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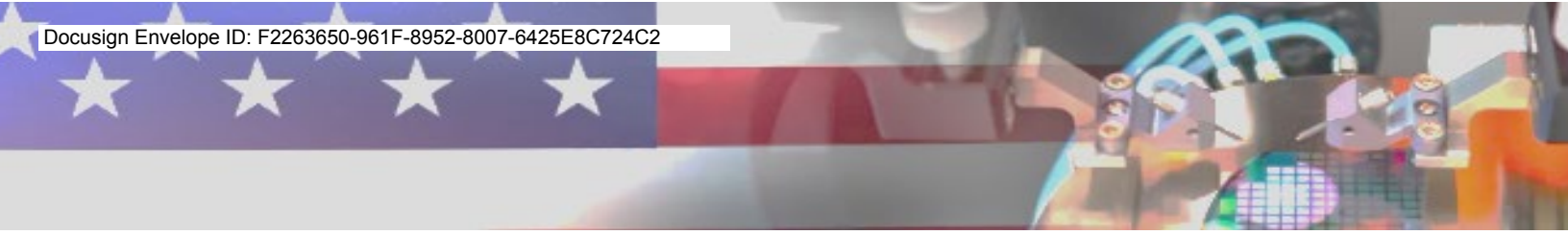

Winning the Technology Race Against Foreign Competition: A U.S. Strategy for Perovskite Optoelectronics

Recommendations from the US-MAP Industrial Advisory Board[1]

Executive Summary

Nations are competing to capitalize on the enormous potential of perovskite semiconductors. Perovskites are an emerging class of thin-film optoelectronic semiconductors that can be rapidly deposited at large scale on flexible or rigid substrates. Leadership in perovskites will ensure that the U.S. will have strategic positions in space, defense, display, and energy technologies. Beyond the importance for national security, commercialization opportunities are worth hundreds of billions of dollars for the U.S. economy.

Perovskites provide significant advantages for civilian, space, and military technologies. Perovskites enhance efficiency and reduce the weight of power generation systems for satellites, warfighters, and aerial drones; they also enable next-generation displays and large-area X-ray scanners for medical and homeland security applications. Manufacturing is relatively labor- and capital-light, which undermines labor-cost and capital-cost advantages that foreign competitors have leveraged to erode US dominance in semiconductor manufacturing over the last 40 years. **Competing in perovskites is both a strategic and economic imperative.**

U.S. investment will counteract foreign dominance in semiconductor manufacturing. China now owns about 93% of worldwide silicon production – which creates a strategic supply chain threat for all semiconductors. Perovskites are poised to replace silicon in optoelectronics. **China has invested more than 30x more than the U.S.** to support perovskite R&D and production, with the aim of securing technological leadership. If China succeeds, it could control supply chains for both silicon and perovskite technologies.

The United States can leapfrog foreign competition by investing in domestic perovskite technology. To seize the opportunity, however, the U.S. must commit to perovskite R&D, scale-up, supply-chain, and know-how across multiple sectors. China is investing nearly $1B, but the U.S. FY2026 budget allocates only $25M for perovskite development and scaling. ***To ensure US competitiveness, we recommend dramatically ramping up federal support for innovation, factory and supply chain investment, and workforce development while also enforcing intellectual property rights in the international arena.***

[1] This document was produced by the Industrial Advisory Board (IAB) of the US-MAP (U.S. Manufacturing of Advanced Perovskites) Consortium. The US-MAP IAB is a group of executives and leaders from companies that develop and deploy perovskite technology. US-MAP IAB independently advises a group of U.S. national labs and universities on research priorities to best support industrialization. All opinions and recommendations expressed herein are the sole responsibility of the US-MAP IAB signatories below.

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Four key recommendations to secure domestic perovskite dominance

Supporting detail and rationale follows

1) **Support and maintain U.S. technological leadership**
   a) Reinstate DOE perovskite R&D awards that were terminated or not started (FY25 and FY26) to ensure continuity of progress.
   b) Triple the investment provided in H. Rept. 119-213 for research, development and demonstration activities related to perovskites from $10M to $30M, and establish a Perovskite Technology Accelerator Consortium. Focus funding on pre-competitive research on advanced materials processing and durability.
   c) Direct Department of War and Department of Energy laboratories to develop tests and standards for reliability and quality for space, military, and terrestrial missions. Allocate $10M each to DOW and DOE for investment in facilities and $20M/year each for standard development and related testing and research.

2) **Support manufacturing deployment and domestic supply chain development, to level the playing field with subsidized foreign competition**
   a) Launch federal loan guarantee program for perovskite manufacturing facilities and equipment; we recommend supporting $200M of guarantees in FY2027, and $500M in FY2028.
   b) Allocate $100M in the FY2028 National Defense Authorization Act to support a domestic supply chain for perovskite manufacturing for defense applications, such as next-generation space and unmanned vehicles.
   c) Support states to create similar programs or participate in risk-sharing to encourage companies to expand in their state. Encourage public / private partnerships in these programs.
   d) Support demand by continuing Section 45X Advanced Manufacturing Production Credit in the OBBB, to ensure that next-generation materials and advanced manufacturing capabilities are built and scaled in the United States.

3) **Defend our intellectual property (IP)**
   a) Develop oversight to restrict imports from companies that use stolen IP or equipment.
   b) Form an “IP Alliance” with partner countries to encourage sharing of best technologies between partners, while sidelining persistent IP violators.

4) **Invest in US workforce, talent, and innovation**
   a) Expand and focus existing technician training programs to build American skills in manufacturing processes and equipment.
   b) Create internship and training programs to prepare technicians and engineers to support industry.
   c) Support post-doctoral internships at National Labs to support advanced training.

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Background: The Opportunity and the Threat

Perovskites are semiconductors, like silicon, but unlike silicon they can be printed onto glass, plastic and other substrates at low cost. The unique characteristics of perovskites makes it a key national security and economically strategic technology for the United States. Unlike silicon, perovskite manufacturing has low capital and labor costs, and a clear path to an all-American supply chain.

Already, a worldwide technology race is on to exploit various applications, such as military and medical imaging devices, large-format X-ray imagers to inspect shipping containers, lightweight solar power for satellites, and lower-cost high efficiency terrestrial power generation. Selected markets, applications, and US companies already exploring those applications are listed in Table 1. If the U.S. acts now, we can develop and expands industries with billions in annual revenues, achieve national energy security, and at the same time strengthen strategic defense technology and supply chains.

Table 1: National security and economically strategic markets for perovskite semiconductors, example applications, and examples of US domestic commercial entities with substantial R&D efforts.

Market (total size)	Perovskite application and advantages	Example commercial R&D and deployment
Space ($630B)	Lightweight/roll-to-roll, higher-efficiency and radiation-hardened satellite power	Blue Origin, Northrop-Grumman, US Space Force
Terrestrial power ($300B)	More efficient and lower-cost solar power for civilian use. Lightweight flexible solar power for military applications.	>10 companies (including US-MAP members)
Medical & Homeland Security Imaging ($63B)	High resolution X-ray and gamma-ray imaging, large-scale cargo container screening, radiation monitoring	GE Healthcare, Innovaflex
Displays ($10B)	Brighter and higher-resolution displays with high color fidelity	Universal Display
Quantum dots ($6B)	Dynamic tintable and energy-saving windows, efficient indoor agriculture	BlueDot, UbiQD

Expanding these industries enables other US industries while creating manufacturing jobs. For example, it is projected that AI datacenters will require 100GW of new electricity demand per year; AI companies are likely to turn to solar power plus storage to meet a large portion of this demand “behind the meter”, due to its available supply and relatively fast installation time. At current domestic prices of about $0.30/W for solar panels, 100 GW of domestic PV on-shores $30B of industry and manufacturing jobs, while de-bottlenecking AI deployment in the US.

The main threat to domestic perovskite development is foreign subsidies. The worldwide perovskite industry is currently either in late-stage R&D or in relatively small-scale manufacturing phases. China is subsidizing its nascent perovskite industry through state-owned enterprises in amounts of >$300M directly, and up to $1B in support for manufacturing capital equipment and facilities. In contrast, the US FY2026 budget allocates only $10M for perovskite R&D and demonstration activities, plus $15M to accelerate the development of perovskite manufacturing.

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China's investments in perovskites are nominally focused on its photovoltaic (PV) solar industry, however history shows this strategy also has major supply-chain implications for defense semiconductors. Throughout the 2010's, the China Development Bank provided over $28 billion in financings to its own renewable energy companies. As shown in Figure 1, in just 10 years this resulted in China dominating the PV industry with 2023 revenues > $130B[2]. But it also granted China a strategic advantage: because PV dominates consumption of global high-purity silicon (>90%), China also came to dominate >80% of global silicon production, with obvious implications for defense and other supply chains.

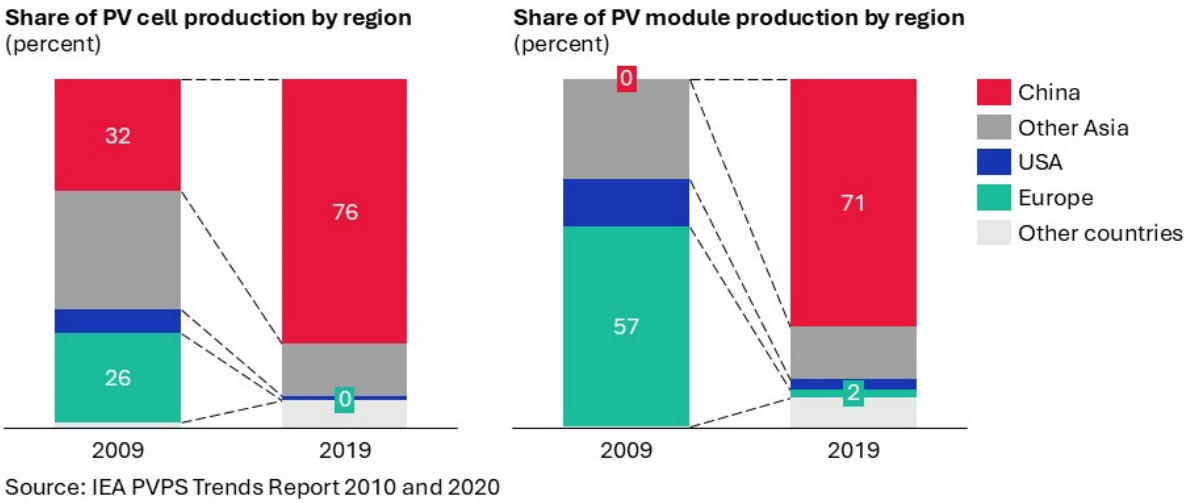

Figure 1: The result of Chinese subsidies in the 2010s is a total dominance of silicon solar. About $28B in financings over a decade resulted in >$130B of annual Chinese revenues.

Perovskite technology (and the expertise to manufacture it) will benefit whoever develops it first and fastest. Because perovskites are still an emerging technology, much smaller investments made wisely can enable the US to stay ahead. By pivoting towards next-generation perovskite semiconductor-based technologies, the US gains a clear path to a domestic supply chain for the strategic national security technologies outlined above.

[2] https://www.woodmac.com/news/opinion/how-will-chinas-expansion-affect-global-solar-module-supply-chains/

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Rationale for the Four Key IAB Recommendations

1) Support and maintain U.S. technological leadership

a) Reinstate DOE awards that were terminated or not started (FY25 and FY26) to ensure continuity of progress.

Reinstating pre-existing awards gets the industry back on track quickly and accelerates the timeline for shovel-ready manufacturing projects. Several companies were already poised to accelerate their R&D activities in collaboration with national labs and universities. A lack of investment and progress in FY26 will leave the US behind existing foreign competition and open the door for new foreign entrants. It is far more efficient to maintain dominance than to play catch-up later.

b) Triple the seed investment provided in HR 119-213 for research, development and demonstration activities related to perovskites from $10M to $30M and establish a Perovskite Technology Accelerator Consortium. Focus funding on pre-competitive research on advanced materials processing and durability.

HR 119-213 reported funding recommendations for two areas: R&D/demonstration activities, and manufacturing support:

> "*The recommendation provides $10,000,000 for research, development, and demonstration activities related to perovskites. The Department is encouraged to consider providing direct support for a companion research accelerator to advance the underpinnings of the technology, following the model established for the CTAC. In addition, the Committee also recommends $15,000,000 to accelerate the development of manufacturing plants for perovskite photovoltaics and to issue awards to entities that are prepared to scale up perovskite solar technologies with an emphasis on building out the U.S. supply chain.*"

We believe increasing the R&D/demonstration budget from $10M to $30M will significantly accelerate our domestic pace of innovation and keep US technology competitive. The IAB's internal survey of its members identifies top research priorities as durability and materials processing.

Given that China has been subsidizing perovskite manufacturing with nearly $1B of state investment, the $15M recommended in HR 119-213 to support perovskite manufacturing is at best a feeble response. We believe a loan guarantee program will be the most effective response, as detailed below in Recommendation 2.

c) Direct Department of War and Department of Energy laboratories to develop tests and standards for reliability and quality for space, military, and terrestrial missions. Allocate $10M each to DOW and DOE for investment in facilities and $20M/year each for standard development and related testing and research.

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Standards are the backbone of efficient industrialization. They are one means by which end-customers (civilian or military) express requirements for products and components. They also enable interchangeability and compatibility of parts, and engineering for performance, durability and safety.

Military, space, and civilian standards (and associated testing and qualification methods) often differ from each other because the applications for products can be very different. The capital equipment needed to develop test methods is significant since it often includes accelerated environmental stress testing for thermal cycling, damp heat, humidity freeze, X-ray/UV and visible light exposure, and combinations of these, plus associated characterization and failure analysis instrumentation. We recommend $10M for space/military and $10M for civilian laboratories to ensure adequate equipment for laboratories; plus $20M/year each to support scientific, engineering, and technician staff to drive this effort. These budgets and efforts should be managed by existing DOW and DOE labs, respectively.

2) **Support manufacturing deployment and domestic supply chain development, to level the playing field with subsidized foreign competition**

   a) *Launch federal loan guarantee program for perovskite manufacturing facilities and equipment; we recommend supporting $250M of guarantees in FY2027, and $500M in FY2028.*

China has invested nearly $1B to date in perovskites, which creates headwinds for domestic industry to compete. China's government directly invests in enterprises and subsidizes capital equipment.

As an alternative to direct investment, the US can instead leverage the strength of its robust private equity and venture capital base by providing facility and equipment loan guarantees to qualified applicants with sufficient equity backing. Government-backed equipment loan guarantees have proven catalytic, by dramatically lowering cost of private capital, with minimal government cash expenditure. In these arrangements, companies pay a down payment and make debt obligations to private debt financiers in exchange for the remainder of cash needed to purchase capital equipment. A government guarantor takes on limited loss backstops in case of corporate default. If all goes well, the guarantor pays nothing; if trouble comes, the government pays an agreed portion of the loss to the capital provider. This allows private capital providers to offer lower interest rates. At the same time, because of the company's required down payments (funded by equity), companies still compete on a fair playing field. This way the government doesn't choose winners, the equity markets do.

This approach is not new; recognizing the centrality of food supply chains to homeland security, the U.S. government provides similar programs for novel capital equipment for farmers through the USDA. In this case loan guarantees could presumably be managed by the existing DOE Loan Programs Office.

In order to prevent such programs from favoring one state's companies over another, the federal government could also consider allowing states to participate in supporting these programs, e.g. with senior/subordinate state/federal tranches of risk.

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It would be fair to ask if these guarantees would be sufficient if China has invested $1B. We believe the government support would leverage private capital which will fill the remaining investment gap.

b) *Allocate $100M in the FY2028 National Defense Authorization Act to support a domestic supply chain for perovskite manufacturing for defense applications, such as next-generation space and unmanned vehicles.*

Perovskites are printable on thin lightweight flexible substrates and can in principle be unfurled in space and terrestrial theatres to enable rapid powering of defense systems. Perovskite / silicon tandems can generate 30% more power per unit area than silicon alone.

The first area of support needed is for companies focused on devices that create these capabilities. But strategic considerations demand also developing a US-based supply chain for essential components to make such devices. Fortunately, perovskites generally contain little to no critical minerals, and key functional chemistry is typically lab synthesized. In short, the supply chain is likely to be dominated by know-how, not natural resources. Supporting specialty chemical companies making perovskite materials and developing manufacturing equipment for specialty applications of perovskite devices can ensure that the US has the knowledge advantages it needs throughout its supply chain.

c) *Support states to create similar programs or participate in risk-sharing to encourage companies to expand in their state. Encourage public / private partnerships in these programs.*

Silicon semiconductor manufacturing facilities depend on having a local ecosystem of smaller support companies for servicing tools and equipment with deep specialty know-how. Perovskites, on the other hand, have relatively low capital and infrastructure requirements, and currently there are no well-established hubs of perovskite manufacture. Therefore perovskites are an opportunity for states to develop a semiconductor manufacturing base.

One simple means for states to quickly and easily encourage private capital investment in their state would be to leverage the proposed federal loan guarantee program. This could be done by having states simply pledge primary or secondary insurance above and beyond federal limits, for companies building manufacturing plants in their state.

d) *Support demand by continuing Section 45X Advanced Manufacturing Production Credit in the OBBB, to ensure that next-generation materials and advanced manufacturing capabilities are built and scaled in the United States.*

Project Warp Speed achieved record times for covid vaccine development and deployment in part because it directly subsidized both supply (upfront R&D costs) and demand for the technology (via demand guarantees); the latter reduced risk and thereby leveraged private investment. Similarly, because 45X is performance-based and paid only after domestic

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production occurs, it aligns with market principles while efficiently leveraging private capital to strengthen U.S. industrial competitiveness and supply-chain security.

3) **Defend domestic intellectual property (IP)**
   a) *Develop oversight to restrict imports from companies that use stolen IP or equipment.*
   b) *Form an "IP Alliance" with partner countries to encourage sharing of best technologies between partners, while sidelining persistent IP violators.*

   The United States as an innovation leader has struggled with IP theft. Without a mechanism for enforcement, competitors that violate our IP will continue to do so.

   The US should efficiently adjudicate requested injunctions against imports of products made by companies that violate US IP. This is simply common-sense application of existing law. Existing courts and law can be leveraged as they often are already. Unfortunately, in the case of thin-film semiconductors like perovskites, IP theft can be difficult to detect by inspection of a competitor's product because single-molecule-thick layers between interfaces are used for specific purposes, so it is technically difficult to prove infringement using physical evidence. However, it may be possible to stop or slow down infringement at the source, by changing the way innovative countries share information. Currently federally supported research is often mandated to be broadly disseminated. This policy could be dropped in the case of fundamental perovskite research, but this is still unlikely to significantly slow the sharing of know-how with countries intent on theft of IP. An additional step has been proposed within the IAB that publication could be subject to masking of specific chemistries or processing details used. However, this conflicts with our goal of attracting top scientists to work on perovskites: scientific reputations are made by publishing. So before we take such an approach, research funding agencies must (a) commit to rapid review and approval for publication (or disapproval), and (b) US and EU-based journals must not penalize authors for not sharing details that have been deemed sensitive by funding agencies. (c) The US should provide funding to support restricted-access conferences to allow dissemination of information with other citizens of countries that enforce IP law.

4) **Invest in US workforce, talent, and innovation**
   a) *Expand and focus existing technician training programs to build American skills in manufacturing processes and equipment.*
   b) *Create internship and training programs to prepare technicians and engineers to support industry.*
   c) *Support post-doctoral internships at National Labs to support advanced training.*

   US-based industry will create demand for many technicians and operators capable of troubleshooting, maintaining and operating complex equipment. These skilled roles are high-paying jobs that do not require a college degree, but do require substantial investment in training. This is a general need in American manufacturing, driven by advanced equipment in many industries. For this reason, we recommend leveraging existing programs and funding for the NSF Technology Innovation & Partnerships. A primary need is advanced machine technology training and internship programs that train Americans in practical electronics, machine troubleshooting and maintenance, and chemical and semiconductor process fundamentals. Needs for such skills will exist in many industries, not just

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perovskites, as we see a renaissance in American manufacturing on the near-term horizon. Training for degree-holders can be supported by the investments recommended in Recommendations 1 and 2, by directing some of the research to be performed by advanced-degree interns and post-doctoral interns.

Summary and Conclusions

Perovskites have many potential applications in military, space and civilian applications, with enormous economic opportunities. Foreign competitors including FEOC are making much larger investments to support perovskite development than the US. The US and EU have not fallen behind in technological know-how, but we are in danger of falling behind in industrial deployment, establishment of supply chains, and we are in danger of having our intellectual property stolen.

The US-MAP IAB signatories below recommend a substantial increase in federal and state funding of perovskites to achieve four key objectives: (1) retain technological superiority, (2) support industrial deployment and establishing domestic supply chains, (3) protect our intellectual property, and (4) invest in workforce development for manufacturing.

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Signatures

DocuSigned by:
Skylar Bagdon
8B8B65BCFE7144F...

Skylar Bagdon
Chief Commercial Officer
Verde Technologies, Inc.
Waterbury, VT

Signed by:
654881CD9FAD46F...

Giles Eperon, Ph.D.
Chief Science Officer
Swift Solar, Inc.
Foster City, CA

DocuSigned by:
1DDB1EE940DB497...

Scott Graybeal
Chief Executive Officer
Caelux Corporation
Baldwin Park, CA

Signed by:
Greg Horner
FE8A42D849314E4...

Greg Horner, Ph.D.
Chief Technology Officer
Tau Sciences
Hillsboro, OR

DocuSigned by:
44D1A35DB8DF40B...

Gervais Jacques
Chief Executive Officer
5N Plus, Inc.
Bridgeport CT / St. George UT

Signed by:
MARTIN KIENER
49616A995D3D4A5...

Martin Kiener
CEO & Founder
FOM Technologies
Seattle WA

Signed by:
Adam Lorenz
4A062B233A8741F...

Adam Lorenz, Ph.D.
Chief Technology Officer
CubicPV
Bedford, MA

DocuSigned by:
Cory Perkins
376A2EF0A2FB45E...

Cory K. Perkins, Ph.D.
Chief Executive Officer
nexTC Corporation
Corvallis, OR

Signed by:
Scott D Wharton
94EC4A441CCF4B6...

Scott Wharton
Chief Executive Officer
Tandem PV
Fremont, CA