[17] There have also been more regulatory and compliance burdens associated with BABA content requirements. Ensuring compliance with BABA can be complex and time-consuming, leading to increased administrative work and potential delays in project timelines, affecting the timely deployment of solar PV systems.

The domestic content calculation methods are based on the cost of parts and labor, not on their criticality to the system. In part, this can be seen by the dramatic growth of domestic PV module manufacturing capacity compared to the modest growth of domestic PV inverter manufacturing capacity since BABA and the IRA were announced. Since PV modules make up a larger part of the overall cost of the system, their domestic manufacture is weighted heavier, despite the fact that the inverters

and other digital or “smart” components are more critical from a cyber supply chain security perspective.

8. Current Industry Response

In response to these challenges, several U.S. companies and government agencies are taking steps to alleviate supply chain bottlenecks and increase domestic production capacity.

8.1 Contract Manufacturing Arrangements

One of the key strategies being employed is the use of contract manufacturing. Companies like Enphase have partnered with third-party manufacturers to establish production lines within the U.S. without having to build their own factories from scratch. For example, Enphase’s partnership with Flex in South Caralina and Salcomp in Texas have allowed them to scale up production relatively quickly, although the efforts are still limited by overall manufacturing capacity. [18]

8.2 Government Support and Grid Modernization

To address the broader supply chain issues, the U.S. government is investing in infrastructure and grid modernization. This includes the development of regional innovation hubs, where solar manufacturers, utilities, and academic institutions collaborate to foster innovation and workforce training. These efforts are intended to improve the long-term capacity of the U.S. solar industry, although they are unlikely to have immediate effects on the current inverter shortage.

9. Conclusion

The U.S. solar industry is at a pivotal moment. The incentives offered by the BABA act and the IRA offer significant opportunities to expand domestic manufacturing, but they also introduce immediate supply chain challenges, particularly for inverters. While the industry is adapting through contract manufacturing and other strategies, further investment in infrastructure, workforce development, and grid modernization will be necessary to meet the growing demand for solar energy. While meeting the demand for clean energy is important, it should not be done with a reckless abandonment of national security. It is crucial that the U.S. can have complete confidence in the components that are being added to the energy grid and should be cautious when importing certain components from FEOCs. Addressing these challenges head-on will be critical to achieving the U.S.’s climate goals and ensuring the long-term success and security of the domestic solar industry.

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