HEARING ON TECHNOLOGY, TRADE, AND MILITARY-CIVIL FUSION: CHINA'S PURSUIT OF ARTIFICIAL INTELLIGENCE, NEW MATERIALS, AND NEW ENERGY

HEARING

BEFORE THE

U.S.-CHINA ECONOMIC AND SECURITY REVIEW COMMISSION

ONE HUNDRED SIXTEENTH CONGRESS
FIRST SESSION

FRIDAY, JUNE 7, 2019

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UNITED STATES-CHINA ECONOMIC AND SECURITY REVIEW COMMISSION

WASHINGTON: 2019

U.S.-CHINA ECONOMIC AND SECURITY REVIEW COMMISSION

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The Commission's full charter is available at www.uscc.gov.

June 26, 2019

The Honorable Chuck Grassley
President Pro Tempore of the Senate, Washington, DC 20510
The Honorable Nancy Pelosi
Speaker of the House of Representatives, Washington, DC 20515

Dear Senator Grassley and Speaker Pelosi:

We are writing to notify you of the Commission's June 7, 2019 public hearing on "Technology, Trade, and Military-Civil Fusion: China's Pursuit of Artificial Intelligence, New Materials, and New Energy." The Floyd D. Spence National Defense Authorization Act for 2001 § 1238, Pub. L. No. 106-398 (as amended by the Carl Levin and Howard P. "Buck" McKeon National Defense Authorization Act for Fiscal Year 2015 § 1259b, Pub. L. No. 113-291) provides the basis for this hearing.

At the hearing, the Commissioners received testimony from the following witnesses: Jeffrey Ding, China lead for the Center for the Governance of AI, Future of Humanity Institute, University of Oxford; D.Phil. Candidate, University of Oxford; Helen Toner, Director of Strategy at Georgetown University's Center for Security and Emerging Technology; Elsa Kania, Adjunct Senior Fellow, Technology and National Security Program at the Center for a New American Security; Research Fellow at CSET; Richard Silberglitt, Ph.D., Senior Physical Scientist, RAND Corporation; Professor, Pardee RAND Graduate School; Dan Coughlin, Vice President of Composites Market Development, American Composites Manufacturers Association; Alan Hill, Government Relations Partner, National Graphene Association; President, J.A.Hill Group, LLC; Joanna Lewis, Ph.D., Associate Professor of Science, Technology and International Affairs, Georgetown University; Jessica Lovering, Director of Energy at the Breakthrough Institute, Ph.D. Student at Carnegie Mellon University; and James Greenberger, Co-founder and Executive Director of NAATBatt International. This hearing examined China's development of artificial intelligence, new materials, and energy storage, renewable energy, and nuclear power. It assessed China's capabilities in producing and commercializing these technologies vis-à-vis the United States and its ambitions to export these technologies and shape their global governance in ways that disadvantage the United States. The hearing also considered China's potential military application of these technologies and strategic implications for the United States.

The full transcript of the hearing, prepared statements, and supporting documents are posted to the Commission's website, www.uscc.gov. Members and the staff of the Commission are available to provide more detailed briefings. We hope these materials will be helpful to the Congress as it continues its assessment of U.S.-China relations and their impact on U.S. security.

The Commission will examine in greater depth these issues and the others in our statutory mandate this year. Our 2019 Annual Report will be submitted to Congress in November 2019. Should you have any questions, please do not hesitate to have your staff contact one of us or our Congressional Liaison, Leslie Tisdale Reagan, at 202-624-1496 or lreagan@uscc.gov.

Sincerely yours,

Carolyn Bartholomew
Chairman

Robin Cleveland
Vice Chairman

cc: Members of Congress and Congressional Staff

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TECHNOLOGY, TRADE, AND MILITARY-CIVIL FUSION: CHINA'S PURSUIT OF ARTIFICIAL INTELLIGENCE, NEW MATERIALS, AND NEW ENERGY

FRIDAY, JUNE 7, 2019

U.S.-CHINA ECONOMIC AND SECURITY REVIEW COMMISSION

Washington, DC

The Commission met in Room 215 of Dirksen Senate Office Building, Washington, DC at 9:30 a.m., Vice Chairman Robin Cleveland and Commissioner Thea Lee (Hearing Co-Chairs) presiding.

OPENING STATEMENT OF COMMISSIONER LEE
HEARING CO-CHAIR

COMMISSIONER LEE: Good morning, everybody.

Welcome to the fifth hearing of the U.S.-China Economic and Security Review Commission's 2019 Annual Report Cycle.

I want to thank our witnesses for being here today and for the time they put into their excellent written testimony.

I would also like to thank the USCC staff for their excellent work in pulling together the hearing and the Senate Finance Committee and its staff for helping to secure our hearing room today.

Today's hearing will assess the Chinese government's ambitions and progress toward global leadership in three sectors: artificial intelligence, new and advanced materials, and new energy, particularly energy storage and nuclear power.

As opposed to more mature sectors, commercialization of technological advances in these fields could be highly disruptive to our current economy, creating many new jobs but also displacing other jobs and commerce.

Many of these advances have military as well as commercial applications and could provide U.S. adversaries with asymmetric advantages against superior conventional weapons systems.

In short, the stakes are high and continued U.S. technological leadership is not guaranteed. The systematic and policy-driven efforts of the Chinese government to secure a decisive advantage in these technologies present a significant threat.

For instance, China's government has expressly enacted a plan of becoming the global leader in AI by 2030 and is already applying AI to a range of problems that challenge U.S. interests and values.

Likewise, Chinese materials science has benefitted tremendously from a combination of state support and an inflow of talent educated in the United States.

China stands poised to commercialize many discoveries made by U.S. laboratories at the expense of U.S. manufacturers, funded at least in part by U.S. taxpayers.

In new energy, China has progressed from catch up to innovation. Through industry consolidation and support of its new energy vehicle market, China has come to dominate the battery supply chain in the last two years and has plans to triple its lithium ion battery production capacity.

It also has the most nuclear reactors under construction and has courted many countries along the Belt and Road as future export market for nuclear reactors and components.

China's rapid technological development is capitalizing on the absence of supportive policy in the United States and a willingness to outsource key stages of the production processes by U.S. companies.

For instance, where U.S. civilian nuclear is on the decline both domestically and abroad, Chinese companies are stepping in, funding R&D to build the next generation of reactors.

China's advances in energy storage production were jump started by a series of acquisitions of U.S. battery manufacturers.

Maintaining strong domestic capabilities is a necessity for ensuring economic dynamism at home, competitiveness abroad and continued influence in global economic governance that will shape our future.

I will now turn the floor to my co-chair, Vice Chairman Robin Cleveland, for her opening remarks.

PREPARED STATEMENT OF COMMISSIONER LEE
HEARING CO-CHAIR

Good morning, and welcome to the fifth hearing of the U.S.-China Economic and Security Review Commission's 2019 Annual Report cycle. I want to thank our witnesses for being here today, and for the time they have put into their excellent written testimony. I would also like to thank the USCC staff for their excellent work in pulling together the hearing and the Senate Finance Committee and its staff for helping to secure our hearing room.

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In short, the stakes are high, and continued U.S. technological leadership is not guaranteed. The systematic and policy-driven efforts of the Chinese government to secure a decisive advantage in these technologies present a significant threat. For instance, China's government has expressly enacted a plan of becoming the global leader in AI by 2030, and is already applying AI to a range of problems that challenge U.S. interests and values. Likewise, Chinese materials science has benefited tremendously from a combination of state support and an inflow of talent educated in the United States. China stands poised to commercialize many discoveries made by U.S. laboratories at the expense of U.S. manufacturers – and funded at least in part by U.S. taxpayers.

In new energy, China has progressed from catch up to innovation. Through industry consolidation and support of its new energy vehicle market, China has come to dominate the battery supply chain in the last two years and has plans to triple its lithium-ion battery production capacity. It also has the most nuclear reactors under construction and has courted many countries along the belt and road as future export markets for nuclear reactors and components.

China's rapid technological development is capitalizing on the absence of supportive policy in the United States and a willingness to outsource key stages of the production processes by U.S. companies. For instance, where U.S. civilian nuclear is on the decline both domestically and abroad, Chinese companies are stepping in, funding R&D to build the next generation of reactors. China's advances in energy storage production were jumpstarted by a series of acquisitions of U.S. battery manufacturers. Maintaining strong domestic capabilities is a necessity for ensuring economic dynamism at home, competitiveness abroad, and continued influence in global economic governance that will shape our future.

I will now turn the floor to my co-chair, Vice Chairman Robin Cleveland, for her opening remarks.

OPENING STATEMENT OF VICE CHAIRMAN CLEVELAND
HEARING CO-CHAIR

VICE CHAIRMAN CLEVELAND: Thank you, Commissioner Lee, and welcome to our panelists and guests. I want to echo Commissioner Lee's comments about the staff.

This was a tough hearing to prepare for. Complicated technical issues and I think I feel as prepared as I possibly can be.

So cutting across the policy-driven technological advances described by Commissioner Lee is China's program of military-civil fusion, a whole of nation effort to foster linkages between commercial production, institutional research, and military programs.

China has long encouraged the integration of the civilian economy with its military industrial base. But under President Xi, these efforts have evolved and deepened, posing a new threat to the United States.

Military-civil fusion is a key component in each of China's major industrial plans, from the thirteenth five-year plan and Made in China 2025, to the AI plan mentioned by Commissioner Lee.

Since 2017, President Xi has chaired a special oversight body to coordinate between government agencies and the military.

China's military-civil fusion aims to reduce China's dependence on foreign technology, align the economy for rapid mobilization and support of the military, and establish strong capabilities in cyber and information warfare.

U.S. universities and corporations are in danger of becoming unwitting partners in China's military-civil fusion as research and collaboration ostensibly conducted by the civilian sector can be made freely deployable by China's military.

In considering our future economic relationship with China, U.S. policy makers must recognize and address these underlying risks.

Where military application used to drive technological advances, the sectors examined in today's hearing show that commercial off-the-shelf technologies are increasing the leading edge of military development.

Achieving and maintaining leadership in these technologies is a matter not only of economic but also strategic advantage.

Before we proceed I would like to remind you that testimonies and a transcript from today's hearings will be posted on our website and you'll find a number of other key resources there including annual reports, staff papers and analysis of key developments in China.

Please mark your calendars for our next hearing, which is June 20th on A World Class Military: Assessing China's Global Military Ambitions.

PREPARED STATEMENT OF VICE CHAIRMAN CLEVELAND
HEARING CO-CHAIR

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China has long encouraged the integration of the civilian economy with its military industrial base, but under President Xi Jinping, these efforts have evolved and deepened, posing a new strategic threat to the United States. Military-civil fusion is a key component in each of China's major industrial plans, from the 13th Five Year Plan and Made in China 2025, to the artificial intelligence plan mention by Commissioner Lee. Since 2017, President Xi has chaired a special oversight body to coordinate between government agencies and the military.

China's military-civil fusion aims to reduce China's dependence on foreign technology, align the civilian economy for rapid mobilization in support of the military, and establish strong capabilities in cyber and information warfare. U.S. universities and corporations are in danger of becoming unwitting partners in China's military-civil fusion, as research and collaboration ostensibly conducted by the civilian sector can be made freely deployable by China's military.

In considering our future economic relationship with China, U.S. policymakers must recognize and address these underlying risks. Where military application used to drive technological advances, the sectors examined in today's hearing show that commercial off the shelf technologies are increasingly the leading edge of military technological development. Achieving and maintaining leadership in these technologies is a matter not only of economic but also strategic advantage.

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PANEL I INTRODUCTION BY VICE CHAIRMAN CLEVELAND

So we'd like to turn to the introduction of the first panel. This one is focused on artificial intelligence. This panel will assess China's current capabilities, ambitions, and limitations in AI, examining its domestic market landscape and local talent as well as policies to promote national champions, develop various applications and establish AI standards.

Panelists will also examine the U.S. strategic response, weighing commercial interests and principles of scientific openness versus national security concerns.

First, we will hear from Mr. Jeffrey Ding. Mr. Ding is China lead at the Center for Governance of AI at the University of Oxford's Future of Humanity Institute.

He has worked at the State Department, Hong Kong Legislative Council, and is also completing his DPhil in international relations as a Rhodes Scholar at Oxford.

For the past year, he has written a weekly newsletter on AI in China featuring translations of Chinese writings that has grown to more than 4,000 subscribers.

In Chinese or in English?

MR. DING: English.

VICE CHAIRMAN CLEVELAND: Okay. Next we have Ms. Helen Toner, who is the director of strategy at Georgetown's Center for Security and Emerging Technology.

She previously worked as a senior research analyst at the Open Philanthropy Project where she advised policy makers and grant makers on AI policy and strategy.

Between working at Open Philanthropy and joining CSET, Helen lived in Beijing for nine months, studying the Chinese AI ecosystem as a research affiliate at Oxford's Center for Governance.

She was the co-author on the seminal report on the malicious use of AI.

And last but not least we have Elsa Kania. Kania is an adjunct senior fellow at the Center for New American Security where she contributes to the AI Global Security Initiative and the Securing Our 5G Future Program.

She also acts as a member of the research team for the Task Force on AI and National Security.

Ms. Kania is concurrently a research fellow at Georgetown Center for Security and Emerging Technology and was named an official Mad Scientist by the U.S. Army TRADOC. That is a new one for me.

So we have had your testimony in advance and have read it, and it is superb. So I would encourage you to summarize and keep your opening remarks to seven minutes so that all the commissioners have an opportunity to ask questions.

Mr. Ding, we will begin with you.

OPENING STATEMENT OF JEFFREY DING, CHINA LEAD FOR THE CENTER FOR THE GOVERNANCE OF AI, FUTURE OF HUMANITY INSTITUTE, UNIVERSITY OF OXFORD; D.PHIL. CANDIDATE, UNIVERSITY OF OXFORD

MR. DING: Thank you so much to the Commission for having me here. It's a distinct honor to be able to testify. I am also really pleased to be joined by my fellow co-panelists and also to learn a lot from them.

I apologize in advance for the lack of my English accent. I hope the Iowan twang will be sufficient.

The bulk of my testimony will focus on assessing the net capabilities of China and the U.S. in AI and my main argument is that the hype of China as an AI superpower poised to overtake the U.S. in the strategic technology domain of AI is not true and I think a lot of this stems from what I call the AI abstraction problem, which is this idea that AI that you hear in every commercial or in every conversation with a stranger has become so slippery of a concept that it encompasses anything from fuzzy branches of mathematics to drone swarms.

And what I try to do in my approach in this testimony is to slice up this idea of national AI capabilities into three buckets.

The first bucket is to look at scientific and technological inputs and outputs. So these are how many research scientists are we putting in, how many research expenditures are we putting into AI and outputs in the form of patents and papers.

The second slice that I take is looking at different values of AI -- different layers of the AI value chain. This ranges from the foundational level of the technology to the technology system and, finally, to the end product.

And the final slice that I take is looking at different subdomains of AI. So teaching machines to see in terms of computer vision is different from teaching machines to read and comprehend things in the subdomain of natural language processing, and in these different subdomains of AI we can see different comparative advantages for different countries.

And the conclusion that I give, after looking at each of these different levels of slicing up national AI capabilities is my approach reveals that China is not poised to overtake the U.S. in the technology domain of AI. Rather, the U.S. maintains structural advantages in the quality of S&T inputs and outputs, the fundamental layers of the AI value chain, and key subdomains of AI.

I'll just briefly summarize some of the statistics. You have the written testimony, and we can dive deeper into the analysis. But in the first bucket of inputs and outputs I look at quantity of patents and scientific publications.

It is often cited that China leads in raw counts in these. I think if we look a little bit deeper at the quality of the patents, the U.S. has a sizeable advantage.

The U.S. Patent Office significantly leads in terms of highly sited patents. China is far behind at fifth.

When we look at patents and key indicators how many patents are sited trilaterally in the U.S., Japan, and European patent offices, only 4 percent of patents filed in the Chinese patent office are actually filed in other jurisdictions.

The similar number for the U.S. is at 32 percent. For Japan it's at 40 percent. A similar story plays out in government expenditures and human talent as well.

The focus in R&D expenditures is often on government expenditures on AI. That is a very murky indicator. It is hard to capture what all of the agencies are spending on AI.

I say, roughly, some of the public analysis says it's about $1 billion a year. That figure is completely dwarfed by corporate R&D expenditures on the technology domain and here the U.S. lead is quite substantial.

Of the top 20 companies who are investing in software and computer services, 12 of them are based in the U.S., three each in Japan and China.

And you see a similar story in human talent. I make a distinction between AI practitioners and AI experts. China is second only to the U.S. in the number of practitioners, which I define as people who can plug and play AI packages versus experts who are driving fundamental research who can lead an AI project from start to finish. China is far behind.

And then in the other two layers I emphasize when you slice up the AI value chain the emphasis is often on the flashy startups who are innovating at the technology and the product level, making smart speakers.

But we underestimate the foundational level of AI, the open source software that major companies like Google and Facebook are developing and the tools that AI developers are using to build off of.

And in that domain the U.S. serves as a home base for the main developers of 66 percent of AI open source software and that statistic is actually from a Chinese government white paper that emphasizes this fundamental domain of AI as an area where China has a notable weakness.

In different subdomains of AI, China possesses a comparative advantage such as in facial recognition that is boosted by the willingness to have a more expansive surveillance system and data sharing between Ministry of Public Security and different companies.

Also, in natural language processing this is teaching machines to read and understand text. There is -- China potentially has an advantage just because of the access to data in Chinese language natural processing. That's a different process than English language natural processing. So it's key to make these distinctions between different subdomains of AI.

I still argue that the U.S. has decisive advantages in many business applications of AI including in the sphere of autonomous vehicles, which is one of the most lucrative potential markets.

And according to one analysis of military patents filed in this space, U.S. has cumulatively about seven times in terms of military patents compared to China between 2003 to 2015.

I won't go over some of the specific arguments I make in terms of Chinese AI policies in industrial ecosystem that cause some of these differences in net technology and net capabilities.

But I think that this framing should shape some of our approaches towards policymaking and I give three policy recommendations.

The first is instead of taking a hasty approach we should take a very deliberate approach. Given the U.S. lead in the space and the potential for it to continue in the future, we should be careful before taking technical industrial policy which often backfires and we don't know what are the counterproductive effects.

So taking a more measured approach would involve better capabilities assessments such as reviving the Office of Technology Assessment.

My second proposal is instead of taking a reactive approach towards focusing on stopping Chinese investments in this space, we should take a proactive approach towards actually building U.S. excellence in this sphere and one example I will give is to build bridges across the Valley of Death, which is where promising ideas are not commercialized into large-scale applications.

And then, finally, rather than taking the approach of "we need to maintain supremacy over China," which is often what is driving policy approaches in this space, we should focus on reducing the risk of accidents and emergent effects with developing some of these AI technologies. That leads to more sustainable development in the future for the U.S. and for us to maintain our existing advantage in this space.

Thank you so much for the time and I am looking forward to your questions.

PREPARED STATEMENT OF JEFFREY DING, CHINA LEAD FOR THE CENTER FOR THE GOVERNANCE OF AI, FUTURE OF HUMANITY INSTITUTE, UNIVERSITY OF OXFORD; D.PHIL. CANDIDATE, UNIVERSITY OF OXFORD

June 7, 2019

"China's Current Capabilities, Policies, and Industrial Ecosystem in AI"

Testimony before the U.S.-China Economic and Security Review Commission
Hearing on Technology, Trade, and Military-Civil Fusion: China's Pursuit of Artificial Intelligence, New Materials, and New Energy

Jeffrey Ding
D.Phil Researcher, Center for the Governance of AI
Future of Humanity Institute, University of Oxford

Introduction[1]

This testimony assesses the current capabilities of China and the U.S. in AI, highlights key elements of China's AI policies, describes China's industrial ecosystem in AI, and concludes with a few policy recommendations.

China's AI Capabilities

China has been hyped as an AI superpower poised to overtake the U.S. in the strategic technology domain of AI.[2] Much of the research supporting this claim suffers from the "AI abstraction problem": the concept of AI, which encompasses anything from fuzzy mathematics to drone swarms, becomes so slippery that it is no longer analytically coherent or useful. Thus, comprehensively assessing a nation's capabilities in AI requires clear distinctions regarding the object of assessment.

This section compares the current AI capabilities of China and the U.S. by slicing up the fuzzy concept of "national AI capabilities" into three cross-sections: 1) scientific and technological (S&T) inputs and outputs, 2) different layers of the AI value chain (foundation, technology, and application), and 3) different subdomains of AI (e.g. computer vision, predictive intelligence, and natural language processing). *This approach reveals that China is not poised to overtake the U.S. in the technology domain of AI; rather, the U.S. maintains structural advantages in the quality of S&T inputs and outputs, the fundamental layers of the AI value chain, and key subdomains of AI.*

A. Outputs and Inputs

[1] I thank Toby Shevlane and Max Daniel for feedback on this written testimony.
[2] See, for example: Kai-Fu Lee, *AI Superpowers: China, Silicon Valley, and the New World Order,* 2018, Houghton Mifflin Harcourt.

One approach to measure national S&T capabilities divides indicators into outputs (e.g. scientific papers, patents) and inputs (e.g. R&D investment, talent).[3] Assessing both types of indicators is essential: Outputs do not reflect all the innovative potential of the inputs, and some inputs may not materialize into productive gains.

In the domain of outputs, China leads the world in the quantity of both patent filings and scientific publications related to AI, but it significantly trails the United States in the quality of those patents and papers. Followed by the U.S. patent office, the Chinese patent office accepts the most first patent filings in AI — a trend since 2014, per a report by the World Intellectual Property Organization (WIPO).[4] As for publications of AI papers, according to a scientometric analysis of Elsevier's Scopus database, China has led the U.S. in this indicator since 2006.[5] In a similar vein, the Obama Administration's strategic plan for AI research showed that the U.S. trailed China in journal articles related to "deep learning," a powerful subset of machine learning techniques.[6]

However, accounting for the quality of patents and publications reveals that China's lead in raw counts does not necessarily translate into "superpower" status in AI capabilities. The same WIPO report found that China ranks fifth, far behind the U.S. (first), in terms of highly cited patent families filed at its patent office; additionally, compared to the U.S. (32 percent) and Japan (40 percent), only 4 percent of patent applications first filed in China are then filed in other jurisdictions.[7] Moreover, one econometric analysis concluded that China's patent subsidy programs inflate patent counts by more than 20 percent.[8] As is the case with patents, taking into account the quality of papers significantly deflates China's lead in publication counts. In 2016, Chinese AI papers were fifteen percent less cited than the global average, whereas U.S. AI papers were cited 83 percent more than the world average.[9]

On the input side, the amount of R&D investment in AI is an important, but often mis-operationalized, indicator of the strength of a nation's AI ecosystem. For instance, a 2018 White Paper by a U.S. House subcommittee on information technology argued that China's rapidly

[3] This approach draws inspiration from Robert L. Paarlberg, Knowledge as Power: Science, Military Dominance, and US Security," *International Security*, *29*(1), pp.122-151.
[4] World Intellectual Property Organization, "WIPO Technology Trends 2019: Artificial Intelligence," 2019, https://www.wipo.int/edocs/pubdocs/en/wipo_pub_1055.pdf.
[5] Yoav Shoham et al., "The AI Index 2018 Annual Report", AI Index Steering Committee, Human-Centered AI Initiative, Stanford University, December 2018, http://cdn.aiindex.org/2018/AI%20Index%202018%20Annual%20Report.pdf.
[6] Sarah Zhang, "China's Artificial-Intelligence Boom," The Atlantic, February 16, 2017, https://www.theatlantic.com/technology/archive/2017/02/china-artificial-intelligence/516615/; original report: "The National Artificial Intelligence Research and Development Strategic Plan," National Science and Technology Council, October 2016, https://www.nitrd.gov/PUBS/national_ai_rd_strategic_plan.pdf.
[7] https://www.wipo.int/edocs/pubdocs/en/wipo_pub_1055.pdf
[8] Jianwei Dang and Kazuyuki Motohashi, "Patent statistics: A good indicator for innovation in China? Patent subsidy program impacts on patent quality," China Economic Review 35 (2015): 137-155.
[9] "The AI Index 2018 Annual Report"

growing investments in AI pose a risk to U.S. leadership in the domain.[10] Reflecting the difficulty of pinpointing AI expenditures, the only piece of evidence cited in support of this claim was China's overall R&D expenditures.[11]

More specific government R&D indicators exist but they provide an incomplete view of the landscape, especially given the prominence of corporate R&D in AI. For example, the Chinese Ministry of Industry and Information Technology plans to spend $950 million annually on strategic AI projects in the public sector and state-owned enterprises.[12] In comparison, the U.S. government invested $1.1 billion in unclassified AI-related R&D projects in 2015.[13] Corporate R&D expenditures on AI most likely dwarf these figures. Here, the U.S. lead is substantial. Out of the top 20 "Software & Computer Services" companies in 2018 R&D spending, twelve call the U.S. home, three each are based in China and Japan, and two are located in Europe.[14] Alphabet, Google's parent company, leads the pack with nearly $15 billion in R&D expenditures.

Lastly, human talent may be the most valuable input into a nation's AI ecosystem. Three major mapping projects support the conclusion that China is second only to the U.S. in the number of "AI practitioners" but is far behind in the number of "AI experts."[15] Using a broader definition of AI talent closer to the "AI practitioner" concept, Tencent Research Institute found that China boasts 39,200 AI talents (13 percent of the global total) and the U.S. has 78,700 AI talents (26 percent of the global total).[16] Defining AI talent in narrow terms, ElementAI traced only two percent of the world's AI experts to China, compared to 41 percent of the world's AI experts in America.[17] Researchers at Tsinghua University backed up both claims. Based on their methodology, China ranks second globally with an AI talent pool at around 65 percent of the U.S. talent pool (the "AI practitioner" angle) and sixth globally in terms of top AI talents (the "AI experts" angle).[18]

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[10] Will Hurd and Robin L. Kelly, "Rise of the Machines: Artificial Intelligence and Its Growing Impact on U.S. Policy," U.S. Congress, House of Representatives, Committee on Oversight and Government Reform, https://www.hsdl.org/?abstract&did=816362.

[11] Taking R&D spending on all domains to be a proxy for R&D investment in AI may be one of the clearest examples of the AI abstraction problem in practice.

[12] "Realising the Economic and Societal Potential of Responsible AI in Europe," Accenture, Spring 2018, https://www.accenture.com/_acnmedia/PDF-74/Accenture-Realising-Economic-Societal-Potential-Responsible-Ai-Europe.pdf.

[13] "The National Artificial Intelligence Research and Development Strategic Plan."

[14] These are the total R&D budgets of companies in the "Software & Computer Services" category as defined by the EU Scoreboard 2018 dataset: http://iri.jrc.ec.europa.eu/data.html

[15] I define AI practitioners as those capable of participating in AI-related projects in corporate and university settings. Though they may not have advanced degrees, they have the ability to plug-and-play with existing AI packages and apply them to specific problem sets. AI experts, who often have advanced degrees, may boast more patents and publications to their names.

[16] Tencent Research Institute, "2017 White Paper on Global AI Talent [2017全球人工智能人才白皮书]," 2017, https://www.tisi.org/Public/Uploads/file/20171201/20171201151555_24517.pdf.

[17] Gagne et al, "Global AI Talent Report 2018," Element AI, February 7, 2018, https://jfgagne.ai/talent/.

[18] China Institute for Science and Technology Policy at Tsinghua University, "China AI Development Report 2018," Tsinghua University, July 2018, http://www.sppm.tsinghua.edu.cn/eWebEditor/UploadFile/China_AI_development_report_2018.pdf; these

B. The Foundation, Technology, and Application Levels of AI

Most assessments of AI capabilities focus on the technology and application layers, as captured by emerging startups and new products, such as smart speakers. Indeed, the growth of China's AI startup scene, backed by a more mature domestic venture market as well as international capital, has been impressive. From 2014 to 2016, the number of new Chinese AI companies constituted 55 percent of all Chinese AI companies ever established, and the scale of Chinese AI investment for those three years accounted for over 90 percent of the total Chinese financing that has ever been committed to AI.[19] Moreover, in 2017, China's AI startup scene received 48 percent of funding going to AI startups globally, surpassing U.S. AI startups, which received 38 percent of the global share.[20]

The U.S. lead is more clear at the foundational level of AI, constituted by the platform and support architecture that power key technologies and applications. This includes the open source software that underpins many AI projects. According to a Chinese government white paper on the topic, the U.S. serves as the home base for the main developers of 66 percent of the world's AI open source software (AOSS), while only 13 percent of AOSS is mainly developed in China.[21] This is a notable weakness of China's AI ecosystem as these backbone systems enable companies to source top talent, shape technical standard-setting, and attract more usage of their products.[22] It is no surprise that the contributors to the AOSS white paper, which included Peking University, Baidu, and Huawei, emphasized AOSS as "an area that must be fought for in seizing global dominance in AI."[23]

C. Different Subdomains of AI

The U.S. and China possess comparative advantages in different subdomains of AI. On the one hand, China has pushed ahead in facial recognition, publishing 900 patents in this subdomain in 2017, with many belonging to unicorn startups such as Sensetime, Megvii (Face++), and Cloudwalk.[24] That same year, less than 150 patents related to facial recognition were filed in the states.[25] In Chinese-language data processing, speech recognition, and knowledge maps,

researchers also found that China's AI talents are mostly concentrated at universities, constituting 81.3% of the national total.

[19] Wuzhen Institute, 2017, Global AI Development Report (Framework Document) 全球人工智能发展报告 (框架篇), http://www.199it.com/archives/617596.html.

[20] CB Insights, "Top AI Trends to Watch in 2018," 2018, https://www.cbinsights.com/research/report/artificial-intelligence-trends-2018/.

[21] Ministry of Industry and Information Technology, "White Paper on China's Artificial Intelligence Open Source Software" [中国人工智能白皮书], July 2018, https://pan.baidu.com/s/1p8hAM8Ggz4LjXagO62-AYg.

[22] Gregory Allen, "Understanding China's AI Strategy," Center for New American Security, February 6, 2019, https://www.cnas.org/publications/reports/understanding-chinas-ai-strategy#fn37.

[23] "White Paper on China's Artificial Intelligence Open Source Software"

[24] CB Insights, "China's Surveillance State: AI Startups, Tech Giants Are At The Center Of The Government's Plans," March 20, 2018, https://www.cbinsights.com/research/china-surveillance-ai/.

[25] CB Insights, "AI Trends to Watch in 2019," March 19, 2019, https://www.cbinsights.com/research/ai-trends-2019/.

Chinese companies benefit from their proximity to the local user base, though Microsoft has made substantial inroads in the Chinese-language natural language processing (NLP) industry.[26]

On the other hand, the U.S. possesses a decisive advantage in many business applications of AI due to its corporate culture and more standardized data practices. Additionally, American firms have a sizeable lead in autonomous vehicles, one of the most lucrative markets for AI.[27] Finally, the U.S. innovative output in military applications of AI laps the rest of the world. Between 2003-2015, there were over 700 military patents filed in the U.S. with the terms "autonomous" or "unmanned" in the patent abstract; the comparable figure in China for that time period was less than 100.[28]

China's AI Policies[29]

The key, guiding document of China's AI strategy in both the domestic and international realm is the State Council's July 2017 AI Development Plan (AIDP).[30] The plan laid out key benchmarks for China's AI industry, sent a clear signal that AI was a national-strategic level priority, and emphasized priority areas where government action could cultivate a favorable environment for sustainable, technical advances. The plan outlines a three-stage progression toward China's ambition of leading the world in AI:

1. By 2020, China's AI industry will be "**in line"** with the most advanced countries, with a core AI industry gross output exceeding RMB 150 billion ($22.5 billion) and AI-related industry gross output exceeding RMB 1 trillion ($150.8 billion).
2. By 2025, China aims to reach a "**world-leading"** level in some AI fields, with a core AI industry gross output exceeding RMB 400 billion ($60.3 billion) and AI-related industry gross output exceeding RMB 5 trillion ($754.0 billion).

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[26] Jia Wei, "Dialogue with MSRA Vice Dean Zhou Ming: Looking back at the past and looking forward to the future, what are the development trends of NLP?" [对话MSRA副院长周明：回望过去，展望未来，NLP有哪些发展趋势?], *jiqizhixin*, February 11, 2019, https://mp.weixin.qq.com/s/rXbuXIs58w28Z7iM55jhfA?fbclid=IwAR1gARB_dDFNOMoYhkpUIwn9cdYT-5BHubVMqA9rtluMHwTmndfwMYaGCM8.

[27] Remco Zwetsloot, Helen Toner,, and Jeffrey Ding, "Beyond the AI Arms Race: America, China, and the Dangers of Zero-Sum Thinking," Foreign Affairs, November 16, 2018, https://www.foreignaffairs.com/reviews/review-essay/2018-11-16/beyond-ai-arms-race.

[28] Jon Schmid, "The Determinants of Military Technology and Diffusion," Unpublished Ph.D. Dissertation, May 2018, https://smartech.gatech.edu/bitstream/handle/1853/59877/SCHMID-DISSERTATION-2018.pdf.

[29] This section draws heavily from my report: Jeffrey Ding, "Deciphering China's AI Dream," Future of Humanity Institute Technical Report, March 2018, https://www.fhi.ox.ac.uk/wp-content/uploads/Deciphering_Chinas_AI-Dream.pdf.

[30] State Council, "State Council Notice on the New Generation Artificial Intelligence Development Plan" [国务院关于印发新一代人工智能发展规划的通知], July 8, 2017, http://www.gov.cn/zhengce/content/2017-07/20/content_5211996.htm.

3. By 2030, China seeks to become the world's "**primary"** AI innovation center, with a core AI industry gross output exceeding RMB 1 trillion ($150.8 billion) and AI-related gross output exceeding RMB 10 trillion ($1.5 trillion).

In a broad sense, these benchmarks map neatly onto three strategic phases of AI development: (1) catching up to the most advanced AI powers, (2) becoming one of the world leaders in AI, and (3) achieving primacy in AI innovation.

Apart from the benchmarks, the bulk of the AIDP text underscores three key features of China's approach to AI development.

1. **Central guidance, local implementation:** The State Council set forth a "wish list" of theoretical breakthroughs and specific AI applications, prompting many local governments to establish their own AI plans and AI funds.[31] 2018 was dubbed "The Year of Local AI Policy," as 15 of the 31 provincial-level governments in China issued AI plans in the year following the AIDP. The combined targets for the scale of the AI industry of these subnational governments nearly tripled the 2020 national-level target.[32]
2. **Focus on standards:** The AIDP demonstrated the Chinese government's desire to play an active role in the construction of international technical standards for AI.[33] In January 2018 a joint effort of more than 30 academic and industry organizations, overseen by the China Electronic Standardization Institute, produced a "White Paper on Artificial Intelligence Standardization" to coordinate the development of AI standards. These efforts are motivated by multiple aims: building reliable AI-enabled systems, promoting the global competitiveness of Chinese tech companies, and achieving the soft benefits of setting the rules of the road in a strategic technology area.[34]
3. **Investment in AI talent:** China's "whole-of-society," long-term approach toward recruiting and training AI talent is bearing some fruit. The State Council's AI plan outlines a two-pronged "gathering" and "training" approach. Under the gathering plank, national-level and local-level talent programs attract international AI talents to work in China. Following the path of other multinationals, China's tech giants have also set up their own overseas R&D institutes to recruit foreign talent.[35] On the training side, China has made

[31] Matt Sheehan, "How China's Massive AI Plan Actually Works," February 12, 2018, https://macropolo.org/analysis/how-chinas-massive-ai-plan-actually-works/.

[32] Qianzhan Chanye Research Institute, "An Article that Reviews the Latest Policies for the AI Industry throughout the Country in 2018!" [一文带你了解2018年全国各地人工智能行业最新政策!], March 30, 2018, www.qianjia.com/html/2018-03/30_288481.html.

[33] The Chinese word for standards (标准) appears 24 times in the AIDP; for context, the Chinese word for policy (政策) appears 26 times.

[34] Jeffrey Ding, Paul Triolo, and Samm Sacks. "Chinese Interests Take a Big Seat at the Ai Governance Table," New America, June 20, 2018, https://www.newamerica.org/cybersecurity-initiative/digichina/blog/chinese-interests-take-big-seat-ai-governance-table/.

[35] Alibaba recently invested $15 billion into global R&D, including seven overseas labs, with a priority on AI; Baidu now has two research labs in Silicon Valley; and Tencent has established a lab in Seattle.

long-term investments in enhancing AI as an academic discipline.[36] The Chinese Ministry of Education has approved the creation of an "Intelligent Science and Technology" major, which more than fifty universities and colleges have adopted. Some schools, such as Nanjing University, have established their own specialized AI institutes.[37]

If past strategic technology plans are any precedent, some aspects of China's AI strategy will under-deliver. Since its establishment in 2014, China's much-touted semiconductor fund has only spent a fraction of the $150 billion allocation and failed to spur advances at the technological frontier.[38] In robotics and smart manufacturing, local government efforts have duplicated projects, wasted money, and produced a glut of low-value products.[39]

One critical question is whether China's AI ecosystem can produce big breakthroughs in fundamental AI research — the cornerstone of U.S. structural advantages in this space. With an eye toward inspiring these fundamental breakthroughs, the Chinese government tacked the Chinese Academy of Engineering's "Artificial Intelligence 2.0" proposal onto a list of fifteen other S&T megaprojects.[40] However, previous Chinese science and technology megaprojects have diverted funds from high-quality labs toward more politically-connected entities.[41]

Undeniably, the openness of the U.S. technology ecosystem — to new ideas, new people, and new debates about AI ethics — provides the bedrock for its AI advantage.[42] For instance, the Defense Advanced Research Projects Agency has made a variety of long-term bets in AI breakthroughs. Past projects, which sparked interest in driverless cars and conversation assistants, are paying off for the U.S. now. Current projects, which include efforts to design more efficient AI chips and improve the security of AI programs, will pay off in the years to come.[43]

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[36] "State Council Notice on the New Generation Artificial Intelligence Development Plan"

[37] "The Current Status of Artificial Intelligence Education in Domestic Universities: Urgent Need to Establish a First-level Discipline and Strengthen Industry-university Integration" [国内高校人工智能教育现状：亟须建立一级学科，加强产教融合], The Paper, April 20, 2018, https://www.thepaper.cn/newsDetail_forward_2087214.

[38] "Beyond the AI Arms Race."

[39] Jost Wübbeke et al., "Made in China 2025: The Making of a High-tech Superpower and Consequences for Industrial Countries, Mercator Institute for China Studies," December 2016, https://www.merics.org/en/papers-on-china/made-china-2025.

[40] AI 2.0 was added on in February 2017. The initial fifteen megaprojects were proposed and finalized in 2016 with the release of the "13th Five-Year Plan for National Science and Technology Innovation."

[41] Cong Cao, Richard P. Suttmeier, and Denis Fred Simon. "China's 15-year science and technology plan," Physics today 59.12 (2006): 38.

[42] Elsa Kania, "China's AI Giants Can't Say No to the Party," Foreign Policy, August 2, 2018, https://foreignpolicy.com/2018/08/02/chinas-ai-giants-cant-say-no-to-the-party/.

[43] Will Knight, "The Out-there AI Ideas Designed to Keep the US Ahead of China," MIT Technology Review, March 8, 2019, https://www.technologyreview.com/s/613089/the-out-there-ai-ideas-designed-to-keep-the-us-ahead-of-china/.

China's Industrial Ecosystem in AI

The key players in China's AI industry can be roughly divided into established technology giants, who can leverage data from their respective user bases to optimize existing algorithms, and new startups, who are pushing the leading technological edge. The Ministry of Science and Technology (MoST) chose a mix of these giants and startups to lead the development of national AI open innovation platforms as part of a "national team" [国家队]. The team's members include: Baidu (autonomous driving), Alibaba (smart cities), Tencent (medical imaging), iFlytek (intelligent voice), and Sensetime (intelligent vision).[44]

The "national team" model differs from the traditional "national champion" approach. For one, all five are hybrid firms, backed by significant foreign capital and largely independent from government subsidies, that had already established themselves in their respective fields before being recruited to the national team.[45] Second, team members actively intrude on each other's turf, as evidenced by the fierce competition over the smart city market. Baidu, Alibaba, Tencent, and other end customers are actively working to develop their own speech and facial recognition capabilities so as to reduce reliance on the services of companies like iFlytek and Sensetime.[46]

China's industrial ecosystem in AI is connected to the global economy, and Chinese technology firms are expanding their AI footprint abroad. One notable case was a March 2018 deal between CloudWalk Technology Co., a facial recognition startup based in Guangzhou, and the Zimbabwe government. Framed by *The Global Times*, an influential Chinese tabloid, as "marking the entry of China's AI technology into Africa," the CloudWalk-Zimbabwe deal raised questions about China's export of its surveillance technology and model.[47]

As China's industrial ecosystem in AI expands internationally, Chinese planners are concerned about dependencies in key technologies. In a November 2018 speech before many of China's leadership at the 13th National People's Congress Standing Committee, Dr. Tan Tieniu, Deputy Secretary-General of the Chinese Academy of Sciences, highlighted the devastating effect of U.S. sanctions on ZTE as a warning about China's dependencies on the U.S. in core technologies. "In order to avoid repeating this disaster, China should learn its lesson about

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[44] MoST designated the first batch of four in November 2017. Sensetime was selected as the fifth member in September 2018.
[45] The possible exception is iFlytek. The company's largest shareholder is China Mobile, and it was incubated under the University of Science and Technology. Also, government subsidies comprise 20-25 percent of its annual net income. I thank David Cunio of Three Body Capital for this point.
[46] One example of this is Ant Financial bringing its facial recognition software in-house, It had previously relied on technology from facial recognition startup Megvii (Face++).
[47] Global Times, "Chinese Facial ID Tech to Land in Africa," May 17, 2018, http://www.globaltimes.cn/content/1102797.shtml.

importing core electronic components, high-end general-purpose chips, and foundational software," Tan stated.[48]

Policy Recommendations

Given the U.S. structural advantages and current lead in AI, maintaining the status quo is a defensible policy option to enhance U.S. competitiveness in AI. Techno-industrial policy is a difficult endeavor, and there is a risk that even the most agreeable policy interventions — say, investing in S&T education — can backfire. For example, Michael Teitelbaum argues that in the past when the U.S. expanded its supply of scientists and engineers, the resulting boom in S&T talent quickly turned into a bust, leaving many without career prospects and deterring younger scientists from entering the field.[49] Notwithstanding this point, the following policy recommendations could help protect U.S. interests in AI:

- **Revive the Office of Technology Assessment (OTA).** Any type of AI policy — increases in R&D investments, protections against vulnerabilities and dependencies in the supply chain, reforms to the high-skilled immigration process — will require balanced assessments of where the U.S. and its rivals stand with respect to different layers and subdomains of AI. From 1972 to 1995, the OTA equipped U.S. lawmakers with crucial advice and information on topics such as the effect of globalization on the defense industrial base and the technological capabilities of the Soviet Union and Japan. Fortunately, some momentum for this proposal exists: in April 2019 U.S. House Representatives Sean Casten and Mark Takano appealed to the House Legislative Branch Appropriations Subcommittee to revive the OTA, and both right and left-leaning think tanks have supported the proposal.[50]
- **Build Bridges across the "Valley of Death" in the AI domain.** Much of current U.S. policy is focused on scrutinizing how Chinese firms and government-aligned entities are exploiting the "Valley of Death" — the immense challenge of turning a startup idea or scientific research into large-scale commercial applications — by investing in promising AI companies.[51] Rather than relying solely on a reactive strategy, the U.S. government should proactively build bridges across the Valley of Death. One such bridge is a Department of Defense loan program office (modeled after the one in the Department of

[48] English translation of Tan Tieniu's speech is available via Cameron Hickert and Jeffrey Ding (translators), "Read What Top Chinese Officials Are Hearing About AI Competition and Policy" New America, November 29, 2018, https://www.newamerica.org/cybersecurity-initiative/digichina/blog/read-what-top-chinese-officials-are-hearing-about-ai-competition-and-policy/.
[49] Michael S. Teitelbaum, "Falling Behind? Boom, Bust, and the Global Race for Scientific Talent," Princeton University Press, https://press.princeton.edu/titles/10208.html.
[50] Katherine Tully-McManus, "House Members Call for Office of Technology Assessment Revival," Roll Call, April 2, 2019, https://www.rollcall.com/news/congress/house-members-call-office-technology-assessment-revival.
[51] The case of Neurala is instructive. This smart drone startup was unable to attract investment from the U.S. military so it turned toward an investment firm backed by a state-run Chinese company instead. See: Paul Mozur and Jane Perlez, "China Bets on Sensitive U.S. Start-Ups, Worrying the Pentagon," March 22, 2017, https://www.nytimes.com/2017/03/22/technology/china-defense-start-ups.html.

Energy)[52] to coordinate with accelerators to fund high-risk, high-reward startups. Another is built on public-private consortiums to share translational research (e.g. brain collection and data analysis capabilities) across industrial partners, universities, and hospitals to improve the drug discovery process for brain disorders.[53]

- **Increase attention to the risks of accidents and emergent effects associated with the deployment of emerging technologies related to AI.[54]** Maintaining U.S. supremacy in AI over rivals such as China should not be the only policy goal; the U.S. should also guard against the risk of losing control over AI technologies. As the software components of cybersecurity and weapons systems become more complex and develop faster than existing mechanisms of control, the risks of accidents and latent vulnerabilities become greater. U.S. agencies should make these concerns a core part of quadrennial reviews, war games, and periodic intelligence and net assessments.

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[52] Joshua Israel, "Commercial Accelerators and the Defense Department: A Blueprint for Collaboration, War on the Rocks, March 14, 2018, https://warontherocks.com/2018/03/commercial-accelerators-and-the-defense-department-a-blueprint-for-collaboration/.

[53] Nao J. Gamo, et al. "Valley of Death: a Proposal to Build a "Translational Bridge" for the Next Generation." Neuroscience research, 115 (2017): 1-4, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5477974/.

[54] This is drawn from Richard Danzig, "Technology Roulette: Managing Loss of Control as Many Militaries Pursue Technological Superiority," Center for a New America Security, June 2018, https://s3.amazonaws.com/files.cnas.org/documents/CNASReport-Technology-Roulette-DoSproof2v2.pdf?mtime=20180628072101.

OPENING STATEMENT OF HELEN TONER, DIRECTOR OF STRATEGY AT GEORGETOWN UNIVERSITY'S CENTER FOR SECURITY AND EMERGING TECHNOLOGY

VICE CHAIRMAN CLEVELAND: Of which there'll be many.

Ms. Toner?

MS. TONER: Madam Chairman, Madam Vice Chairman, members of the Commission, thank you so much for this opportunity to testify on this important and timely topic.

I am the director of strategy at the Center for Security and Emerging Technology, or CSET, a new policy research organization at Georgetown University that was founded this January to focus on the security implications of new technologies.

Our initial suite of research products, which we expect to begin making public this summer, addresses many of the questions I'll discuss today in more detail.

Before joining CSET, I previously worked on similar issues of AI and national security in San Francisco where I worked closely with AI researchers at corporate and university research labs in Silicon Valley and elsewhere.

I've also spent time discussing similar issues with researchers and engineers in China.

My written testimony addresses a number of different areas requested by the Commission. So rather than trying to cover all of those points now, I am instead going to offer a couple of framing comments, summarize my recommendations, and then look forward to discussing more in the Q&A.

So, first, I wanted to give a brief overview of what artificial intelligence actually is. It's often referred to vaguely as if it were one thing, maybe a strategic capability of some kind.

But in fact, AI is an umbrella term for a collection of approaches to essentially getting computers to do things that seem smart.

For a long time the dominant approaches in AI were based on manually specifying rules of behavior. So if this happens, do this; if that happens, do that.

Deep Blue, the chess computer that beat Grand Master Gary Kasparov, is an example of this kind of system, which was used in 1997.

Starting around 2012, though, we have seen a huge boom in a different type of approach to AI called machine learning, where instead of acting according to rules set by humans, the computer is instead given many examples of something and uses statistical techniques to learn the connections between an input -- for example, an image -- and an output -- for example, a label for what's in that image.

Much of the most interesting machine learning work we have seen uses an approach called deep learning or deep neural networks. These systems are very good at pattern recognition and are responsible for the huge leaps that we have seen in image recognition, speech recognition, natural language understanding, recommendation systems, game playing, and other areas.

Examples of machine learning powered applications include Siri in your iPhone, autonomous vehicles, how Netflix or Amazon recommend products to you, medical imaging, and Google Search, each of which is based on a different subfield of AI research.

The reason I wanted to give that background is that it's really important in considering how to set policy around AI to understand just how general purpose it is as a technology to ensure, for one thing, that policies intended to target one subdomain don't end up having a much wider set of unintended effects.

And it's also critical to understanding how AI researchers in the U.S. and around the world view the technology, how they make decisions about what to work on, and how they are likely to react to changes in the policy environment.

In terms of recommendations, based on reasoning that I elaborate on more in my written testimony, I make three specific recommendations to the Commission as well as four more general recommendations.

My three specific recommendations are, first, to improve the immigration options available to AI researchers and engineers.

As Jeff discussed, talent is a critical input to a strong AI ecosystem and one where the advantage is ours to lose.

Foreign-born researchers and engineers make up around half of the AI workforce in the U.S. Foreign students studying computer science in the United States attempt to stay here at very high rates. Around 85 to 90 percent of Chinese students studying computer science would stay in the U.S. if they could and, largely, do and perhaps more would stay if there were more visa options available.

However, this status quo could be threatened both by strategic immigration policies currently being enacted by other countries including China and by a worsening U.S. immigration environment.

I elaborate on specific proposed reforms in my written testimony and CSET has a forthcoming report that will go into even more detail.

My second recommendation is to allocate resources to the National Institute of Standards and Technology to support its efforts to develop and implement standards for AI.

My third specific recommendation is to increase R&D funding for basic research. Strength and fundamental research is the backbone of American advantage in AI.

But so far, no major federal effort has been made to strengthen that backbone during the current wave of progress in deep learning, in contrast to major investments by many other countries, including China.

Beyond these specific policy options, I also offer the following four suggestions to the Commission and to Congress to inform any other future action relating to AI competitiveness.

First, in all that we do, we must place liberal democratic values front and center. These values are what give the U.S. a sustainable long-term advantage over countries like China.

They are the foundation of deep alliances and the magnet that draws smart, enterprising people to our shores.

Secondly, and relatedly, it's important to recognize the benefits the United States has drawn from the fact that AI researchers perceive the U.S. as a good place to live and work.

We should seek to maintain or improve these attitudes.

Third, in cases where it is necessary to restrict foreign access to U.S. research for security or other reasons, we should ensure that these restrictions are highly targeted and that their motivations are explained clearly.

This point is relevant, for example, if the U.S. is planning to respond to the atrocities China is currently perpetrating in Xinjiang.

If it is clear that any measures taken are targeted to and motivated by human rights abuses, AI researchers and the world at large will be behind us.

If that is not clear, they may not be.

Finally, wherever possible, we should provide information rather than enacting restrictions. The AI research community is actively engaged in discussions about ethical and unethical uses of the technologies under development.

The Commission, Congress, and other U.S. government entities can play an important role in informing that AI research community about realities on the ground, for example, about connections between Chinese research institutes and the Chinese state.

To conclude, I would like to reiterate that, in my view, the U.S.'s primary concern here should be to think about what long-term sustainable advantages we can maintain over China.

I have tried to address these in my testimony. Once again, I thank the Commission for this opportunity to speak on behalf of CSET and to address these issues with you. I look forward to your questions.

PREPARED STATEMENT OF HELEN TONER, DIRECTOR OF STRATEGY AT GEORGETOWN UNIVERSITY'S CENTER FOR SECURITY AND EMERGING TECHNOLOGY

Testimony before the U.S.-China Economic and Security Review Commission
"Technology, Trade, and Military-Civil Fusion: China's Pursuit of Artificial Intelligence, New Materials, and New Energy"

by

Helen Toner
Director of Strategy, Center for Security and Emerging Technology
Walsh School of Foreign Service, Georgetown University

June 7, 2019

Madam Chairman, Madam Vice Chairman, members of the Commission: Many thanks for this opportunity to testify on this crucial and timely topic.

I am the Director of Strategy at the Center for Security and Emerging Technology. CSET is a new center at Georgetown University that was founded this past January to examine the security implications of new tech developments, including the kinds of questions addressed by this hearing. Our initial suite of research products—which we expect to begin making public this summer—combines our team's expertise on China, national security and artificial intelligence to produce in-depth analysis of key issues related to U.S. competition with China on AI.

I previously worked on similar issues of AI and national security in San Francisco, including substantial engagement with AI researchers at corporate and university research labs in Silicon Valley and elsewhere. In order to deepen my understanding of the equivalent ecosystem in China, I spent most of 2018 living in Beijing, undertaking independent research and study.

In order to address the themes suggested by the Commission today, I'll start with some scene-setting to describe what I see as key features of AI as a technology and address some common misconceptions. In brief, I'll describe why AI should not be thought of as a typical dual-use technology; why AI research is characterized by an unusually open and collaborative environment, and what value that has; the potential costs to the United States of any restrictive measures that are not highly targeted; the role of human capital in AI research, and importance of strategic immigration policy to bolster U.S. competitiveness; China's approach to data privacy, and why I believe discussions of human rights abuses in Xinjiang should not be closely tied to discussions of AI; and the current state of standardization efforts for AI. I'll close with recommendations for how to strengthen the U.S. competitive advantage in AI.

1. AI as a general purpose technology

Artificial intelligence is a general purpose technology. The concept of a GPT, which comes from economics, refers to a technology that has the potential to significantly affect all sectors of society and the economy.[1]

[1] Jovanovic & Rousseau (2005), *General Purpose Technologies*, https://www.nber.org/papers/w11093

Despite some overlap with the concept of "dual use," which generally refers to militarily-useful technologies that also have some civilian applications, the terms are not synonyms. Unlike those of a dual-use technology, the military applications of a GPT generally represent only a small part of the technology's overall usage and potential for value creation, rather than being one of its major facets. Commonly-cited examples of GPTs include electricity and information technology, in contrast with typical dual-use examples such as nuclear energy, rocketry, or biotechnology.

In the case of AI, we are already seeing promising applications across sectors with clear humanitarian implications, such as scientific innovation, healthcare, energy and transportation. Additionally, advances in technologies like speech recognition, translation, natural language processing and image processing can be applied across all sectors of the economy, spurring growth and making possible further new technologies and ways of living that are hard to imagine now. Consider how electricity not only led to artificial light, but also made possible elevators (and thereby high-rise buildings), telecommunications, modern agriculture, and myriad other inventions that revolutionized society. AI holds the promise of unleashing a similar transformation, and this has important implications for how governments should interact with this technology.

2. AI research norms and collaborations

a. Publishing norms

Since well before the beginning of the current boom in AI in around 2012, the field has been characterized by strong norms of open publishing. The vast majority of research progress is published on arXiv.org, a freely accessible repository for scientific papers maintained by Cornell University. These norms of openness are so strong that most major technology companies with AI research labs, including Google, Facebook, Amazon and Microsoft, also allow researchers to publish much of their work freely.

This open, distributed environment accelerates research progress in several ways. Researchers in one lab can easily test and build off of results published by a different lab; researchers in different labs (and even different countries) can straightforwardly collaborate on projects; researchers moving between jobs need less time to get settled with their new organization's research and practices; less experienced researchers can easily teach themselves from online resources and quickly get to the level where they can contribute their own insights; and so on.

Because of AI's substantial potential to benefit humanity, as described in the previous section, the boost to research progress provided by this structure is extremely valuable.

b. Research collaborations

Collaborations of many different kinds are a natural consequence of this model. Cooperative arrangements between universities and corporations are commonplace. Because many American companies with large AI research efforts (such as Google and Microsoft) operate around the globe, these companies have a wide range of partnerships with other entities in foreign countries, including China.

Overwhelmingly, these collaborations relate to very basic research that could have many potential applications. For example, Microsoft Research Asia—a Beijing-based research group that is one of China's best AI labs, and certainly the most prestigious Western lab in China—announced a set of 40 research collaboration grants in December 2018, 23 of which went to Chinese institutions. Of these grants to Chinese institutions (listed alphabetically by author name), the first five topics relate to using AI for rehabilitation, improving conversational question-answering, segmenting objects in video footage, machine translation, and system architecture.[2] In other words, the typical US-China research collaboration represents a marginal improvement to a basic machine learning problem, contributing to the global commons of scientific research progress.

The most infamous example of a government-industry partnership is of course Google's work on, then withdrawal from, the U.S. Department of Defense's Project Maven. This withdrawal gave rise to a narrative sometimes heard in Washington that Silicon Valley refuses to work with the U.S. government, but is happy to cooperate with China. Contrary to this narrative, there are in fact many examples of arrangements in which U.S. tech companies (including Google) work with U.S. government partners.[3] While the Washington-Silicon Valley relationship can be fraught and requires attention, oversimplifications of this kind should be avoided.

c. The costs of a restrictive approach

The openness of the current AI ecosystem can seem undesirable to policymakers concerned with shoring up the United States' technological advantage and securing American innovation, especially given AI's potential military applications. A natural impulse is to seek ways to close off external access to U.S. research, perhaps drawing inspiration from case studies like nuclear energy or rocketry.

However, an approach like this is likely to be counterproductive, given the general purpose nature of AI as described above and the field's interconnected global research environment. Because sensitive applications of AI represent such a small chunk of its potential uses, and non-sensitive applications hold such promise for promoting growth and prosperity, measures that attempt to broadly restrict access to AI research (for example, applications of export controls or restrictions on collaborative research that are not highly targeted) are likely to backfire in two mutually-reinforcing ways.

First, measures that restrict collaboration or open sharing of research are likely to slow down the pace of research progress within U.S. university and corporate labs, which would damage their standing on the world stage and reduce their market share in AI-enabled products and platforms.

Second, because AI workers are highly mobile, any such measures enacted in the United States are likely to prompt researchers to emigrate to other countries to continue their work unencumbered. Because AI is not primarily a military technology, even patriotic American experts may not see the case for staying in the United States if they will be more able to push the scientific frontier elsewhere. As described in the section on human capital below, researchers will quickly find employment overseas, including in the growing AI sectors of Canada and the UK (which are actively taking measures to

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[2] Microsoft Research Lab – Asia (2018), *MSRA Collaborative Research 2019 Grant Awards Announcement*, https://www.microsoft.com/en-us/research/lab/microsoft-research-asia/articles/msra-collaborative-research-2019-grant-awards-announcement/

[3] Examples include Google's work on DARPA programs on deepfakes and semiconductor design (https://www.c4isrnet.com/it-networks/2019/03/13/forget-project-maven-here-are-a-couple-other-dod-projects-google-is-working-on/), bids by Amazon and Microsoft on the Pentagon's cloud contract (https://www.nytimes.com/2019/04/10/technology/amazon-microsoft-jedi-pentagon.html), and Google and Facebook assisting the Census Bureau to defend against disinformation (https://www.reuters.com/article/us-usa-census-fakenews-exclusive/exclusive-fearful-of-fake-news-blitz-u-s-census-enlists-help-of-tech-giants-idUSKCN1R812S).

recruit AI talent). Not to mention the many Chinese and Russian researchers currently contributing their talents to the United States, who might be prompted to return to their home countries instead.

In short, I fear that attempts to bolster American competitiveness using restrictive measures will instead degrade U.S. leadership in science and technology, both due to the direct effect on U.S. research progress and due to the indirect effects of deterring talented workers from settling in the United States.

d. A framework for controls

In her recent testimony to the House Foreign Affairs Committee, New America Fellow Samm Sacks provides a useful framework for thinking about where to apply controls on technology:[4]

"In general, a technology should be subject to greater control if:

1. It is essential to military technology; however, the term "essential" should not be interpreted to encompass technology that is simply used or is usable by the military, since the defense industry is increasingly reliant on commercial off-the-shelf technology. The International Traffic in Arms Regulations (ITARs) are designed to fulfill this purpose, but differentiating between essential military technology (often controlled by the United States Munitions List) and dual-use technology remains a challenge;
2. There is a scarcity of knowledge about the technology, except among a small group of experts located in the United States or like-minded countries; and
3. The United States is truly ahead of the curve, and that technology is developed exclusively in the United States or other countries that enforce similar export controls. Technical experts must be regularly consulted to evaluate incremental differences between our technology and that of other countries on this point. Not doing so risks the "designing out" of U.S.-made components from products for global markets, which would advantage foreign companies with similar products that are not subject to export controls."

This framework was provided in the context of export controls, but it applies equally well to international research collaborations. I urge the Commission to adopt this framework when considering what types of AI research might merit restriction, given that the vast majority of AI research does not meet any of these three criteria.

3. Human capital as a driver of AI progress

Access to skilled researchers and engineers is a key area of competition in the field of AI. The United States' unique ability to attract and retain foreign talent represents, therefore, a key American advantage. See for example Figure 1 below, which shows the unique U.S. position as a massive net importer of patent holders.

China is working hard to catch up, with government initiatives like the Thousand Talents Plan (千人计划) and educational programs described in the April 2018 *Artificial Intelligence Innovation Action Plan*

[4] Sacks (2019), *Samm Sacks Testifies Before House Foreign Affairs Committee on 'Smart Competition' With China*, https://www.newamerica.org/cybersecurity-initiative/digichina/blog/samm-sacks-testifies-house-foreign-affairs-committee-smart-competition-china/

[for] Institutions of Higher Learning (高等学校人工智能创新行动计划) aiming to step up the training of indigenous talent, and to incentivize Chinese abroad to return home.

The current U.S. approach stands in stark contrast to measures like this from China and other countries. Far from actively stepping up efforts to draw top foreign talent to its shores, recent changes in the U.S. immigration environment are actively undermining this historical—and critical—strength.

More than half of the computer scientists with graduate degrees working in the United States were born abroad (59% of workers with PhDs, 51% of those with Master's).[5] Many of these workers came to the United States as international students, who disproportionately prefer to stay in the United States after completing their studies. More than 85% of Chinese and Indian students in U.S. computer science and engineering PhD programs state that they intend to stay after graduation, and the actual stay rates over five and ten years suggest that nearly this number do in fact remain.[6]

This status quo reflects the high quality of the U.S. commercial and research environment, as well as the attractiveness of the liberty, openness and prosperity found here.

A strategic approach to U.S. AI policy would seek to leverage these strengths in order to cement the United States' place as the standout global hub for AI talent. Unfortunately, recent changes in the immigration environment seem to be pushing in the opposite direction, with Executive Branch policies to constrain legal immigration to this country compounded by increasing reports of long delays in processing of Chinese students in STEM programs.

Ultimately, U.S. action or inaction that restricts the inflow of top-tier research talent from China is a dream come true for the Chinese government. Such actions do more than any Thousand Talents Plan ever could to bolster Chinese competitiveness.

4. Data as a driver of AI progress

a. Data privacy in China

Despite perceptions to the contrary, awareness of and concern about data privacy is rising among Chinese consumers, and the Chinese government is actively developing laws and regulations in response. This push is part of the country's larger effort to build a complex governance regime for cyberspace and information and communications technology.[7]

In broad strokes, this data privacy regime seeks to protect consumer privacy from technology companies working in China. A standard called the Personal Information Security Specification (个

[5] National Science Foundation (2015), *Figure 3-32: Foreign-Born Scientists and Engineers Employed in S&E Occupations, by Highest Degree Level and Broad S&E Occupational Category: 2015*, https://www.nsf.gov/statistics/2018/nsb20181/assets/901/figures/fig03-32.pdf

[6] National Science Foundation (2015), *Appendix Table 3-21: Plans of Foreign Recipients of U.S. Doctorates to Stay in the United States, by Field of Doctorate and Place of Origin: 2004–15*, https://www.nsf.gov/statistics/2018/nsb20181/assets/901/tables/at03-21.pdf.

[7] Sacks, *China's Emerging Cyber Governance System*, https://www.csis.org/chinas-emerging-cyber-governance-system

人信息安全规范) took effect in May 2018 and forms the first piece of the regime.[8] Although modeled heavily on the European Union's General Data Protection Regulation (GDPR), this specification seeks to be somewhat more permissive than GDPR in order to be more business friendly.[9]

One consideration for the United States is whether China will be able to significantly affect global data privacy practices simply by virtue of beginning to regulate companies operating in China before the United States regulates companies operating here. GDPR is already considered to have played a significant role in setting the parameters for future privacy conversations, because multinational companies that operate in Europe have had to build out compliance structures based on the European law, and will likely use those same structures to implement any future legislation.

b. Data as a strategic resource

One related note worth delving into is that I believe the idea of data as a general-purpose strategic resource ("the new oil") has been exaggerated. While it is true that data is an important input to AI systems, data is not generically useful for training any kind of system. This is because AI systems are essentially pattern-recognition machines. Any given AI application will require data that is relevant to the specific problem it is trying to solve, from which it can learn what kinds of patterns are likely to exist in similar data. For example, data on consumers' purchasing history is valuable for predicting future purchasing behavior, data collected by autonomous vehicles can be used to improve autonomous vehicle algorithms, and so on.

In other words, even if China's laws and norms around consumer data privacy remained significantly laxer than the United States', that would not necessarily have many implications beyond the possibility that Chinese companies could more effectively sell their products to Chinese consumers.

Inasmuch as it makes sense to think of data as conferring a strategic advantage, a more productive approach might be to identify specific applications of concern, consider what data would be required to train those systems, and work to improve U.S. access to that type of data. Notably, the United States appears well-positioned in several security-relevant domains, for example due to the fact that the United States has far more platforms and bases, in many more environments, collecting military-relevant data from many more sensors, than China.

Efforts to utilize and protect valuable existing datasets like this would be much more beneficial to the United States than worrying excessively about Chinese citizens' attitudes to privacy.[10]

c. The role of data in digital authoritarianism

Of course, any discussion of privacy in China would be incomplete without mention of the ways in which the Chinese government uses citizen data to implement its authoritarian goals.

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8 Sacks, Shi, & Webster (2019), *The Evolution of China's Data Governance Regime: A Timeline*, https://www.newamerica.org/cybersecurity-initiative/digichina/blog/china-data-governance-regime-timeline

9 Sacks (2018), *China's Emerging Data Privacy System and GDPR*, https://www.csis.org/analysis/chinas-emerging-data-privacy-system-and-gdpr

10 See forthcoming analysis by Carrick Flynn (a CSET Research Fellow) for a more detailed treatment of the strategic role of data.

Predictably, China's emerging consumer data privacy regime described above does not attempt to restrict the Chinese government's ability to surveil its citizens or access their data. All signs indicate that the government will continue to use intrusive techniques to surveil, monitor and oppress its population, up to and including the techniques involved in the horrific treatment of Muslim Uighurs in Xinjiang.[11]

These activities represent gross human rights violations, and deserve the attention of the U.S. Government.

However, a discussion of the future of AI is not the right venue for such attention. As much as the CCP would love to be perceived as having bleeding-edge AI surveillance tools at their fingertips, in reality the technologies that appear to be in use in Xinjiang and elsewhere (such as facial recognition or predictive policing) are straightforward applications of widely available data analysis tools. This is to say nothing of the even more basic methods at play, including ubiquitous checkpoints, the ability to seize and search cellphones, eavesdropping on electronic communications, and regular old human intelligence.

It would therefore be extremely challenging to effectively slow down Chinese access to these technologies. I fear that if the conversation about Xinjiang and other Chinese authoritarianism focuses too heavily on AI and other new technologies, the wrong countermeasures will be taken. While the impulse to ensure that U.S. researchers are not contributing to the surveillance state is a laudable one, we must not deceive ourselves that research like this is a key ingredient in China's actions. What's more, as described in the section on research collaborations above, we must be mindful of the costs to U.S. innovation and competitiveness that could come from poorly-targeted controls.

The determining factor in Chinese oppression is the CCP's willingness to pursue totalitarian ends, not the technological sophistication of its means.

As such, the goal of any measures to condemn the situation in Xinjiang should be just that—to condemn. Measures with the goal of preventing the development or use of a given technology will not work, and will instead damage the United States' standing on the world stage as the global leader in science and technology.

5. Standards and standardization

a. Chinese standardization efforts

China is well aware of the power that can be gained by having a hand in the design of widely implemented standards. As such, there has been an active push within China to develop and establish standards for AI.

One of the most prominent aspects of this push was the release of an in-depth white paper on AI standards in January 2018, which included contributions from over two dozen Chinese companies,

[11] See, for example, this recent Human Rights Watch report for a detailed description of one strategy to collect and use citizen data in Xinjiang: https://www.hrw.org/report/2019/05/01/chinas-algorithms-repression/reverse-engineering-xinjiang-police-mass-surveillance

associations, and academic organizations.[12] Another was a meeting held in Beijing in April 2018, where this white paper was presented to the first meeting of SC 42, a subcommittee on AI that sits within two internationally respected standards bodies, the International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC).[13]

Due to the general purpose nature of AI technologies, it is likely to be more difficult and time-consuming to develop standards for these than for other technologies. So far, the efforts described above do not seem particularly close to producing specific technical standards that will be widely implemented, instead focusing on statements of broad ethical principles. Principles of this kind offer an opportunity for U.S. stakeholders to engage with their Chinese counterparts to reaffirm the importance of the ethical principles expressed, as well as providing a venue to point out incongruities between stated principles of this kind and how the technology is being utilized on the ground.

b. Informal standardization

It is worth noting in this context that while few formal, top-down standards yet exist for AI systems, the widespread use of specific platforms to develop and deploy AI models provides an analogous opportunity to influence the technology.

To the extent that such platforms exist, they primarily stem from U.S. companies. Prominent examples include two software libraries for deep learning: Tensorflow and Pytorch, developed by Google and Facebook respectively, are by far the most widely used platforms of their kind, including in China. (This despite attempts by Chinese companies to release their own versions, most notably Baidu's PaddlePaddle). Platforms like this provide the United States with a form of AI-relevant soft power, and in some ways could be considered analogous to a bottom-up standardization process, inasmuch as they could be used in certain circumstances to affect widespread features of the technology.

6. Recommendations

a. Specific policy recommendations

Specific measures Congress can take to strengthen U.S. competitiveness in AI and protect U.S. interests include the following:

- Improve immigration options available to AI researchers and engineers. As described above, foreign students studying in the United States attempt to stay at very high rates, but this could be threatened by strategic immigration policies currently being enacted by other countries in tandem with a worsening U.S. immigration environment. Specific options here include lifting numerical limits on H-1B visas and/or green cards for AI workers; creating a clear path from student/scholar status to permanent residence; and reducing processing times and application burdens. A forthcoming report from CSET will lay out immigration policy options to bolster U.S. competitiveness in AI in more detail.

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[12] Ding, Triolo, & Sacks (2018), *Chinese Interests Take a Big Seat at the AI Governance Table*, https://www.newamerica.org/cybersecurity-initiative/digichina/blog/chinese-interests-take-big-seat-ai-governance-table/
[13] ibid

- Allocate resources to the National Institute of Standards and Technology to support its efforts to develop and implement standards for AI, as initiated by the recent NIST Request for Information on this topic.[14]
- Increase R&D funding for basic AI research, for example by allocating new funding to the National Science Foundation's Directorate for Computer and Information Science and Engineering. Strength in fundamental research is the backbone of American advantage in AI, but no major federal effort has been made to strengthen that backbone during the current wave of progress in deep learning (in contrast to many other countries, especially China).

b. General recommendations

Beyond specific policy options, I also offer the following suggestions to the Commission and to Congress, to inform any other future action relating to AI competitiveness:

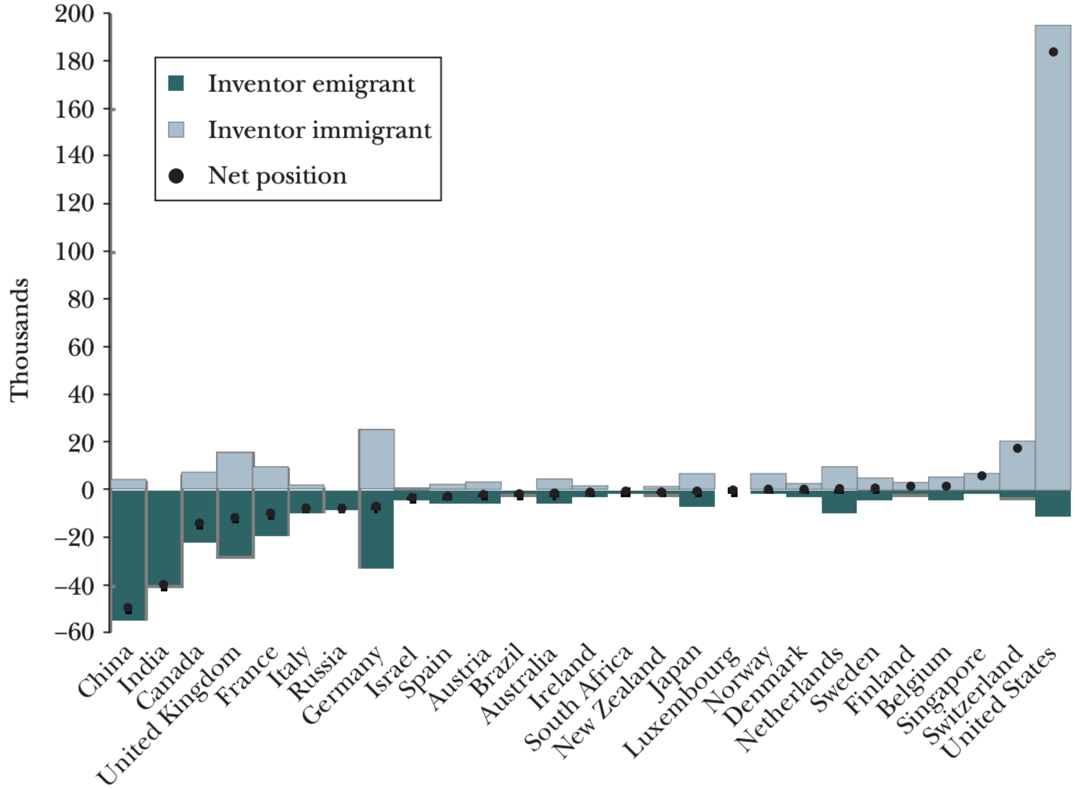
- Place liberal democratic values front and center, in action as well as in word. These values are what give the United States a sustainable, long-term advantage over countries like China. The more we compete on brute force, the better China's chances. If it is clear that we are competing on values, the whole free world is behind us.
- Relatedly, recognize the benefits the United States has drawn from being perceived by researchers as a good place to live and work, and seek to maintain or improve these attitudes. Do not lose sight of the wide-ranging benefits AI can bring to the United States and other countries alike, and have those benefits in mind when enacting measures that will affect how and where AI researchers can work.
- Where it is necessary to restrict foreign access to U.S. research, ensure that these restrictions are highly targeted and that their motivations are explained clearly. Work closely with experts with a strong understanding of the technology to ensure that the restrictions will not have unintended side-effects.
- Wherever possible, provide information rather than enacting restrictions. The AI research community is actively engaged in discussions about ethical and unethical uses of the technologies under development. The USCC, Congress, and other U.S. government entities can play an important role in informing that community about realities on the ground, for example about connections between Chinese research institutes and the Chinese state.

Once again, I wish to thank the Commission for this opportunity to speak on behalf of CSET and to address these issues with you. I look forward to your questions.

[14] Federal Register (2019), *Artificial Intelligence Standards*, https://www.federalregister.gov/documents/2019/05/01/2019-08818/artificial-intelligence-standards

Figure 1[15]

Migration of Inventors, 2000–2010



[15] Kerr, Kerr, Özden, & Parsons (2016), *Global Talent Flows*, https://pubs.aeaweb.org/doi/pdfplus/10.1257/jep.30.4.83

OPENING STATEMENT OF ELSA KANIA, ADJUNCT SENIOR FELLOW, TECHNOLOGY AND NATIONAL SECURITY PROGRAM AT THE CENTER FOR A NEW AMERICAN SECURITY; RESEARCH FELLOW AT CSET

VICE CHAIRMAN CLEVELAND: Thank you.

Ms. Kania?

MS. KANIA: Madam Chairman, Madam Vice Chairman, members of the Commission, thank you for the opportunity to testify this morning.

I'll first provide an overview of the Chinese military strategic thinking and advances in artificial intelligence and then discuss considerations for U.S. policy.

Xi Jinping has called upon the People's Liberation Army to become a world-class force by mid-century. In the process, Chinese military modernization has been directed towards learning from and targeting the U.S. military, which is seen as a powerful adversary.

The PLA aspires not only to equal but also, in the long term, to surpass the U.S. by achieving an advantage in the ongoing revolution in military affairs.

Chinese strategists believe that the character of conflict is being transformed from today's informatized warfare to future intelligentized warfare as a result in these advances in artificial intelligence as a general purpose technology and a range of interrelated emerging technologies.

The PLA is actively exploring and experimenting with new concepts and capabilities to leverage artificial intelligence to enhance its combat power and future strategic deterrence.

PLA strategists recognize that data is a critical resource for combat power and anticipate that the tempo and complexity of future warfare will necessitate greater involvement of AI in command decision making.

Xi Jinping has urged the PLA to accelerate the development of an agenda of military intelligentization, which is starting to take shape.

The essential military commission, science and technology commission, is launching new plans, funds, and contests focused on such frontier technologies.

Its equipment development department is founding dual-use advances in machine learning and a range of armaments development.

The influential Academy of Military Science is integrating theoretical and technological innovations with the establishment of the National Innovation Institute of Defense Technology, which has launched new research centers in unmanned systems, artificial intelligence, and cross-disciplinary research such as biotech and quantum technology involving several hundred researchers and expanding.

Meanwhile, the PLA's National University of Defense Technology is very active in AI research including through international collaborations and its National Defense University has been starting to leverage AI in war gaming.

The Chinese defense industry is also deepening its focus on AI as well as intelligent manufacturing and weapons development and its export of unmanned and semi-autonomous weapons systems is already driving global diffusion of these capabilities.

To date, relevant directions in research development in China have included data fusion to improve situational awareness, applications of machine learning and space systems including for remote sensing and in support of early warning, improved command and control, particularly through decision support, swarming and autonomy and drones and robotics across all domains, greater precision and autonomy in cruise missiles, and even neural networks for the guidance of hypersonic live vehicles, among many other applications and developments.

Each service of the PLA in undertaking its own projects and initiatives. The PLA army has concentrated on military robotics and ground systems. The PLA navy is highly interested in undersea drones and even developing autonomous submarines.

The PLA air force is pursuing new techniques for swarming and man-to-man teaming. The PLA rocket force may leverage use cases of remote sensing, targeting and decision support, and the PLA strategic support force is looking to apply AI to its missions of space, cyber, electronic and psychological warfare.

Although these efforts are nascent, the ambitions and strategic thinking driving them should not be dismissed or overlooked, and at the same time the dynamism of China's academic research and commercial developments will also contribute to this agenda as the PRC pursues a national strategy of military-civil fusion that could provide a systemic advantage if implemented successfully and is starting to progress considerably nationwide.

A growing number of universities and enterprises are involved in this agenda, as I detail in my written report, from Yunzhou Tech's shark swarms of drone vessels to the Beijing Institute of Technology's new class in autonomous weapons development.

Despite these increased capabilities, China does continue to leverage and depend upon foreign technologies and international innovation resources including because of continued weaknesses in some core technologies.

China's active efforts in tech transfer have involved the going out of Chinese enterprises to undertake research, investment and acquisitions internationally, along with parallel attempts to facilitate the so-called "bringing in" of tech and talent back to China, even outright IP theft in some cases.

Chinese military scientists have been sent to study and pursue research abroad, concealing their actual affiliations in some cases. Some of these problematic partnerships involved research with potential defense applications.

Meanwhile, seeking to catch up and catalyze innovation, the Chinese government has been launching guidance funds for military-civil infusion in emerging technologies which are reaching tens, even hundreds of billions in scale by some estimates of which a considerable proportion could be dedicated to AI going forward, and in the long term the returns on these massive investments may start to become more apparent.

The full impact of AI across China's economic development and military modernization could prove transformative though, of course, the trajectory is uncertain.

I assessed in my testimony to the Commission in early 2017 China evidently possesses the potential to compete with or even leapfrog the United States in artificial intelligence, which could become a vital force multiplier for its future military capabilities.

It is even clearer today that Chinese leaders are determined to seize those commanding heights and this new frontier of strategic competition.

The evidence that China is emerging as an AI powerhouse, despite some of its continued limitations have become more compelling and the contours of the PLA strategy for military intelligentization have become more apparent.

Of course, the PLA continues to confront a number of critical challenges in actually operationalizing AI from issues of talent and training to the management of data and adaptation as an organization.

However, the scope and scale of these efforts and their potential for success in the long term should not be dismissed or underestimated and in the years, perhaps decades, to come, the PLA may offset and even surpass the U.S. military.

The advent of AI in military affairs, including synergies with other game-changing technologies on the future battlefield, from 5G to biotech to quantum, may disrupt the balance of power in ways that risk jeopardizing strategic stability and undermining deterrence in the U.S.-China relationship.

Looking forward, a core priority for American strategy should be ensuring our future competitiveness and contesting leadership in strategic technologies.

First, the U.S. should surge support for science and concentrate on expanding educational opportunities while sustaining our openness to immigration.

Next, Congress must ensure that American defense innovation initiatives receive adequate resources including fully funding the Joint Artificial Intelligence Center at the Pentagon.

The U.S. defense budget should also emphasize investment in future capabilities. Furthermore, given the threats of IP theft and tech transfer, U.S. policies should undertake carefully calibrated counter measures to mitigate these risks of exploitation of the openness of our innovation ecosystem while also sustaining the benefits of global research collaboration.

Ultimately, the United States must also sustain its commitment to AI safety and surety, pursue pragmatic initiatives for risk mitigation while advancing a strategy that centers upon our core values.

Thank you, and I will look forward to your questions and the conversation.

PREPARED STATEMENT OF ELSA KANIA, ADJUNCT SENIOR FELLOW, TECHNOLOGY AND NATIONAL SECURITY PROGRAM AT THE CENTER FOR A NEW AMERICAN SECURITY; RESEARCH FELLOW AT CSET

June 7, 2019

Testimony before the U.S.-China Economic and Security Review Commission
Hearing on Trade, Technology, and Military-Civil Fusion

Chinese Military Innovation in Artificial Intelligence

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Xi Jinping has called upon the Chinese People's Liberation Army (PLA) to become a world-class military (世界一流军队) by mid-century.[1] Chinese military modernization has been directed towards learning from and targeting the U.S. military, which is seen as a powerful adversary (强敌). Since the 1990s, the PLA has concentrated on developing asymmetric capabilities aimed at exploiting potential American vulnerabilities and undermining current American advantages. The PLA aspires not only to equal but also to surpass the U.S. military by seizing the initiative in the course of the ongoing Revolution in Military Affairs (RMA) that is being catalyzed by today's advances in emerging technologies.[2] Chinese military strategists anticipate a transformation in the form and character of conflict, which is seen as evolving from today's "informatized" (信息化) warfare to future "intelligentized" (智能化) warfare.[3] The PLA may even offset U.S. military power if successful in advancing innovation and leapfrogging ahead in the course of this transformation. The advent of AI on the future battlefield might disrupt the balance of power in ways that risk jeopardizing strategic stability and undermining deterrence in the U.S.-China relationship. At the same time, the PLA continues to confront critical challenges to operationalizing artificial intelligence (AI) across a range of applications, from issues of talent to the management of data and adaptation as an organization. Looking forward, as this rivalry intensifies, the United States must recognize the imperative of investing in our own innovation and sustaining our core competitive advantages.

The PLA is actively exploring and experimenting with new concepts and capabilities to leverage artificial intelligence to enhance its combat power and deterrence. Chinese defense academics and military strategists are creating ideas and theories of 'intelligentized operations,' seeking to determine new mechanisms for victory.[4] The use of AI in war-gaming and operations research could contribute to conceptual advancements, including the exploration of new notions of human-machine coordination and confrontation.[5] In the process, the PLA is closely studying and adapting lessons learned from U.S. concepts and initiatives, but there is often a significant asymmetry of information, insofar as the state of AI research and applications in China often receive less attention from American strategists. The primary purpose of this testimony—and the author's research over the

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Innovative.

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past couple of years, which is based entirely on open sources that are readily available—has been to contribute to improved understanding of the implications of these military and technological advancements in the People's Republic of China, in ways that can inform future directions in American competitive strategy.[6]

A New Era of Chinese Military Innovation

The PLA is avidly pursuing and prioritizing military innovation. Chinese leaders assess that a new Revolution in Military Affairs (RMA, 军事革命) is underway that presents urgent challenges and historic opportunities for China. In August 2014, the Politburo devoted a study session to the topic of new trends in global military developments and promoting military innovation. At the time, Xi Jinping discussed the emergence of this "new RMA," calling for China to keep pace with the times (与时俱进) in "vigorously advancing military innovation" in order to "narrow the gap and achieve a new leapfrogging as quickly as possible."[7] Xi Jinping's exhortation continues a legacy and trajectory of military modernization that can be traced to the initial reaction of Chinese leaders, including Jiang Zemin himself, to the Gulf War and early American thinking on the RMA.[8] In his remarks at the time, Xi called upon the PLA to carry forward its tradition of innovation through striving to develop new military theories, institutional structures, equipment systems, strategy and tactics, and models for management that could fulfill the demands of its missions in an era of informatized warfare.[9] For China, the emphasis on leveraging science and technology to rejuvenate its military (科技兴军) is central to the Party's "powerful military objective" (强军目标) in the "new era."[10]

This Chinese strategy of "innovation-driven development" could transform the PLA.[11] Discussing Xi Jinping has emphasized, "Under a situation of increasingly fierce international military competition, only the innovators win."[12] As a result, he highlighted the importance of "aiming at the frontier of global military scientific and technological developments," urging:

> "We must attach great importance to the development of strategic frontier technologies, determine the correct follow-up and breakthrough tactics, select the main attack direction and breach, and intensify the formation of unique advantages in some domains of strategic competition, and striving to surpass the predecessor as latecomers, turning sharply to surpass."[13]

Xi has stressed that such technological developments can directly contribute future combat effectiveness.[14] Despite continued challenges, this ambition to leverage next-generation technologies in order to surpass the current global leader (i.e., the U.S. military) is consistently articulated in Xi's remarks and reiterated in authoritative statements by a range of military strategists. This aspiration should be recognized as a serious potential challenge to American military-technological superiority, but whether such surpassing will be realized remains to be seen, as PLA initiatives for military innovation continue to progress through military planning and armaments development, while becoming incorporated into strategy and doctrine.

Throughout its history, Chinese military strategy has evolved and been adjusted in response to new assessments of the form or character of conflict.[15] The latest revision of China's "military strategic guideline" (军事战略方针) to "winning informatized local wars," was confirmed by the 2015 defense white paper, China's Military Strategy, which also discussed a "new stage" in the global RMA as resulting from increasing prominence and sophistication of long-range, precise, smart [*sic*, or "intelligent," 智能],[16] stealthy, and unmanned weapons and equipment."[17] Chinese concerns about the U.S. Third Offset Strategy, which was seen as threatening to create a new "generational difference" (时代差) between U.S. and Chinese military capabilities, appears to have influenced and intensified this imperative of innovation.[18] However, the PLA's approach to leveraging the same technologies that the U.S. military has prioritized will differ as a result of its distinct strategic culture, organizational conditions, and operational requirements. For instance, Chinese strategists have often espoused that "technology determines tactics."[19] Preparing to "fight and win" future wars, the PLA is determined to seize the initiative in the strategic technologies of the future.

The PLA's military reforms, launched in late 2015, have advanced a historic restructuring that is intended to enable the PLA to increase its capability for integrated joint operations across all domains of warfare.[20] In the course of these reforms,[21] the Strategic Support Force (战略支援部队), which has integrated the PLA's space, cyber, electronic, and psychological warfare capabilities, has been directed to pursue innovation and develop new capabilities to contest these new frontiers of military power.[22] Notably, the reforms have also included the creation of the Central Military Commission (CMC) Science and Technology Commission, which has taken on a mission of promoting defense science and technological innovation, launching new plans, funds, and contests focused on "frontier" (前沿) technologies.[23] Concurrently, the transformation of the PLA's Academy of Military Science (AMS) has also positioned this influential institution, which has been traditionally responsible for the formulation of PLA strategy and doctrine, to integrate theoretical and technological innovations. Notably, AMS has established a new National Defense Science and Technology Innovation Research Academy (国防科技创新研究院, or "National Innovation Institute of Defense Technology" in its typical English translation),[24] including a new Artificial Intelligence Research Center, that has already brought together several hundred researchers and is actively recruiting new civilian personnel and military scientists.[25]

Chinese leaders believe artificial intelligence is a strategic technology that is critical across all dimensions of national competitiveness, with the potential to transform current paradigms of military power. Beijing's decision to prioritize AI to enhance China's economic development and military capabilities is evident across a growing number of plans, policies, and authoritative statements.[26] In July 2017, the New Generation Artificial Intelligence Development Plan elevated AI as a core priority, catalyzing what has become a whole-of-nation strategic initiative.[27] Since then, this agenda has progressed at all levels of government and through the efforts of across a range of stakeholders, building upon and harnessing the robust efforts of China's dynamic technology companies, while introducing strong state support and funding that amounts to tens, perhaps ultimately hundreds, of billions in investments across a range of local and central programs.[28] In the process, the Chinese government has launched five open innovation platforms that are intended to advance AI development, which have been launched by a 'national team' of AI champions, who include Baidu, Alibaba, Tencent, iFlytek, and Sensetime to start, concentrating on such applications as driving, smart cities, medicine, smart voice, and intelligent perception.[29] This plan also discussed the implementation of a strategy of military-civil fusion (军民融合) in AI, calling for strengthening its use in military applications that include command decision-making, military deductions (e.g., wargaming), and defense equipment.[30]

The concerns of Chinese defense academics and military strategists with the potential impact of AI in future warfare have been influenced by an increased awareness of the rapid progress in AI.[31] In particular, AlphaGo's defeat of Lee Sedol in the game of Go in March 2016, which appeared to demonstrate the potential advantages that AI could provide in future command decision-making, shaped these assessments, prompting high-level attention.[32] Starting around that timeframe, the PLA writings highlighted with increased frequency the assessment that today's "informatized" warfare was undergoing a transformation towards future "intelligentized" (智能化) warfare, catalyzed by the rapid advances in these emerging technologies, a conclusion that has since received ever more official imprimatur.[33] Writing in an authoritative commentary in August 2016, CMC Joint Staff Department called upon the PLA to leverage the "tremendous potential" of AI in operational command, planning and deductions, and decision support, while urging the advancement the application of big data, cloud computing, artificial intelligence, and other cutting-edge technologies to the construction of the PLA's command system for joint operations.[34] Significantly, in October 2017, in his report to the 19th Party Congress, Xi Jinping urged that the PLA, "Accelerate the development of military intelligentization" (军事智能化), and improve joint operations capabilities and all-domain operational capabilities based on network information systems."[35]

This authoritative exhortation has elevated the concept of "intelligentization" as a guiding principle for the future of Chinese military modernization. The PLA's apparent enthusiasm for embracing AI reflects a recognition of the potential dividends of success or leadership in this new RMA. In October 2017, Lieutenant General Liu Guozhi (刘国治), director of the CMC Science and Technology Commission, personally emphasized the imperative of promoting intelligentization, arguing, "This is a rare strategic opportunity for our nation to achieve innovation surpassing and to achieve a powerful military, and it is also a rare strategic opportunity for us to achieve turning sharply to surpass (弯道超车)."[36] His comments articulate the intention to take advantage of disruptive changes in order to take the lead. Whereas the PLA was a spectator and latecomer to the early stages of RMA, this new RMA presents an opportunity for the PLA to perhaps emerge as the first to realize disruptive capabilities, including based on breakthroughs in new theories for intelligentization.[37] Although the PLA continues to confront certain challenge in catching up,[38] its relative backwardness also presents the potential for certain advantages in the process of "leapfrog development" (跨越发展) in its technological advancement.[39] In particular, the PLA possesses fewer legacy weapons and platforms and appears to be prioritizing investments in next-generation weapons systems, such that it and could prove capable of introducing new systems more rapidly, for instance, than the U.S. military.

In practice, the process of intelligentization appears to involve the development and operationalization of artificial intelligence and the enabling and interrelated technologies that are required for its realization for military applications.[40] In practice, intelligentization is intended to build upon prior stages of mechanization and "informatization," the process through which the PLA has introduced information technology and undertaken the development of its C4ISR (command, control, communications, computers, intelligence, surveillance, and reconnaissance) capabilities.[41] For the PLA, force construction requires simultaneous undertaking of all three processes, which may present distinct difficulties but also enables the leveraging of synergies among them.[42] The concept of military intelligentization is not only about AI but "refers to the overall operational description of the force systems consisting of people, weapons equipment, and ways of combat," according to one PLA scholar.[43] This new 'system of systems' consists of not only intelligent weapons but also a new military system of systems that involves human-machine integration and with (artificial) intelligence in a 'leading' or dominant (智能主导) position.[44]

Chinese military scientists and strategists are undertaking extensive theoretical research on the impact of AI on future warfare. These initial conceptual developments will likely influence future directions in PLA strategy, doctrine, and weapons development. In March 2016, *China Military Science*, the journal of the Academy of Military Science, convened a workshop on the implications of AlphaGo's recent match with Lee Sedol for future command decision-making, bringing together senior strategists and researchers.[45] Starting in 2016, a series of seminars on future warfare have been held annually, organized by the China Electronics Technology Group's (CETC) Strategy Research Center and the National University of Defense Technology, which have convened an array of prominent researchers from the military and defense industry to discuss the impact of such technological advancements.[46] The Chinese Association of Artificial Intelligence (CAAI) in February 2018 organized a conference to discuss the role of AI in the RMA that involved academicians from the Chinese Academy of Engineering, the China Institute for Command and Control, the PLA Academy of Military Science, and National University of Defense Technology, as well as the Army, Naval, Air Force, and Rocket Force research institutes.[47] This seminar was described as undertaking "innovation in theoretical and technology integration" (理技融合创新), concentrating on new approaches to intelligent command and control for a new era. In the aggregate, these activities can be characterized as robust indications that the PLA is engaged in the intellectual exploration and speculation that can establish a conceptual framework for future experimentation and eventual operationalization.[48]

The PLA's premier academic and research institutions have been tasked to prioritize innovation in disruptive and emerging technologies. During his visit to the PLA's Academy of Military Science in May 2018, Xi Jinping called for AMS to concentrate on "increasing the intensity of innovation in emerging domains, and strengthening the incubation of strategic, frontier, and disruptive technologies."[49] His remarks emphasized the importance of placing innovation in a prominent position and pursuing innovation in military theories, national defense science and technology, military science and research work on organizational models. During his visit, Xi also spoke to Major General Li Deyi (李德毅), who is currently a research fellow with the AMS Systems Engineering Research Institute, who is focusing on unmanned systems and artificial intelligence.[50] The PLA's National University of Defense Technology (NUDT) is considered an "important highland for indigenous in national defense science and technologies" that is concentrating on "developing the key technologies for national defense in the intelligent era."[51] In particular, NUDT has built upon its existing research in automation through the Academy of Intelligent Sciences (智能科学学院), which is pursuing research that includes intelligent robotics, including bionic robotics and autonomous control, such as swarm intelligence. The PLA's National Defense University has also started to explore the impact of AI in its research and teaching, including through war-gaming.[52]

Chinese military science and research on the dynamics of future intelligentized operations are informed by close study of U.S. ways of war-fighting and intended to 'offset' or undermine current American military advantages.[53] As an authoritative commentary in *PLA Daily* urged, "Keep an eye on future opponents, adhere to using the enemy as the teacher, using the enemy as a guide, and using the enemy as a target... We must develop technologies and tactics that can break the battle systems of powerful adversaries and counter the high-end combat platforms of powerful adversaries."[54] Although the PLA has not yet finalized or formalized doctrinal concepts for intelligentized operations, a review of the range of semi-authoritative and authoritative writings can reveal some initial insights about the current trajectory and continued evolution of this thinking among the community of scholars and scientists who are engaged with these issues. For instance, in early and seemingly relatively impactful writings, Major General Li Bingyan (李炳彦), who has served as a senior editor of the *PLA Daily* newspaper and a researcher for China's National Security Commission, has argued for a concept of "light warfare" (光战争), which would leverage directed energy (i.e., 'light') technologies in conjunction with autonomous systems for "zero-hour" attacks enabled by real-time information, informed by a study of the U.S. Third Offset strategy.[55] Zhang Zhanjun (张占军), a senior researcher with the Academy of Military Science's Theory and Operational Regulations Research Department,[56] who also serves as editor-in-chief of its journal *China Military Science*, wrote a lengthy commentary in October 2017 on how the PLA might compete to seize the initiative in future maritime combat, arguing, "using new-type combat forces to fight in new domains such as networks and space, we must implement asymmetric autonomous operations."[57] The PLA's traditional concentration on devising capabilities designed to target perceived weaknesses an adversary's ways of warfare will likely persist in conceptual and technological developments that leverage these emerging technologies.

It is noteworthy that the latest edition of *The Science of (Military) Strategy* released in 2017 by the PLA's National Defense University has added a new section on "military competition in the domain of (artificial) intelligence" (智能领域军事竞争), in an unusual, off-cycle revision of this authoritative textbook,[58] of which Lt. Gen. Xiao Tianliang (肖天亮), who remains the vice commandant of the PLA's National Defense University, is the editor.[59] The section discusses the "new military intelligentization revolution" underway that involves strategic competition among nations worldwide that are seeking to "seize this new strategic commanding heights in military affairs." Beyond the trend of increased prominence of intelligent unmanned systems, intelligent operational systems are expected to become 'unavoidably 'the dominant forces on the battlefield in future warfare. As a strategic guidance for the character of competition in this new frontier:

> "military intelligentization advances new and higher requirements for armed forces construction; it is provides a rare opportunity for latecomer militaries [to undertake] leapfrog development, achieving turning sharply to surpass (弯道超车). It is necessary to actively confront the challenge of intelligentization, planning and preparing a strategy for the development of military intelligentization [and] seizing the commanding heights of future military competition."

According to *Science of Military Strategy*, the strategic guidance for this new domain in military competition involves a number of lines of effort through which the PLA intends to progress in accordance with the following principles and objectives.[60]

- "Scientifically undertake planning and programs, and advance holistically the construction and development of military intelligentization."

This undertaking is characterized as a complex endeavor of systems engineering that involves the development of intelligent systems across all domains, the exploration of new styles and theories of intelligentized weapons and operations, while influencing and requiring the reform and adjustment of military organizational structures. This process requires "top-level design," a plan and roadmap for development, and the pursuit of focal points and breakthroughs.

- "Strive to attack core technologies, seizing the initiative in the development of military intelligentization."

The capability to achieve breakthroughs in core and critical (核心关键) technologies is seen as a critical determinant of success or failure in competition in military intelligentization, which will require overcoming current bottlenecks. This pursuit of advances in fundamental research will also concentrate on increasing original innovation capabilities in interdisciplinary research involving brain science, cybernetics, and biological sciences.

- "Strengthen cutting-edge research, and unceasingly deepen military theoretical innovation."

This new direction in force construction requires theoretical guidance. For instance, research is required on a number of major problems that include the opportunities and challenges of promoting intelligentization, along with the changes in combat styles that might result from the employment of intelligentized weapons and equipment. In this process of inquiry, it will be important to focus on future trends with an eye to the dynamics of actual combat and the threat of a powerful adversary (强敌), a term that is often a byword for the U.S. military.

- "Promote deeper military-civil fusion, and leverage societal resources for the development of military intelligentization."

The implementation of military-civil fusion can concentrate on leveraging basic advances that include deep learning, machine perception, and intelligent robotics. In practice, these efforts will involve the mechanisms to promote the sharing of resources and collaboration in research and applications, leveraging new institutional mechanisms. The objective is to ensure the coordination and complementarity of economic and national defense construction in the process.

- "Properly manage each kind of relationship, and achieve the scientific development of military intelligentization.

This agenda must be implemented in accordance with future military requirements, while balancing between drawing lessons from foreign militaries and engaging in entirely indigenous innovation. The PLA must also balance between pursuing incremental development to fulfill national security requirements, while also taking full advantage of the opportunity for 'leapfrogging' ahead with the ultimate objective of seizing the strategic commanding heights in order to surpass the current leader, implicitly the U.S. military.

As the PLA continues to concentrate on revising military policies and doctrine, these research activities may contribute to future revisions to PLA military strategic guidelines (军事战略方针) and the next generation of the PLA's operational regulations (作战条令), which are still under development.[61] The inclusion of discussion of competition in artificial intelligence in this authoritative textbook reflects a further formalization of the PLA's strategic thinking on the importance of military intelligentization. While the PLA's process of adjusting certain elements of its equivalentn to doctrine remains ongoing, there are indications that new theories and concepts involving AI could be incorporated into future revisions. According to Wang Yonghua (王永华), a scholar with the Academy of Military Science's Operational Theories and Regulations Department, writing in November 2018:

> "At present, to research and develop concepts of operations, it is necessary to focus research on the profound influence of such high-tech groups as artificial intelligence, big data, and Internet of Things upon the methods and routes for combat victory. [We must] research the development of changes to the winning factors of information, forces, time, space, and spirit; study the impact of the interactions of space, cyber, electromagnetic, deep sea and other spaces' with traditional combat spaces on future operations, developing new operational concepts though future combat research and design."[62]

However, these concepts must be officially incorporated into the PLA's "operational regulations" in order to inform more directly future military operations and training. The PLA's process of transforming concepts into doctrine requires a more formal process of evaluation and authoritative assessment, including on the basis of ideological considerations. In this regard, it would be premature to say that the PLA has a formal doctrine or framework of firm policies established on questions of autonomy and artificial intelligence. Nonetheless, this theoretical research is nonetheless informative of the direction that these initiatives are taking.

Across such writings, there is often recurrence of the assessment that the tempo and complexity of operations will increase to an extent, changing the role of humans on the battlefield. Already, today's informatized warfare has placed a premium upon competition in the cognitive domain, demanding rapid processing of information and evaluation of the operational environment in order to enable superior decision-making.[63] Looking forward, "on the future battlefield, with the continuous advancement of AI and human-machine fusion (人机融合) technologies, the rhythm of combat will become faster and faster, until it reaches a "singularity" (奇点): the human brain can no longer cope with the ever-changing battlefield situation, unavoidably a great part of decision-making power will have to be given to highly-intelligent machines," by the assessment of Chen Hangui (陈航辉), a researcher with the Army Command College.[64] As a result, the role of humans could transition from being 'in' the loop, to 'on' the loop, and perhaps even out of the loop.[65] Although there is not sufficient evidence to conclude that the PLA is likely to take humans 'out of the loop' entirely, this expectation that there will be a future point at which "the rhythm of intelligentized operations will be unprecedentedly accelerated," beyond the capabilities of human cognition, does recur across a number of PLA writings that appear to be reasonably authoritative.[66] However, PLA thinkers to appear to recognition of the importance of balancing human and machine elements in decision-making, which is emphasized as an important 'dialectical relationship,' as Chen Dongheng (陈东恒) and Dong Julin (董俊林) researchers with the PLA Academy of Military Science have highlighted.[67]

The realization of intelligentization will also involve and require a number of supporting and interrelated technologies. For instance, cloud computing is recognized as important to realizing intelligentization, including to improve the management of military data.[68] The recent advances in AI chips and the requisite hardware can enable improved analytic and processing capabilities 'at the edge.'[69] In practice, such future warfare could involve a range of intelligentized weaponry, enabled by the Internet of Things (IoT), and leveraging networked information systems that are integrated across all domains.[70] Some military scientists have emphasized that 5G will be vital to enabling the process of intelligentization, since such increases in connectivity can allow for improvements in data sharing, new mechanisms for command and control, and enhanced systems to fulfill future operational requirements.[71] In particular, 5G is anticipated to allow for machine-to-machine communication among sensors, drones, or even swarms on the battlefield, as well as improvements in human-machine interaction.[72] As China looks to construct a more integrated information architecture, 5G could become critical to this new 'system of systems.'[73] Ultimately, it is not AI alone but the synergies of AI as a force multiplier for a range of weapons systems and technologies, also including directed energy, biotechnology, and perhaps even quantum computing, that could prove truly transformative.

Chinese military scholars and scientists are also focused on the challenges that data presents. From a practical perspective, data, recognized as a "pivotal strategic resource," is expected to become "an important foundation for the creation of the intelligentized battlefield,"[74] on which dominance in artificial intelligence could constitute the "core mechanism" for victory.[75] In July 2018, the PLA's first "military big data forum" was convened by the Chinese Academy of Sciences, Tsinghua University, and Chinese Institute of Command and Control in Beijing.[76] The symposium concentrated on the importance of military big data, with an emphasis on ways that the military could learn lessons from enterprises and government in the management of big data. Among the participants was Song Jie, vice president of Alibaba Cloud (Aliyun), who discussed how Alibaba had leveraged big data to achieve a major advantage relative to traditional business infrastructure.[77] At the time, He You (何友), who is director of PLA Naval Aeronautical University's Information Fusion Research Institute argued that defense competition "is centering on cognitive advantages and decision-making advantages" that require data.[78] In a prominent commentary in February 2019, PLA scholar Zuo Dengyun (左登云) emphasized, "data is the "blood" of maritime operations…It is necessary to obtain massive amounts of information through data deposits, grasp the weaknesses of enemy systems through data mining, share the operational situation through data presentation, and open up multi-domain joint channels, activating the "sense" of "smart" network empowerment."[79] In the future, "without data, (you) can't (fight) a war" (无数据不战争), and the PLA is concerned with improving its collection, management, and processing of data.[80]

Increasingly, Chinese strategic thinkers are arguing that the advent of AI could change the fundamental mechanisms for winning future warfare. The increased prominence of intelligent weapons on the future battlefield could result in "remote, precise, miniaturized, large-scale unmanned attacks" becoming the primary method of attack, according to Yun Guanrong (游光荣) of the Academy of Military Science.[81] Given the ways that AI can increase the tempo, accuracy, efficiency of operations, some strategists anticipate that "[artificial] intelligence will transcend firepower, machine power, and information power, becoming the most critical factor in determining the outcome of warfare."[82] In future intelligentized warfare, today's "system of systems confrontation" could become instead a "game of algorithms" in which algorithmic advantage is a dominant determinant of operational advantage, as Li Minghai (李明海) of the PLA's National University of Defense Technology has anticipated.[83] The employment of superior algorithms could dispel the 'fog' of the battlefield and enable decision-making advantage, while increasing the efficiency of operations.[84] In particular, decision-making could leverage the respective strengths of human and machine cognition, while leveraging a 'cloud brain' that allows for swarm and distributed decision-making, enabled by deep neural networks. As a result, new styles of operations could emerge, particularly penetrating the cognitive and information domains. Beyond the battlefield, AI is also expected to contribute to more far-reaching transformations that could result in the intelligentization of logistics support, models of combat power generation, organizational mechanisms, and education and training.[85]

The capability to counter or subvert an adversary's capabilities in AI could become a critical determinant of victory in intelligentized operations. PLA academics and strategists have discussed options for countermeasures against adversary's military employment of AI,[86] which might include interference, damage, and destruction through kinetic or non-kinetic (e.g., electromagnetic, microwave weapons) means, or even attempts to make the enemy lose control of its AI and modify its procedures, to result in an 'uprising' that could advantage one's own side.[87] In particular, "counter-intelligentized operations" would involve to "paralyze the enemy's artificial intelligence, this the "brain"; cutting the enemy's combat network, this the "nerve"; and draining the enemy's combat data, this the "blood," as Maj. General Li Dapeng (李大鹏) of the PLA's Naval Engineering University has argued, calling for research on such techniques as counter-swarm combat, adaptive electronic warfare, and intelligent cyber warfare.[88] The use of AI can identify weak links and important targets in an adversary's system for joint operations, including to enable assaults intended to collapse an opponent's system of systems architecture.[89]

Artificial Intelligence in the People's Liberation Army

The PLA has been actively pursuing research, development, and experimentation with an array of applications of artificial intelligence. The PLA's interest in AI is not a recent phenomenon. Chinese research and development of dual-use advances in robotics and early artificial intelligence can be traced back to the mid-1980s, at which time the 863 Plan also launched a project that involved robotics and intelligent computing.[90] Certain initiatives to apply expert systems to military operations research also date back to the late 1980s and 1990s.[91] Some Chinese military researchers who are active in work on decision support systems, such as Major General Liu Zhong (刘忠) of the PLA's National University of Defense Technology, have been leveraging what might be considered 'AI' in their research since around the mid-2000s.[92] Some lines of effort in weapons development, such as the application of advanced algorithms to work on hypersonic glide vehicles can also be traced back to the mid-2000s.[93] The Chinese defense industry's attempts to make cruise and ballistic missiles more 'intelligent' build upon advances in Automatic Target Recognition (ATR) that also predate the recent concern with autonomous weapons. As early as 2011, the PLA's official dictionary included the definition of an "AI weapon" (人工智能武器) as "a weapon that utilizes AI to pursue, distinguish, and destroy enemy targets automatically (自动); often composed of information collection and management systems, knowledge base systems, decision assistance systems, mission implementation systems, etc."[94] The trajectory of weapons research and technological development in China since the 1990s, particularly robust research undertaken by various elements of the Chinese Academy of Sciences, has established a fairly robust foundation for today's transition from informatization to intelligentization.

Today, as Xi Jinping calls upon the PLA to pursue military innovation, such efforts are redoubling. The stakeholders that have a designated involvement in promotion and implementation of China's New Generation Artificial Intelligence Development Plan include the Central Military-Civil Fusion Development Commission Office, the Central Military Commission (CMC) Science and Technology Commission, and the CMC Equipment Development Department.[95] The PLA's Central Military Commission (CMC) Science and Technology Commission is guiding and supporting research in such 'frontier' technologies, including through a new 'rapid response small group' for national defense innovation that seeks to leverage commercial technologies.[96] The CMC Equipment Development Department, which is responsible for defense armaments development, is also funding and promoting research involving unmanned systems and artificial intelligence, including supporting dual-use technological developments with guidance from an "AI Expert Group." It is likely that support for AI has been and will be included in the PLA's plans for weapons development. The PLA Army, Navy, Air Force, Rocket Force, and Strategic Support Force are all pursuing their own service-specific projects and initiatives through their respective equipment departments and through their research institutes and partnerships. To date, each service in the PLA has started to field and deploy a number of unmanned (i.e., remotely piloted) systems, of which some have at least a limited degree of autonomy.[97]

The PLA's pursuit of military intelligentization is intended to enhance and augment existing weapons systems, while also enabling novel capabilities. The patents, funding, and technical publications that are often openly published and demonstrated provide initial indications of the direction of these developments, and there are also certainly classified programs underway about which no or fewer details are known. The PLA should be expected to employ AI across an array of applications in all domains of warfare and a range of missions in combat and to support operations. Based on the information that is readily available, the PLA is exploring and/or pursuing research and development of technologies and potential capabilities that include, but are not limited to:

- leveraging machine learning in support of maintenance, including for fault prediction,
- the application of new algorithms, including machine learning, to remote sensing and battlefield environmental support,[98]
- the employment of natural language processing for analysis in military intelligence,
- machine learning techniques that can function under conditions of limited computing capabilities,
- the exploration of options to leverage artificial intelligence for political work and psychological operations,
- advances in generative adversarial networks that can be leveraged for image manipulation, including the potential employment of deep fakes,
- the improvement of algorithms for Automatic Target Recognition (ATR) to enhance precision, including the identification of multiple targets in real time based on the use of neural networks,
- the application of virtual and augmented reality to modeling, simulations, and actual combat training,
- the use of deep learning and other algorithms to model the dynamics of offense and defense in free air combat,
- the introduction of AI to war-gaming as a tool for training and evaluating the dynamics of intelligent confrontation,
- the use of neural networks for missile guidance to enable greater autonomy in cruise missiles for control and targeting,[99]
- the introduction of new approaches to spectrum management and techniques for electronic countermeasures, including an emphasis on cognitive electronic warfare,[100]
- the use of AI technologies for cyber security and cryptography, including in advanced steganography,[101]
- the use of artificial intelligence to improve communications and to secure networks against jamming,[102]

- new techniques for data fusion intended to improve situational awareness, including through potentially integrating information from sensors and unmanned systems in support of anti-submarine warfare,
- the use of expert systems and more advanced techniques for decision support to commanders or to the operators of specific platforms (e.g., fighter jets and submarines)
- overcoming obstacles to and challenges of human-machine interaction, involving new models to improve reliability
- the application of neural networks to the guidance of hypersonic glide vehicles to enable more precise and autonomous control,
- increased autonomy in 'unmanned' systems across all domains of warfare, including a number of aerial vehicles, ground vehicles, surface vessels, and underwater robotics, as well as autonomous submarines,
- new algorithms and architectures for swarm intelligence aimed at enabling 'swarm combat,'
- methods for modeling and evaluation of unmanned equipment to test reliability and functionality,
- 'AI satellites' and software-defined satellites for military, commercial, and dual-purpose applications with the onboard capability for intelligent processing,[103]
- wearable systems for individual personnel intended to enhance situational awareness and decision-making on the battlefield
- the management of massive amounts of military data, including through parallel processing, in support of joint operations,
- improving the integration and processing of information for the PLA's integrated command platform, and
- capabilities and techniques to counter or subvert an adversary's AI systems via manipulation of data and/or exploitation of hardware vulnerabilities, among others.

Please note that this listing is not intended to be comprehensive but rather generally representative of the overall directionality of these efforts that can be readily confirmed based on open sources.

The PLA's research, development, and experimentation with applications of artificial intelligence can also be examined within the priorities and missions of each service, which are here outlined in an initial review of known efforts.

PLA Army

The PLA Army (PLAA) has primarily concentrated on military robotics and ground systems to date. The PLAA Equipment Department has organized a series of biannual competitions, known as "Crossing Obstacles" (跨越险阻) for the development of unmanned ground systems in 2014, 2016, and 2018.[104] Each competition has involved a range of teams from academic, industry, and military research institutes, reaching a total of 136 teams as of 2018.[105] The Army Equipment Department has also established an Expert Advisory Group for Ground Unmanned Systems.[106] The PLAA Equipment Department has been reportedly reevaluating its plans for armaments development against priorities from the 19th Party Congress, including unmanned operations, artificial intelligence, and electromagnetic attack.[107]

PLA Navy

To date, the PLA Navy has deploying and experimenting with a range of intelligent/autonomous surface vessels and underwater vehicles.[108] Notably, the *Haiyi* (海翼) or "Sea Wing," underwater glider designed by the Chinese Academy of Sciences (CAS) Shenyang Institute for Automation, has been used so far for primarily scientific missions but also possesses potential military applications.[109] The Sea Wing, which has a low acoustic signature, could be leveraged to enable undersea surveillance to support the detection of foreign submarines,[110] thus potentially enhancing to enhance PLA anti-submarine warfare capabilities.[111] To date, various variants of this glider are known to have been operated not only in the South China Sea,[112] but also as far afield as the Indian Ocean,[113] and even in support of Arctic exploration.[114]

The PLAN is also exploring and could expand its employment of unmanned and autonomous vessels. Notably, China has also established the world's largest facility for the testing of such vessels at the Wanshan Marine Test Site in Zhuhai.[115] To date, the *Jinghai* (精海), an 'intelligent' vessel with the reported capability to navigate autonomously, appears to be in use with the PLAN and might support maritime sensing and domain awareness.[116] Some of the future unmanned warships under development by the Chinese defense industry could augment the PLAN's growing fleet.

Reportedly, the PLAN is also developing AI-enabled submarines to advance Chinese capabilities in undersea warfare, through a classified military program known as the 912 Project.[117] This disclosure in English-language reporting appears to constitute a deliberate signaling of potential future capabilities. Although fully autonomous submarines may remain a long-term objective, the introduction of AI technologies for decision support on submarines, including to improve acoustic signa processing, could prove more feasible in the meantime.[118]

The PLAN is funding and engaging in ongoing research that concentrates on data fusion. Indeed, He You (何友), who also holds a rank of rear admiral (i.e., as a technical general) in the PLAN and serves as the current director of the Military Key Laboratory of Naval Battlefield Information Perception and Integration Technologies, is actively engaged in research on "advanced maritime information acquisition and processing technologies to achieve continuous, real-time and accurate monitoring and forecasting of marine targets."[119] Rear Admiral He You has highlighted new trends in research in information fusion, enabled by advances in AI, that could have highly promising military applications, including target recognition, situation evaluation, and impact estimation, going forward.[120] The PLAN is directly funding and supporting a number of research projects involving new techniques in data fusion, information processing, and target recognition.

PLA Air Force

The PLA Air Force (PLAAF) is continuing its research, development, and operationalization of a range of UAVs with varying degrees of autonomy, while exploring new techniques for swarming and manned-unmanned teaming. In 2018, PLA Air Force's Equipment Department organized a competition for the development of swarms with greater degrees of autonomy, capable of collaboration and coordination for involving racing, cooperative reconnaissance, searching, and assaults; and autonomous confrontation.[121] This contest involved 448 players from 50 teams, of which winners came from the Air Force Engineering University and Harbin Engineering University.[122]

As PLAAF thinkers evaluate the impact of AI on future warfare, there is active interest in the impact of AI on new styles of air combat and as applied in weapons systems and supporting equipment.[123] For instance, AI technologies are expected to have applications in early warning, detection, route planning, and task management. Reportedly, the PLA Air Force is funding at least seven classified projects that involve AI technologies, including intelligent imaging, unmanned swarm combat platforms, agile coherent radar, and cognitive radar.[124]

The PLAAF is experimenting with expanding its use of small drones from commercial companies in support of logistics. In October 2017, the PLA Air Force Logistics Department introduced major partnerships with logistics companies, including Jingdong (JD) and SF Express,[125] which are known for their use of drones in logistics.[126] In January 2018, the PLAAF engaged initial trials of using drones from these rapid delivery companies to deliver supplies troops in the field.[127] This initial drill was intended to mark the start of a new trend towards the development of unmanned and intelligent technologies in support of logistics, which the Air Force Logistics Department is continuing to pursue." [128]In particular, Jingdong (JD) has reportedly constructed a logistics hub base in conjunction with the Air Force Logistics Department,[129] while continuing to pursue research and develop more large-scale drones for use in commercial and military logistics,[130] such as the JDY-800, which can carry over 840 kilograms of cargo for distances up to 1,000 kilometers.[131]

PLA Rocket Force

The PLA Rocket Force (PLARF) is exploring applying machine learning, including neural networks, to remote sensing and intelligence in ways that could support targeting in future operations. Of the research published and publicly available from Rocket Force Engineering University researchers, there is a strong emphasis on applying machine learning techniques to remote sensing, including the use of adversarial networks in a new framework for domain adaptation and classification based on deep convolutional neural networks,[132] as well as to hyperspectral image classification.[133] Some of their research to date has focused on fault diagnosis and prediction that contribute to improved maintenance of weapons systems, explored leveraging new techniques for the modeling of complex systems, and pursued advances in robotics and multi-agent systems.[134] The PLARF Engineering University also contributed as a co-organizer to an international workshop on AI and evidential reasoning that was convened in January 2018 included a focus on intelligent reasoning and decision-making.[135]

PLA Strategic Support Force

The PLA Strategic Support Force (PLASSF) is looking to leverage advances in AI in support of its missions of space, cyber, electronic, and psychological warfare. The PLASSF is also engaged in extensive research and academic activities through a number of institutes and its flagship universities, the Information Engineering University and Aerospace Engineering University. Pursuant to changes to the PLA's system for civilian personnel, the PLASSF has been recruiting researchers with a background in AI, including for positions focused on "aerospace artificial intelligence."[136] At PLASSF Information Engineering University (IEU) researchers have focused on applications of AI to cyber security, remote sensing, cryptography, and intelligent chipsets, among others.[137] The PLASSF IEU has indicated that its future institutes will concentrate on advancing innovation in fields including big data, artificial intelligence, and quantum information.[138] PLASSF researchers are also exploring the application of artificial intelligence to electronic reconnaissance and countermeasures.[139]

Today's advances in AI could be integral to China's future space capabilities. For instance, researchers with the PLASSF Aerospace Engineering University (AEU) have published on concepts for data-driven spatial target recognition that applied machine learning algorithms, including convolutional neural networks, to develop models for identification.[140] In May 2018, the AEU teams participated in the "Eye Cup" (眼神杯), a competition that was co-sponsored by a research program through the National Natural Science Foundation of China on basic theories and key technologies for spatial information networking.[141] This contest concentrated on SAR remote sensing image recognition, optical remote sensing image recognition, and remote sensing satellite tracking, leveraging machine vision and image processing.

Military Science and Research Institutions

The PLA's premier institutions for military science, the Academy of Military Science and National University of Defense Technology, are pioneers for Chinese military initiatives in advancing artificial intelligence. The PLA's National Defense University will also be an important contributor to strategic research and education in this context.

Academy of Military Science

In the course of the PLA reforms, the PLA's Academy of Military Science (AMS) has experienced a surprising and far-reaching transformation, integrating new directions in science and technology with its traditional concentration on military strategy and doctrine. The recent reorganization at AMS positions it to advance this agenda, with the creation of the National Defense Science and Technology Innovation Research Institute (国防科技创新研究院) as of July 2017,[142] which is referred to in English as the National Innovation Institute of Defense Technology (NIIDT).[143] Initially, in early 2018, AMS reportedly introduced a contingent of 120 top researchers, a significant proportion of whom had PhDs, to pursue research that included military applications of artificial intelligence and quantum technologies.[144]

Based on initial estimates, NIIDT includes several hundred researchers in total and is recruiting for continued expansion.[145] This new institute includes an Artificial Intelligence Research Center, which pursues research on intelligent algorithms, robotics operating systems, intelligent computing chips, big data, and cognitive radio and communications; an Unmanned Systems Technology Research Center, which focuses on the design, research and development, integration, verification, and application of intelligent unmanned systems and systems of systems; and the Frontier Cross-Disciplinary Technologies Research Center (前沿交叉技术研究中心), which will pursue research in neurocognition, quantum technologies, and flexible electronics, among others.[146] To date, these institutes are starting to publish actively, in Chinese and English language journals, on a range of topics, including, for instance, networking among robotic systems.[147] NIIDT intends to cooperate to establish research centers in collaboration with other universities, research institute, and high-tech enterprises on intelligent aerospace, intelligent maritime, and intelligent manufacturing technologies.[148] There are also virtual centers affiliated with the center, the Intelligent Computing Research Center and the Intelligent Countermeasures Research Center.

AMS will likely continuing deepening this scientific direction under the leadership of Lt. Gen. Yang Xuejun (杨学军). Yang Xuejun was formerly the commandant of NUDT and is known for his research in supercomputing, such that his selection to lead AMS is another noteworthy indication of its transformation in a more scientific direction. Yang Xuejun has co-authored some publications on robotics and artificial intelligence, and he is personally engaged on the subject of AI in future warfare.[149] Under his leadership, AMS may continue to undertake more extensive collaboration with scientific institutions in ways that may bolster this defense innovation capability. For instance, AMS has also signed a strategic cooperation framework agreement with the Chinese Academy of Sciences, which involves joint research and talent training, as well as the construction of a platform for collaborative innovation.[150]

National University of Defense Technology

The National University of Defense Technology (NUDT, 国防科技大学) is building upon its existing strengths to expand its AI research. The NUDT Institute of Automation has long engaged in a range of research involving big data and AI, leveraging synergies with NUDT's National Key Laboratory for High-Performance Computing. NUDT's Key Laboratory of Information Systems Engineering has engaged in research to optimize and increase the intelligentization of the PLA's command and control systems.[151] The National Defense Science and Technology Laboratory for Precision Guidance and Automatic Target Recognition (ATR) is engaged in research on leveraging information processing and intelligent image processing for ATR.[152] At NUDT's Academy of Electronic Countermeasures, researchers are also exploring the potential of artificial intelligence and development of advances in electromagnetic weaponry.[153] NUDT's new Academy of Intelligent Sciences (智能科学学院) is concentrating on advancing new research directions to promote intelligentization, including developing and prominently demonstrating swarms of UAVs.[154] NUDT is also engaged in international competitions and conferences. In June 2018, a team from the National University of Defense Technology was also at the top of a competition organized by Apple and Google for "robust vision."[155] NUDT researchers have often participated in international conferences and are actively engaged in research collaborations.

National Defense University

The PLA's National Defense University (NDU) has been exploring opportunities to leverage AI in wargaming and operations research. In particular, Major General Hu Xiaofeng (胡晓峰) has been very active in exploring the potential of AI in war-gaming and command information systems.[156] Notably, NDU has convened a number of competitions that involve the use of AI in war-gaming that have involved "human-machine confrontation" and "machine-machine confrontation."[157] NDU has also engaged in strategic research on guidance and implementation of intelligentization, often involving senior scholars and strategists.

Defense Industry Initiatives

Pursuant to ongoing reforms, the Chinese defense industry has also been seeking to become more innovative through investing in and pursuing next-generation research and development. This shift is influenced by not only state policies but also apparently commercial incentives that stem from to the potential for profits from export markets. It is worth noting that the National Defense Science and Technology Industry 2025 Plan (国防科技工业 2025), which could be considered a counterpart to Made in China 2025, was released by the State Administration for Science, Technology and Industry for National Defense (SASTIND), which establishes policies and guidance for long-term research priorities within the defense industry, in June 2015.[158] This plan included a focus on robotics and intelligent manufacturing, as well as an opinion encouraging the use of advanced industrial technology, such as intelligent robotics.[159]

The results of increased innovation in the Chinese defense industry have been featured prominently, while attracting the attention of international customers. For instance, during the 2018 Air Show at Zhuhai, drones and intelligent weapons systems were a major attraction.[160] In particular, certain of the "new concept" weapons under development that are anticipated to be relevant for future warfare, include hypersonic weapons and new energy weapons. Some Chinese military experts anticipate that new modes of operations could involve manned-unmanned coordination, as well as stealthy and distributed approaches to combat.

The Chinese defense industry has often confronted impediments to original innovation but is actively engaging with these new directions of development.[161] China's state-owned defense conglomerates are adapting and starting to prioritize the incorporation of AI, recruiting AI engineers and pursuing new partnerships with universities. These major players in weapons development are actively involved in cutting-edge research, but their activities often remain relatively obscured, relative to more prominent activities in the private sector and universities. However, there are a number of initial indicators of their increasing engagement in AI development.

China Electronics Technology Group Corporation

The China Electronics Technology Group Corporation (CETC), a leading state-owned defense conglomerate, has prominently demonstrated its advances in swarms of drones, while expanding its research initiatives in AI.[162] Starting in June 2017, CETC has tested swarms of 67, 119, and then 200 fixed-wing UAVs, which engaged demonstrated complex formations, through its partnership with Tsinghua University and Poisson Technology.[163] At the time, one CETC UAV expert argued swarms could "change the rules of the game" in future warfare.[164]

CETC has also launched its own action plan for special projects involving new-generation artificial intelligence.[165] The plan undertakes an "X+AI" approach that emphasizes the potential synergies of AI with various sector and applications that are integral to the company's core businesses in defense and commercial technologies. In particular, this initiative has highlighted data intelligence, machine intelligence, and group/swarm intelligence as major directions for development. Among the applications it is pursuing are smart cities, industrial robotics, and medical applications. CETC has also started to move into AI chip development, building upon its strengths in defense electronics. CETC claimed to have 7,000 AI researchers in total as of mid-2018 and has continued to recruit new talent in this field.[166]

CETC has contributed to the Chinese military's command platforms and a range of military information systems, and its research will likely be at the forefront of upgrading this existing software to integrate new technologies.[167] Notably, Baidu has partnered with the China Electronics Technology Group (CETC), a state-owned defense conglomerate, through the Joint Laboratory for Intelligent Command and Control Technologies (智能指挥控制技术联合实验室), to pursue applications of big data, cloud computing, and artificial intelligence, in military command and information systems.[168] CETC has also developed the "Integrated Joint Operations Platform" that has been used by police in Xinjiang according to research from Human Rights Watch.[169]

China Aerospace Science and Technology Corporation

The China Aerospace Science and Technology Corporation (CASC), which is the primary contractor for China's space program, is also prioritizing expanding its efforts in AI. The CASC's Chinese Academy of Launch Vehicle Technology (CALT) has been very active in exploring AI research and applications, including launching its own dedicated initiative for AI development.[170] CALT established the Joint Innovation Laboratory for Human-Machine Hybrid Intelligence (人机混合智能创新联合实验室) with Tianjin University in March 2018, and their research will focus on human-computer interaction and aerospace applications.[171] In addition, the Aerospace Group (Artificial) Intelligence Research Center (航天群智能研究中心) at the Qian Xuesen Space Technology Laboratory has concentrated on research on deep learning and related theories and algorithms.[172]

The China Aerospace Science and Industry Corporation

The China Aerospace Science and Industry Corporation (CASIC), which is the primary developer and manufacturer of Chinese missiles, has been engaged in research and application of AI for at least the past couple of years. Since as early as 2015, the CASIC 3rd Academy 35th Research Institute started to pursue breakthroughs in core technologies that include target detection and recognition techniques based on deep learning and deep neural network compression, as well as smart sensors that combine data from multiple radars.[173] Notably, in 2016, this CASIC team organized an innovation competition for "Radar Target Classification and Recognition based on Artificial Intelligence," which was the Chinese defense industry's first major event of this kind, involving major universities with particular proficiency in AI research applying that expertise to find intelligent processing solutions for targeting.[174]

In 2017, CASIC established a new Artificial Intelligence Technology Research Department that built upon its prior track record of expertise in information processing to pursue new directions in intelligentization. Going forward, the team also plans to introduce AI technologies into the process of weapons systems design and to explore further opportunities to advance military (artificial) intelligence developments.[175] In addition, CASIC's Second Academy Second Department has established an Artificial Intelligence Laboratory as of 2017, which has started to pursue research involving deep learning as applied to intelligent assistance in driving, among other applications.[176]

The China Shipbuilding Industry Corporation

The China Shipbuilding Industry Corporation (CSIC) is exploring advances in robotics and unmanned or autonomous vessels, while also looking to leverage intelligent manufacturing to improve shipbuilding. For instance, CSIC researchers have developed a prototype deep-sea crawling robot that can crawl or cruise longer distances underwater, described as capable of navigating the complex terrain of the seabed.[177] During a September 2018 defense exhibition, a CSIC subsidiary revealed "JARI," a multi-purpose unmanned surface vessel (USV) that was reportedly designed for use by the PLAN and for export as a warship.[178] In supporting enhancing shipbuilding capabilities, the China Shipbuilding Industry Corporation is also focused on new techniques to employ intelligent manufacturing, concentrating on "AI+ research."[179]

The Aviation Industry Corporation of China

The Aviation Industry Corporation of China (AVIC) has pursued research on leveraging AI for decision support and to enhance weapons systems under development. In October 2017, AVIC established two new laboratories, the Robotics Research Center/Machine Vision and Intelligent Sensing Joint Laboratory, in collaboration with Xian Jiaotong University, and a Machine Vision and Intelligent Sensing Joint Laboratory with Northwestern Polytechnic University.[180]

Autonomy for New Expeditionary Capabilities

The PLA's advances in autonomy will also have relevance for its ambitions for deep sea and polar exploration. These domains are recognized as emerging frontiers of competition.[181]

Deep Sea Exploration—and Dominance?

As China pursues deep sea exploration and seeks increase its operational capabilities in this domain, advances in robotics and autonomy are a critical priority in which there has been robust progress to date. Chinese researchers have developed a robust range of unmanned and autonomous underwater vehicles that appear to be at the forefront of global developments. For instance, the Sea Wing glider has been used extensively in deep sea exploration,[182] and the *Haiyan* glider has established a new world record for endurance.[183] There are a number of unmanned submersibles, including the *Hailong* and the *Qianlong*, that have undergone testing and initial employment in support of deep-sea activities.[184]

China's development of deep-sea capabilities could improve situational awareness in this critical maritime domain. There have been reports that there is an "undersea great wall" under development that could involve seabed sensors for detection to be integrated with a network of underwater systems.[185] Notably, the Chinese government is funding the development of a deep sea base, named after Hades, lord of the underworld, for underwater science and submarine operations.[186] Sanya's Institute of Deep-Sea Science and Engineering is taking the lead on this project, which will receive 1.1 billion RMB or at least $160 million in funding to start, seeking to pioneer unique advances in deep sea technology.[187] In the aggregate, these advances could start to change the balance in the undersea domain, augmenting PLAN capabilities for anti-submarine warfare.

Polar Exploration and Potential Exploitation

As China undertakes surveying and scientific observations in polar exploration, the use of gliders and submersibles introduces a critical capability for undersea science. The Chinese Academy of Sciences Shenyang Institute of Automation (CAS-SIA) initially developed an Arctic Autonomous/Remote Vehicle (ARV),[188] a 'new concept' underwater vehicle, which first employed as early as 2008.[189] In August 2014, a second-generation ARV accompanied the Snow Dragon on China's sixth Arctic expedition, conveying a variety of measurement equipment that contributed to enhancing Arctic ice monitoring. Notably, the Sea Wing (海翼) glider, also developed by CAS-SIA, was first used in 2018 during China's ninth Arctic expedition.[190] Characterized as highly autonomous, the gilder can operate under own power for up to three months prior to recovery, collecting data at depths of up to 1000 meters to monitor hydrological conditions and transmitting data back via satellite signals.[191]

The use of drones can contribute to localized sensing and surveying of the polar landscape. For instance, the Polar Eagle *(Ji Ying,* 极鹰), a fixed-wing UAV developed by Beijing Normal University, was first used for remote sensing in Arctic in September 2015, when it completed a three-dimensional mapping of a glacier near Yellow River Station, and has since been used in Antarctica.[192] This UAV, powered by lithium battery, is capable of operating for up to one hour with flight ceiling of 1,500 meters. The variants of the *Ji Ying* that have been used in polar regions contribute to capturing imagery of areas that are not visible via satellite due to overcast weather or inaccessible difficult conditions.[193]

In the Arctic and Antarctic, the use of unmanned (surface) vessels (USVs) may become more prevalent due to the difficult conditions. In China's November 2017 Antarctic expedition, China's Snow Dragon was accompanied by the M80B "seabed exploration unmanned boat,"[194] which was jointly developed by the People's Liberation Army (PLA) Naval Surveying and Mapping Research Institute, the State Oceanic Administration's South China Sea Survey Technology Center, and Yunzhou Tech.[195] The preference for employment of the M80B reflects that the harsh climate and complex maritime environment would render the use of manned vessels for survey and detection dangerous. The M80B is described as having a battery life of over 100 nautical miles and a maximum load weight of 150 kilograms, while conveying a range of acoustic detection equipment, magnetic detectors, and mobile laser scanners.[196]

Similarly, given the perilous conditions of transiting over ice, UGVs can contribute to surveys and resupply, as well as the determination of safe transit routes. For instance, the "Polar Rover" (极地漫游者), which uses turbines for wind energy, has been tested so far in Antarctica.[197] This robotic system, jointly developed by Beihang University, CAS-SIA, and the Polar Research Institute of China, was intended to gauge the feasibility of using renewable energy for long-term, unattended presence, such as to support environmental monitoring, while demonstrating a higher level of automation.[198] In February 2018, Chinese researchers first used a small UGV, developed by CAS-SIA,[199] to undertake a topographic survey in the Antarctic in support of the determination of routes, traveling over 200 kilometers in 25 days.[200] As China continues to assert its interests as a polar power, this employment of robotic and autonomous systems will be a critical enabler of presence, exploration, and potentially resource exploitation or even future military operations.[201]

Military-Civil Fusion in Strategy and Practice

The PRC's pursuit of a strategy of military-civil fusion (军民融合) could provide a systemic and structural advantage that could contribute to national priorities in innovation, if its implementation overcomes current obstacles. Some early attempts to coordinate and facilitate increased integration among military and civilian resources have a long history in China, even dating back to concepts of people's warfare (人民战争) launched under Mao Zedong. The implementation of a concept of civil-military integration (军民结合) has been a priority throughout the 2000s. However, the Chinese military and defense industry had seemingly struggled to overcome prior stove-piping and bureaucratic obstacles that had limited its capacity to leverage commercial stakeholders and technologies.[202] The PLA's recognition of the importance of such integration can be traced to its close study of successes in American 'military-civil fusion,' including such signature institutions as DARPA. The elevation of military-civil fusion to become a national strategy, even described in some cases as a grand strategy (大战略) starting in 2015 can be characterized as intensifying the impetus to innovate and advance implementation of this approach in practice.[203] In some respects, the PLA can be seen as attempting to catch up relative to the U.S. defense innovation in this endeavor, but the momentum behind these initiatives is intended to create a more deeply integrated ecosystem in the future.

The realization of military-civil fusion is linked to China's national ambitions and imperative of innovation. Significantly, the Outline of the National Innovation-Driven Development Strategy (国家创新驱动发展战略纲要) was launched in 2016, under Xi Jinping's leadership, thus initiating a new direction and guidance for China's future development.[204] As this strategy highlights, the capability to innovate is considered a core enabler of national power, and China's past weaknesses and experiences of predation are attributed its past failure to keep pace with scientific and technological revolutions. These authoritative guidelines assert, "disruptive technologies are constantly emerging, continually reshaping the world's competitive landscape, changing the balance of forces among states."[205] The core concern is that, "Our nation is not only facing a rare historic opportunity to catch up and leapfrog ahead but also confronting the serious challenge of a gap that could widen."[206] This strategy highlighted the importance of military-civil fusion, including closer coordination and sharing of resources, as an important pathway to enabling this innovation. For instance, in one notable early initiative, in November 2016, the Military-Civil Fusion Intelligent Equipment Research Institute (军民融合智能装备研究院) was established as a collaboration between the North China University of Technology and a private technology company.[207] The institute received support from the Naval Equipment Research Institute, the Army Equipment Department, the Rocket Force's Equipment Research Academy, and other military organizations.[208] It was tasked to pursue AI research to include intelligent robotics, unmanned systems, and military brain science.[209] Some of its initial research involved the 'brain control' of unmanned systems. Such research partnerships are becoming more prevalent across universities and national laboratories as military-civil fusion progresses.

Xi Jinping has taken personal responsibility for the implementation of this agenda, leading the Central Commission for Military-Civil Fusion Development, which was established in January 2017. As it progresses, this concept encompasses not only a more integrated approach to technological development, but is also applied to missions that include talent, logistics, and national defense mobilization.[210] Some of China's senior leaders and scientists, including Zhou Ji (周济), dean of the Chinese Academy of Engineering, believe that artificial intelligence will be the most important dual-use technology in the coming decades.[211] The implementation of this priority is starting to take shape through a range of plans and policy initiatives that are promulgated nationally and at the province, and even municipal levels. For instance, the 13th Five-Year S&T Military-Civil Fusion Special Projects Plan (科技军民融合发展专项规划), released in September 2017, highlighted intelligent unmanned and cross-disciplinary technologies among its priorities, while also calling for integrated development of space, cyber, biology, new energy, and maritime technologies.[212]

During his remarks for the 19th Party Congress' work report in October 2017, Xi Jinping emphasized:

> "We should ensure that efforts to make our country prosperous and efforts to make our military strong go hand in hand. We will strengthen unified leadership, top-level design, reform, and innovation. We will speed up implementation of major projects, deepen reform

of defense-related science, technology, and industry, achieve greater military-civilian integration, and build integrated national strategies and strategic capabilities."[213]

The Chinese government is attempting to harness and support the dynamism of market activity in AI to promote national strategic purposes, which has extended to experimentation with new techniques for state support and funding.

New Capital for Military-Civil Fusion

The Chinese government has been launching a number of new state-driven investment funds, as well as "guidance funds" (引导基金) at various levels. These new vehicles for funding often combine government direction with a combination of state funding and private venture capital. This paradigm of partnership indicates a further blurring of boundaries between market and governmental objectives and investments in AI. The total funding that has been allocated for a wide variety of guidance funds appears to reach the range of several hundred billion dollars, by some estimates.[214] However, a smaller portion of that funding is directly relevant to AI development, and the recency of the launch of these initiatives makes it difficult to evaluate within what timeframe or how effectively the funding will be allocated going forward.

Today, experimentation with new policies and initiatives is continuing. During the World Artificial Intelligence Conference in September 2018, China's State Development and Investment Corporation (SDIC) initiated the launch of the All-Nation Artificial Intelligence Venture Capital Service Alliance (全国人工智能创业投资服务联盟).[215] This initiative is a "national, industry, and open public service platform" created through National Development and Reform Commission. Among the investment institutions involved in launching this 'alliance' are Sequoia Capital, Huaxing Capital, and Softbank China, as well as AI research enterprises, including Baidu, Tencent, Tsinghua University, and the Chinese Academy of Science. It was created with support from the National Emerging Industries Venture Capital Guidance Fund (国家新兴产业创业投资引导基金), which was itself launched in January 2015 with the objective of promoting innovation and "mass entrepreneurship." As of 2017, that fund had reached a scale of 17.86 billion RMB or $2.58 billion, and a sizable proportion of the funding may go to AI enterprises.[216]

The promotion of military-civil fusion as a strategy is increasingly leveraging guidance funds as an important mechanism to drive capital and activities. For instance, one national fund for military-civil fusion industrial development launched in September 2016 involved 30.2 billion RMB or $4.4 billion in its initial round of funding.[217] These activities are expanding in response to a State Council opinion released in December 2017, which called for "expanding the investment and financing channels for the development of military-civil fusion," including through the establishment of funds for investments in military-civil fusion industries and encouraging local governments to launch their own funds to promote high-tech military industries.[218] As of mid-2019, tens of billions of RMB—or several billion dollars and counting—of funding had already been dedicated to military-civil fusion through funds launched in localities that included Sichuan, Shanghai, Hebei, Henan, Guangdong, Zhejiang, Shaanxi, Guizhou, Hunan, Heilongjiang, Liaoning, among other cities and provinces.[219] These funding mechanisms have been described as prominent and even "indispensable" to deepening the implementation of military-civil fusion, stimulating high-tech industries.

Local Initiatives

As of 2019, the majority of China's cities and provinces have launched their own efforts to promote military-civil fusion, with varying degrees of success and intensity. While the scope and scale of these activities is beyond the scope of this testimony, and the results of more nascent programs are inherently difficult to evaluate, an initial survey of some relevant initiatives can illustrate some of the current directions of development.

Beijing

Beijing is home to some of China's leading companies, universities, and institutions of defense research, constituting a vital center of military research. In particular, Tsinghua University, often characterized as 'China's MIT,' is strongly and institutionally committed to military-civil fusion and to supporting the advancement of military applications of AI. Tsinghua Vice President You Zheng has highlighted the university's contributions to military research and to enabling China's emergence as an "AI superpower."[220] Tsinghua launched the Military-Civil Fusion National Defense Peak Technologies Laboratory, which will create a platform for the pursuit of dual-use applications of emerging technologies, in June 2017.[221] With support from the Central Military Commission, Tsinghua is also reportedly constructing the High-End Laboratory for Military (Artificial) Intelligence.[222] The apparent dedication of some of China's leading universities to military-civil fusion could prove significant.

Increasingly, the high-tech zone of Zhongguancun has focused on advancing military-civil fusion in emerging technologies. The Zhongguancun Military-Civil Fusion Industry Alliance, established as early as 2014, has growth to include 600 members, while taking on hundreds of projects, including in robotics and intelligent equipment.[223] The alliance organized a special contest in December 2017 that involved advances in cyber security, unmanned systems, and perception and recognition capabilities.[224] Within Zhongguancun, a new Military-Civil Fusion Industrial Park (中关村军民融合产业园) was also established in early 2018.[225] During the Beijing Military-Civil Fusion Expo 2019, among the systems on display was a new 'armored multipurpose drone launching vehicle.'[226] This new system is capable of launching a dozen of drones to conduct reconnaissance or even accurate 'suicide attacks,' distracting and swarming the enemy.

In June 2018, the Beijing Science and Technology Innovation Fund (北京科创基金) was launched as a new sizable and long-term government guidance fund in China that is designed to focus on next-generation information technology, nanotechnology, big data, artificial intelligence and other "high-end hard technology" fields.[227] The fund is 30 billion yuan ($4.46 billion) to start, with plans to increase the size 100 billion RMB ($14.86 billion), across a number of sub-funds that may amount to as many as 102, in total, with a focus on high-tech industries, signing agreements with Peking University, Tsinghua University, and the Chinese Academy of Sciences, among others.

Shanghai

The Shanghai municipal government has been very active in providing policy support for AI that is extending into efforts that might bolster military advances. Shanghai's new Military-Civil Fusion Industry Investment Fund launched in 2017 at a scale of 4 billion RMB or $579 million, intends to include a focus on dual-use intelligent equipment.[228] For 2018, Shanghai will support special military-civil fusion projects that include dual-use artificial intelligence and intelligent equipment.[229] The PLA's NUDT is cooperating with the Shunde district of Shanghai on the establishment of a military-civil fusion innovation park based on total investments of 1.5 billion RMB or over $217 million that will include, including an industrial zone focused on artificial intelligence and information security.[230] The Shanghai Artificial Intelligence Industry Fund was officially launched as of September 2018. This new initiative jointly established by several venture capital players, in collaboration with the Shanghai government, which plans to increase its scale to from the 10 billion RMB or $1.49 billion raised to start towards the range of 100 billion RMB ($14.86 billion) in the future.[231]

Tianjin

Tianjin has been distinctly forceful in its promotion of AI. The city announced the launch of the New Generation Artificial Intelligence Industry Fund,[232] which amounts to 100 billion RMB ($16 billion), based on a combination of state and venture capital funding, in May 2018.[233] In August 2018, Tianjin has uniquely launched a special action plan for military-civil fusion in the domain of intelligent science and technology that aims to build a platform for collaborative innovation and realize the transformative applications of intelligent science and technology by 2020.[234] Tianjin is a hub of research activities and collaboration. In addition, the new AI Military-Civil Fusion Innovation Center, located next to the National Supercomputer Center in Tianjin, was established by the local government in partnership with the Academy of Military Science in October 2017.[235] The city plans to strengthen and accelerate collaboration with the National University of Defense Technology and the PLASSF Information Engineering University. [236] Tianjin is also exploring options to build a military cloud and a new virtual platform system to support simulations and equipment development.

Shenzhen

Shenzhen is the home base for some of China's most high-tech and successful companies. Unsurprisingly, there are active efforts to start to harness that dynamism in support of military missions, including the use of drones developed through commercial technologies. Concurrently, the CMC Science and Technology Commission is exploring new mechanisms for leveraging commercial technologies with the launch of China's first "defense S&T innovation rapid response small group" (国防科技创新快速响应小组) in Shenzhen.[237] This team will leverage "the innovation advantages of the Shenzhen Special Economic Zone to rapidly respond to the needs of national defense S&T innovation," while "accumulating experience in promoting the formation of a flexible and highly efficient defense technology innovation value chain."

The priority fields highlighted for this program include biology, new materials, manufacturing, and artificial intelligence. According to a notice released in April 2018, some of the priorities for the new projects included the development of maritime intelligent target recognition technology and a module for intelligent human-machine interaction.[238] In April 2019, this team co-organized a competition for the development of intelligent processing algorithms for massive optical remote sensing satellite data. This new model for rapidly developing and accessing commercial technologies is still at an early stage but does demonstrate the PLA's capability to experiment with new mechanisms for defense innovation, seemingly adapting American approaches in the process.

Qingdao

Qingdao has emerged as a major center for military-civil fusion in maritime technologies through leveraging its existing strengths in research and industrial activities. As of 2017, the Underwater Vehicle Intelligent Equipment Base (水下无人航行器智能装备基地) was established in Qingdao, undertaking research and development, as well as the design and manufacture, for a range of marine robotics and engineering equipment, including the white Dolphin (白豚) autonomous underwater vehicle.[239] When a new "demonstration zone" was established in April 2018, initial investments amounted to 9.17 billion RMB or $1.33 billion, which included plans to support aerospace equipment, strategic emerging materials, and marine science and technology.[240] In Qingdao, the first forum on military-civil fusion in the AI industry was convened in April 2018. [241] These discussions and exchanges, convened by Harbin Engineering University, concentrated on fields that included intelligent underwater robots, high-speed unmanned boats, smart ships, and target recognition.

Prominent Enterprises

The forceful implementation of military-civil fusion has reflected an attempt to change a status quo in which a relatively smaller proportion of private companies were directly involved in military projects and procurements. Several examples provide indicators of successful enterprises that have, among many others, actively pursed opportunities for military sales.

Yunzhou-Tech

Yunzhou-Tech has emerged as a leader in the development of unmanned vessels. The company claims to hold a quarter of the global patents for unmanned vessels and to have fully mastered the core technologies in question.[242] Reportedly, it has achieved major advances that include multi-sensor intelligent detection and autonomous navigation, actively engaging in military-relevant research, including testing a shark swarm of drone vessels in June 2018.[243]

Yunzhou-Tech is recognized for its significant contributions to military-civil fusion, have develop a wide array of models and designs intended for and/or entering employment for defense applications.[244] Certain of these vessels appear likely to be acquired by the PLA Navy for supporting and/or operational functionalities, including with capabilities in patrolling, reconnaissance, and electromagnetic countermeasures.[245] Notably, during the 2018 Airshow China at Zhuhai, Yunzhou-Tech displayed the Look Out II unmanned missile vessel, equipped with four precision missiles capable of hitting targets up to 5 kilometers away.[246] Although the drone vessel itself is described as autonomous, the actual operation of its missiles is still designed to be subject to human control. The project director for Look Out II has emphasized its speed, stealth, and cost effectiveness.

Ziyan

Ziyan is a private enterprise that has developed capable drones and unmanned helicopters that with varying degrees of autonomy that are starting to enter usage for policing, paramilitary, and military operations.[247] The company's founder Wang Jiangping (王江平) leveraged the perspective of experience in PLAAF aircraft maintenance and subsequent international business activities that reportedly exposed him to military experts and modern drone technology in building a company that has proven competitive against traditional contenders within China and internationally.

Since Ziyan tested its first drone in December 2015, the company has achieved rapid success. To date, a number of its drone helicopters, including the "Blowfish A2," which can be equipped with radar, jamming devices, and guns or bombs under its spine, have been exported internationally to at least four countries so far.[248] Ziyan has been working on a series of unmanned helicopters, known as the ZYG 800, ZY-50 and ZY-280, which vary in capability and in levels of potential autonomy.[249] In February 2019, Ziyan displayed and demonstrated during an international defense exhibition its unmanned helicopter intelligent swarming technology, which can now realize self-organizing networks of smart swarms and be switched to 'attack' model to go after targets autonomously in a coordinated manner.[250]

Some additional examples of companies that have contributed to military-civil fusion and/or provided their commercial technologies in support of military activities include, but are not limited to:

- Hikvision, which has been partly owned by the CETC's 52nd Research Institute, has provided its AI-enabled video surveillance technology for national defense and security purposes.[251]
- Skyeye Data is a next-generation information technology company that concentrates on big data, cyber security, artificial intelligence, etc., collaborating with the National University of Defense Technology and the PLASSF Information Engineering University, for which it has been providing a platform for 'open technology applications and innovation' that aims to integrate "production, learning, research, usage, and warfare."
- iFlytek has promoted its products in voice recognition to Chinese military, where it may have utility in intelligence, in addition to well-documented involvement in supporting surveillance.[252]
- Kuang-Chi (光启) Technologies, which has specialized in the development of metamaterials and aerospace technologies, has also expanded into AI, including its application to new materials developments.
- Sensetime's new SenseRemote 'remote sensing image intelligent interpretation solution,' which combines visual AI technology and spatial information, could possess relevance for military applications.[253]
- Sugon (曙光), initially established as a high-technology to support Chinese advances in high-performance computing, has signed an agreement partnership with the China Institute for Command and Control, through which it would support cloud adoption for China's military command information systems.[254]
- Ruichen Xinchuang (睿辰欣创) is a leader in the national defense simulation industry that has developed a virtual military simulation platform and developing new techniques for assessments, including launching an AI R&D center.
- Vimicro Corporation, a fabless chip company, has developed chips that appear to be used for defense applications.[255]
- DeepBlue (深之蓝) specializes in underwater robotics and is enthusiastically supporting military-civil fusion through developing a range of gliders for defense and commercial applications.[256]
- Aobo (遨博) Intelligent Technology Company, which emerged from research at the Beihang Robotics Research Institute, has developed autonomous controllable robots for the military industry.
- Alibaba's Damo Academy has been named in government plans and policies in Hangzhou as contributing to military-civil fusion initiatives.[257]

The PLA's attempts to achieve deeper integration and improve its capacity to leverage commercial technologies are incomplete and continuing to progress with varying degrees of success, but such examples are nonetheless illustrative of initial initiatives that are underway.

Prominent Academic Institutions

The academic ecosystem for AI research in China is extensive and rapidly expanding within it. Of the major universities and academic research institutions, a significant proportion are engaged in research that supports or has relevance to defense applications. In particular, the Chinese Academy of Science is a powerhouse in artificial intelligence, which is evident from its strength in patents and publications, and a number of the research institutes and laboratories under its umbrella specialize in military-oriented research.[258] Those universities and laboratories that possess particular relevance for these efforts include, but are nnot limited to:

- Tsinghua University, which has launched a High-End Laboratory for Military (Artificial) Intelligence (军事智能高端实验室);[259]
- Beijing University of Aeronautics and Astronautics (Beihang) University, which has engaged in research on autonomy and human-machine teaming, including prominent initiatives at the Beihang Robotics Research Institute;
- Harbin Engineering University, which has strengths in robotics and autonomy, including the National Key Laboratory of Intelligent Robot Technology;
- Northwest Polytechnic University, which includes the National Defense Science and Technology Key Laboratory for Special Drone Technologies;
- Beijing Institute of Technology, which has reportedly established an "intelligent weapons experimental class" that has recruited an initial class of 30 highly talented students to pursue degrees and innovative research under the mentorship of senior weapons scientists;[260]
- Nanjing University of Aeronautics and Astronautics University, which established its Artificial Intelligence Academy and Artificial Intelligence Research Academy in July 2018;
- Xi'an Jiaotong University, which launched a new Academy of Artificial Intelligence and has contributed to a base for the AI and robotics industry;[261] and
- Xidian University, which established a new Academy of Artificial Intelligence in spring 2019; among many others.[262]

Pursuant to the implementation of military-civil fusion as a national strategy, a growing number of universities that have not engaged in as extensive research to support military initiatives in the past may become more involved going forward.

Challenges and Shortcomings in Chinese Military Innovation

The PLA's ambitions and advances in robotics, autonomy, and a range of applications of artificial intelligence should not be dismissed or underestimated, but there are also a number of likely difficulties and apparent shortcomings that will impede its implementation of this agenda. Not unlike the U.S. military or any bureaucracy, the PLA will confront a number of constraints and challenges in the process. It remains to be seen whether attempts to overcome such impediments will prove successful.

- *The PLA's capacity to innovate may be impeded by bureaucratic politics and its culture as an organization, particularly considering the disruption that results from the ongoing reforms.*

The Chinese military, not unlike any bureaucracy, may struggle to adopt and adapt new technologies that may, in some cases, present threats to existing interests. The PLA has been assessed to be an organization that is highly hierarchical, operating in a top-down manner with a high degree of centralization of power. These features, including the low levels of trust often considered characteristic of authoritarian militaries, could impede more junior officers and enlisted personnel from having the opportunity to exercise initiative and experiment with new technologies and techniques. Such typical difficulties could be exacerbated by the disruption that has resulted from significant organizational restructuring that remains ongoing, seemingly encountering some resistance in the process. For these reasons, despite the CCP's and PLA's rhetorical commitment to innovation, implementation may be impeded by such dynamics. Moreover, if the slowdown of China's economy constrains the resources available for military modernization, the tradeoffs between the development of new capabilities and sustainment of existing platforms could become more acute.

- *The PLA's capability to leverage AI could be hindered by continued shortcomings in talent and human capital.*

For the PLA, persistent challenges in recruitment and perhaps continuing shortcomings in the technical proficiency of its officers and enlisted personnel could challenge its agenda for intelligentization. The PLA has attempted to overcome prior difficulties to expand the recruitment 'high-quality' talents, including through targeting those with higher levels of education. As of spring 2019, over 2,500 colleges and universities nationwide have reportedly established recruitment workstations.[263] There have also been reforms to the PLA's personnel management to shift from 'civilian cadre' to civilian personnel, who receive benefits comparable to those of civil servants. The new rounds of recruitment for these civilian positions have aimed to attract candidates with M.A. and PhD degrees who have backgrounds in computer science and artificial intelligence. However, the PLA's actual success in recruiting and retaining those with such technical proficiencies remains to be seen.

The PLA will be competing for high-tech talent at a time of relative scarcity, including because of intense demands from a growing private sector. There are particular bottlenecks in the availability of AI talent to date that have also presented significant challenges to technology companies. The application of an approach of military-civil fusion to talent development could contribute to resolving this problem, including through dedicated programs that leverage closer collaboration with the tech sector. For instance, Beihang University has launched in new degree program in AI to which Baidu is contributing, and the Beijing Institute of Technology has also established a new program for intelligent weapons development.[264] As Chinese universities expand their educational programming in AI research, and as plans and programs for the recruitment of overseas talents continue to expand, the PLA may have a more sizable pool of talent to draw from. These attempts to cultivate 'first-class talent' continue, but progress will take time to realize and may prove limited in some cases.[265]

Despite progress in increasing the realism of its training, the PLA may continue to struggle to match the sophistication required for preparations for future warfare.

The PLA's training was once highly scripted and has improved in sophistication, but may remain inadequate relative to the complexities and challenges of future intelligentized operations. PLA officers and researchers recognize the importance of innovation in techniques for training in response to new demands. However, the adoption and promulgation of new techniques that could eventually be incorporated into the PLA's official Outline of Military Training and Education, which was last revised in 2017, could prove challenging.[266] Potentially, the PLA's experimentation with techniques involving the use of virtual reality and artificial intelligence to training, as well as war-gaming, could enable future improvements in realism that could facilitate preparation for actual combat, despite the PLA's lack of operational experience. In particular, the complexities of managing human factors in training with complex systems could present particular challenges for the PLA.

The PLA appears to struggle with revising its doctrine and may confront difficulties in adopting new theories and concepts in practice.

The Chinese military does not appear to have fully revised its doctrine since 1999, despite ongoing, rolling revisions that have involved some updates. The new, 'fifth-generation' of operational regulations (作战条令), including campaign guidelines (战役纲要) has been under development since 2004 and was nearly, but not fully or officially, launched in 2008. Despite ongoing research activities, which appear to have contributed to limited adjustments, the PLA appears to have yet to finalize this process, which appears to indicate a lack of consensus and/or institutional impediments. This 'third front' of PLA reforms will be a priority in 2019, as the PLA looks to complete new military policies, guidelines, and regulations.[267] The apparent complications of doctrinal development also raise questions about whether the PLA will be able to incorporate new theories and concepts of intelligentized operations into this framework in practice or could confront comparable difficulties in the process.

The PLA appears to have difficulty in managing and integrating its data, including due to bureaucratic challenges and limited adoption of cloud computing.

The PLA appears to be encountering a number of challenges in the management of its data, which will be critical to the adoption of AI. The level of stove-piping and fragmentation across bureaucracies within the PLA could remain an impediment to progress. Chinese military researchers have expressed concern that there are current inadequacies in data mining, analytic processing capabilities, awareness of security and secrecy, and support of training data.[268] Moreover, the PLA will have to deal with practical difficulties of cleaning and labeling disparate sources of data for use, which can be time and labor intensive, but could be facilitated by the access to cheap services for data labeling that has been available in China.[269] The adoption of shared infrastructure, including cloud computing, to enable deployment will also be required for the PLA to achieve an integrated approach to AI development. If the redundancies, inefficiencies, and corruption often associated with informatization recur in the process of intelligentization, the PLA may be hindered from effective utilization of these technologies.

In this regard, while China may appear to possess a data advantage given the aggregate amount of data that it possesses as a nation, that edge may prove limited in actuality and unlikely to directly translate into military advantage. However, the PLA may benefit from easier access to sources of data that may be leveraged for dual-purpose applications, such as remote sensing, leveraging deepening integration with academic and commercial endeavors. The access to data enabled by the expansion of initiatives through Digital Silk Road, including research collaborations that involve data sharing, also could increase the PLA's capabilities going forward. In some cases, certain sources of data that may be made available to the Chinese military, including in support of intelligence, after theft or exfiltration, may also be beneficial. The PLA's capacity to improve its approach to leveraging data going forward will be important to evaluate.

The PLA's lack of operational experience could result in a failure to appreciate the challenges of operating highly complex automated or autonomous systems under actual combat conditions.

The PLA approaches warfare through the lens of military science. Lacking operational experience in its recent history, the PLA has confronted the unique challenge of 'learning without fighting,' often based on engaging in theoretical research that examines trends and technologies. Traditionally, military innovation in peacetime has been considered particularly challenging, and the PLA is unlikely to be an exception in that regard. Nonetheless, the sense of threat and urgency that comes with facing a 'powerful adversary' appears to have overcome inertia that often impedes change. The progress in 'actual combat' training, including involving confrontations between blue and red forces, could compensate for the lack of operational experience. Nonetheless, the PLA may fail to appreciate the extent to which the full complexity of warfare can extend beyond that anticipated in theories or exercises.

Whereas initial American enthusiasm about the notion of a Revolution in Military Affairs was tempered by the realities of combat and the failures of certain capabilities to materialize as anticipated, the PLA's focus on the notion of the RMA has persisted, seemingly without a comparable recalibration of expectations. For instance, certain Chinese military writings go so far as to claim that these advances could render the battlefield 'clear and transparent,' lifting or perhaps lessening the fog of war.[270] In actuality, the advent of AI could change that fog, perhaps creating new sources of confusion and novel cognitive challenges, particularly given the likely limitations of AI. In this regard, the PLA's efforts could be undermined by 'hot thinking' on AI that is not always qualified by the 'cooler' realities.[271]

The particular ideological constraints and characteristics for the PLA as a party army may impede or condition its development in ways that could prove unique.

The PLA is a Party army, not a national military, and that reality could influence its approach to AI. Xi Jinping has consistently reiterated that the PLA must adhere to the Party's "absolute leadership," expanding and emphasizing the importance of innovation in "political work" that is intended to ensure that obedience. At first glance, these imperatives of capability and controllability could appear to be at odds in some cases. For instance, time dedicated to political activities is time taken away from training, and the imposition of ideological indoctrination seems unlikely to be conducive to the creativity that can enable innovation. Moreover, certain idiosyncrasies might be introduced into the PLA's approach to AI as a result of the ideological environment within which it is being developed. Some writings have called for a dialectical approach to AI or emphasized the importance of ensuring that AI possess certain political qualities and adhere to the necessary ideological requirements, avoiding any disloyalty.[272]

The implementation of military-civil fusion might prove inefficient and be undermined by poor coordination or corruption.

The scope and scale of Chinese initiatives in military-civil fusion indicate the potential to provide a systemic advantage, yet the implementation of the various efforts within this agenda remains nascent. The decision to elevate the concept of military-civil fusion as a national strategy—and to create institutional mechanisms dedicated to its implementation—can be characterized as indicative of the difficulties and challenges that such policy support is intended to overcome. The Chinese defense industry has remained relatively inefficient and tending towards monopoly, and beyond these traditional stakeholders, there had been relatively limited involvement by China's emerging technology companies in supporting national defense, given institutional obstacles to their participation and competition. In some respects, China's concept of military-civil fusion must be recognized as influenced by a close study of the U.S. history of successes of closer collaborations between the military, industry, and academia. However, the relative strength of China's innovation ecosystem in AI, including the relative willingness of companies to support defense applications, bolstered by ample resources and experimentation with new initiatives could start to change the equation.

The massive investments dedicated to promoting military-civil fusion and the development of emerging technologies may not be allocated efficiently and could create distortion.

China has a mixed track record on S&T plans. The implementation of industrial policies has varied greatly over time and across sectors, from apparent successes in 5G to more lackluster progress in semiconductors. The current initiatives to promote military-civil fusion are mobilizing massive amounts of capital, combining state funding with private investments, in ways that could accelerate innovation in critical emerging technologies, while promoting robust efforts in the defense industry. However, given that so many of these funds and mechanisms were launched recently, and the funding is just starting to be allocated, it is too soon to come to a definitive conclusion about the likely return on investment from these initiatives. Some of these efforts may be effective despite perhaps unavoidable inefficiencies, but there is also a risk such largescale investments could prove counterproductive through creating distortion. For instance, there have even been concerns about the potential for an 'AI bubble' or future AI winter.

There are still certain weaknesses in key and core technologies within China's technological ecosystem that will be difficult to redress.

Despite its strengths, China's innovation capabilities still possess distinct weaknesses in AI. There are more robust efforts in applications than in basic and cutting-edge research. Fewer tools, algorithms, and platforms have been developed indigenously to China to date. In some of the "key and core technologies," including semiconductors, China's efforts to catch up have achieved limited success to date, but recent progress in AI chips appears to be more promising. The increased support for research, including new open innovation platforms and national laboratories, could contribute to this transition towards more original innovative research in the future. However, for the time being, China's progress continues to depend partially upon access to 'international innovation resources,' including talent and knowledge.

PRC Tactics for the Transfer of Technology and Knowledge

In recent history, China's attempts to catch up in defense and technological development have often involved attempts to access and absorb foreign technologies through licit and illicit means, and such efforts continue to adapt and expand. These tactics and techniques have evolved but remain prominent as applied to the new priorities of emerging technologies. Insofar as China today aspires to advance beyond catching up towards leading in next-generation developments, the theft of IP outright may have less relevance in these fields, including because the state of research in AI is quite open to begin with. Since there has been greater scrutiny upon and pressure against China's tech transfer and industrial espionage, certain of these activities are also seemingly becoming more targeted and obfuscated, including involving the use of fronts or proxies. The measures employed range from the outright illegal (i.e., theft of data and blueprints leveraging cyber and/or human espionage) to those that are legal but nonetheless problematic (e.g., targeted acquisitions and investments or academic exchanges and partnerships). Often, such state-driven and directed attempts to access foreign technologies have exploited the relative openness of the scientific community.

Even as its indigenous capabilities for innovation are increasing, China continues to leverage international engagement and collaborations to enable training, education, and the transference of skills and knowledge. Although the U.S. has been a prime target, it is clear that these efforts are global in scope and scale. For instance, the semiconductor sector has been targeted extensively in the United States in theft and attempted acquisitions, and the recent acquisition of Danish semiconductor companies indicates the adaptability of these global activities.[273] In particular, the targeted recruitment of talent is a clear priority and imperative to overcome the current bottleneck of human capital.[274] Xi Jinping has personally emphasized, "talent is the first resource," urging, "introducing foreign talents and intelligence is an important element of China's opening up to the outside world" and other important instructions."[275] The undertaking of this "talent work" (人才工作) has involved the creation of a growing number of 'offshore science and technology talents offshore innovation and entrepreneurship base.'[276] The intense concerns about shortfalls in talent, relative to the demands for it, including in AI, have motivated the 'talent warfare' that is characteristic of this competition.[277] Often, these mechanisms for recruitment, such as a wide array of talent plans, are aimed at those whom the Chinese government calls 'overseas Chinese' (华侨).[278] However, there are also numerous scientists who have no familial or historical connection to China who have been recruited through and/or participated in such programs.

Often, such activities are described as a "going out" (走出去) of Chinese enterprises, which have increased their engagement in research, investment, and acquisitions internationally, complemented with parallel attempts to facilitate the "bringing in" (引进来) of tech and talent back to China.[279] In the United States and worldwide, some of the recent mechanisms aimed at access to talent and cutting-edge technologies include a number of 'innovation centers' and 'innovation and entrepreneurship bases.' In lieu of a more detailed mapping, several notable examples can serve to illustrate this pattern of activities.

- Zhongguancun (ZGC) Capital, which supports the activities this high-tech zone of Beijing, has launched a number of incubators and incubation centers.

- The ZGC Innovation Center in Silicon Valley (中关村硅谷创新中心) was established in May 2016 to incubate and 'accelerate' start-ups,[280] including to help facilitate their pursuit of opportunities for cooperation with Chinese enterprises.[281]
- The ZGC Boston Innovation Center was launched in of April 2018, with Beijing government officials in attendance. The establishment of this incubator was characterized as important to "build the ecosystem of Zhongguancun's overseas collaborative innovation resources."[282]
  - The 'Z-Park' incubator involves sub-centers that concentrate on bio-tech, artificial intelligence, information technology, blockchain, and virtual reality.[283]
- The ZGC "Innohub" Innovation Center in Heidelberg, Germany was established in May 2018.[284]

- The China Association for Science and Technology (Shenzhen Overseas Talent Offshore Innovation and Entrepreneurship Base plans to establish a number of overseas innovation centers based on a cooperation agreement with the Shenzhen Municipal Government signed in May 2015.[285]
  - The "Radical Force Innovation Boston Innovation Center" (源创力波士顿创新中心) was established in May 2017.[286]
  - The initial locations planned for these centers include San Francisco, Seattle, and Boston in the United States; London, England; Evelyn, France; Tel Aviv and Haifa, Israel; and Toronto, Canada.
- The non-profit "Silicon Valley Global," which oversees the New Silicon Valley Offshore Incubator, has served as a bridge and matchmaker in support of the 'bringing in' of innovation to China.[287]

Pursuant to the Digital Silk Road, Chinese companies may gain access to new sources of data that can reinforce China's advantage in AI development, while expanding the deployment of Chinese cloud computing.[288] There is a strong emphasis on promoting global scientific cooperation under the umbrella of One Belt, One Road in ways that may also provide access to unique sources of data and to new talent resources.

In some cases, Chinese military scientists have been sent to study abroad at international institutions, concealing their actual affiliations, or engaged in problematic collaborations with foreign researchers on research that may have defense applications. The PLA's National University of Defense Technology has been particularly prominent in these exchanges and research collaborations, which have involved several thousand scientists to date by some estimates.[289] Certain prominent PLA researchers in AI, including a number of those at the Academy of Military Science, have either received their PhDs or been visiting researchers through a number of international universities. As a growing number of universities in China are mobilized to contribute to military-civil fusion, there are reasons to question whether even longstanding collaborations with prominent institutions, such as Tsinghua, should be reconsidered in light of the potential externalities. When potential research partnerships also risk enabling advances in surveillance technologies that are known to be abused in ways that violate human rights, such activities tend to raise difficult questions of ethics.[290]

Implications for U.S.-China Strategic Rivalry and Technological Competition

I assessed in my testimony to the Commission in February 2017, "China's advances in artificial intelligence may have immense strategic implications… China evidently possesses the potential to compete with—or even leapfrog—the United States in artificial intelligence…[which] could become a vital force multiplier for its future military capabilities."[291] Since then, the evidence that China is emerging as an AI powerhouse has become increasingly compelling, and there are additional indications of the momentum that is building up behind these initiatives, including basic research and applications in AI that are increasingly at the forefront of global developments. Today, it is clear that competition in AI is a new frontier of U.S.-China rivalry, and Chinese leaders are determined to seize this "strategic commanding heights." Xi Jinping declared in his remarks to a Politburo study session in the fall of 2018:

> "Accelerating the development of a new generation of AI is an important strategic handhold for China to gain the initiative in global science and technology competition, and it is an important strategic resource driving our country's leapfrog development in science and technology, its industrial optimization and upgrading, and a comprehensive leap ahead in productivity."[292]

The implications of these advances could become a fundamental determinant of the future balance between these great powers. The impact of AI across economic development and military modernization may be unpredictable but could prove transformative. The new technological revolution that is occurring through the advent of emerging technologies with powerful synergies among them could reshape our economies, societies, and militaries in ways that are difficult to anticipate. Initially, China's potential for innovation tended to be dismissed; presently, there can be, at the other extreme, a tendency to overestimate or exaggerate its strengths, while neglecting to recognize persistent weaknesses. Today, the United States still possesses significant advantages, including in talent and as the center of cutting-edge resource, but those advantages must not be taken for granted, and recent policies risk undermining such strengths.

Looking forward, American military-technological superiority cannot be assumed, but rather must be contested. China's emergence as a technological powerhouse—and would-be superpower—presents a compelling competitive challenge. At the same time, since commercial developments have been a primary impetus for today's advancements in emerging technologies, within fields in which research has been open and internationally collaborative, the diffusion of ideas, knowledge, and the technologies themselves has occurred more readily. Neither the United States nor China may achieve an absolute or enduring advantage, yet their relative trajectories in taking advantage of the opportunities that these technologies present could change the future balance of power across economic and military dimensions of power.

Within this military rivalry, the relative capacities of the U.S. and Chinese militaries as organizations to operationalize these emerging capabilities could be the critical differentiator. Chinese military strategists are seeking to seize the initiative, believing "first-class militaries design warfare, second-rate militaries are trailing in warfare, and third-rate militaries have to contend with warfare."[293] The PLA's ambitions to be a truly world-class military imply its intention to be at the forefront of shaping and 'designing' the conditions of future battlefield.[294] The challenge of intelligentized warfare is seen as rendering the creation of new concepts to be imperative, including responding to the threats of enemy advances and studying new strategies to defeat an adversary.[295]

As the PLA has started to catch up with the U.S. military, its attention has shifted to seizing the advantage in future military competition. Xi Jinping has established that modernization is intended to be "basically completed" by 2035, declaring, "by the mid-21st century, our people's armed forces will have been fully transformed into world-class forces."[296] The PLA's conceptualization of the bar for becoming a "global first-class" or "world-class" military (世界一流军队) may remain subject to debate and perhaps continued evolution. Could the PLA equal, or perhaps surpass, the U.S. military? Will the Chinese military remain primarily regional or progress towards global power projection? To what extent will the PLA imitate or adhere to American antecedents, or could the Chinese military possess distinct priorities and paradigms of military power? Inherently, the trajectory of Chinese military modernization remains contingent upon China's capacity to sustain economic growth.

The PLA is still implementing disruptive reforms and attempting to overcome bureaucratic impediments to innovation, yet despite these uncertainties, there are initial indicators that the PLA is actively exploring novel directions in its development. From expanding into the new frontiers of the deep sea and polar regions, to increasing its investments in more expeditionary capabilities, the PLA today is evolving into a force that is almost unrecognizable relative to its onetime backwardness. The PLA's advances in autonomy in advanced weapons systems, including hypersonic glide vehicles, could extend its reach for strategic assaults in ways that reinforce its deterrence and war-fighting capabilities. As the PLA is called upon to defend China's overseas interests, the use of unmanned and autonomous weapons systems also could be favored as an option that allows for flexible options. In a range of regional contingencies, these new capabilities could introduce a degree of unpredictability, from crises involving the use of drones in disputed territories to the potential accidents that might result from the increased complexity of human factors in such systems.

As U.S.-China military rivalry intensifies at a time of technological transformation, these trends may present new risks to strategic stability under complex geopolitical circumstances. There are real reasons for concern that arms racing dynamics could create adverse incentives for AI deployment, at worst creating dynamics in which concerns of speed and relative capability take precedence over safety and surety. However, it is encouraging that military specialists and technology stakeholders in the United States and China alike appear to be aware of and actively engaged on these issues.[297] In this context, the frequent framing of an "AI arms race" is also problematic,[298] insofar as this conceptualization can be misleading and has significant limitations, including the reality that "AI" is best considered a general-purpose enabling technology that has a diverse array of applications.

At the same time, the qualitative character of how AI can enhance military capabilities creates a level of uncertainty that impedes assessments of relative advances and the overall impact on the military balance. At worst, such uncertainty can exacerbate a tendency towards arms racing dynamics, including because of a tendency towards worst-case scenario thinking and overestimation of a potential adversary's capabilities. Since the contributions of AI to military power are essentially intangible, there are incentives for militaries to signal, display, and demonstrate relevant capabilities, such as swarming, in attempts to bolster deterrence, including through activities that may be intended for purposes of deception or misdirection. As the U.S.-China military-to-military relationship evolves going forward, there may be opportunities to progress towards greater clarity and transparency through dialogue on shared concerns of strategic stability, including questions of risk mitigation and crisis management.

Policy Recommendations and Considerations

At the nexus of U.S.-China competition and cooperation in artificial intelligence, American policymakers confront complex challenges that raise urgent questions for U.S. policy. The core concern for American strategy should be ensuring future competitiveness and contesting leadership in strategic technologies. For the U.S. military, current initiatives for defense innovation must take on a new level of urgency and could require rethinking of current priorities and practices, from talent and training to military research and acquisitions.

Today, the United States confronts the unique challenge of strategic competition with a rival with which there is a high level of economic interdependence that includes extensive technological entanglement. The American and Chinese innovation ecosystems have been often synergistic in ways that can be mutually beneficial, but can also be exploited or even weaponized.[299] The current rebalancing and recalibration of the U.S.-China economic and technological relationships could reduce current frictions and mitigate concerns over potential vulnerabilities but must be undertaken with care to avoid collateral damage to American innovation capabilities. Ultimately, the future trajectory of this rivalry may hinge upon U.S. policy choices today.

I. Surge support to sustain future American competitiveness in science and technology.

- Increase and commit to sustaining funding for basic research and the long-term development of strategic technologies.
    - Consider increasing support for science to levels comparable to that of the Cold War.[300]
- Create a strategy for artificial intelligence in education through the Department of Education, including to encourage experimentation in new approaches to the use of AI in education and education in AI at the state and local levels.
    - Prioritize improving the accessibility and affordability of STEM education at all levels, including creating new scholarships to support those studying priority disciplines.
- Sustain openness to immigration, welcoming graduating students and talented researchers, while potentially offering a fast-track option to citizenship.
- Explore the expansion of coordination and cooperation with allies and partners in innovation, including deeper collaboration in research, development, and experimentation with new technologies and their applications.
- Identify categories of U.S. data (e.g., faces, biometrics, genomic information, sensitive personal information) that should be prioritized for protection.
    - Enhance and enforce cyber security standards and requirements for contractors and laboratories engaged in sensitive academic research.

II. Contest and compete for competitive advantage in an era of emerging capabilities and challenges.

- Ensure that the implementation of the National Defense Strategy is fully resourced to enable innovation and experimentation.
- Recognize the criticality of talent, and undertake necessary reforms to the personnel system.
    - Support new approaches to identifying and rewarding technical expertise, such as the Computer Language Initiative that the Air Force has launched.[301]
    - Continue to implement new approaches to training, education, and incentives to improve proficiency and readiness in computer science, big data analytics, and machine learning.
- Sustain and increase support for defense innovation initiatives, including funding the Joint Artificial Intelligence Center at the levels deemed necessary.

    - Prioritize investment in future capabilities, not only sustainment of existing programs.
    - Explore new options for venture capital and novel funding mechanisms to catalyze commercial innovation.[302]
- Deepen partnership with stakeholders in universities and technology companies, building and strengthening bridges to promote new advances in innovation.
    - For instance, the Air Force's recent partnership with MIT's Computer Science and Artificial Intelligence Laboratory is a promising initiative that may establish a valuable precedent.[303]
- Prepare for a mobilization of industrial resources and innovation capabilities in potential scenarios of large-scale conflict.
- Consider supporting dialogues and military and/or governmental engagement on issues of AI safety and security between American and Chinese counterparts.

III. Pursue carefully calibrated countermeasures to mitigate the risks of exploitation of the openness of the American innovation ecosystem.

- Identify incubators and organizations engaging in talent recruitment that are linked to the Chinese central and local governments or to the Chinese Communist Party (CCP).
    - Monitor their activities in the United States and worldwide, and/or require their registration as foreign agents when applicable, while sharing information with allies and partners where appropriate.
- Focus on early warning and enforcement to prevent illicit transfers of technology and hold those engaged in such activities accountable.
    - Enhance counterintelligence capabilities, increasing funding and personnel where necessary, including by augmenting language and technical expertise.
- Engage in outreach to companies and universities to ensure their understanding of policies, and appropriate precautions for the protection of sensitive technologies.
    - Consider reestablishing the now-disbanded FBI National Security Higher Education Advisory Board or a similar mechanism to facilitate and institutionalize such engagements.[304]
- Review recent and ongoing research and commercial partnerships on prioritized technologies that involve support and funding from foreign militaries, governments or state-owned/supported enterprises, evaluating the dual-use risks and potential externalities in each case.
    - Create an advisory board of scientists who can provide an independent assessment and perspective on cases in which the facts or nature of scientific activities are unclear or disputed.
- Introduce safeguards to ensure that the enforcement of U.S. laws and policies is undertaken in a manner that is appropriately balanced.
    - Ensure that students or scientists who are suspected of having violated U.S. laws or regulations receive due process through a careful evaluation of the totality of the circumstances.
    - Undertake an independent assessment of past incidents in which U.S. law enforcement, counterintelligence, and/or indictments have been mistaken or wrongly charged against individuals later determined to be innocent of wrongdoing.[305]

    - Commit to transparency and accountability about the findings, and actively implement changes that are deemed necessary.
- Create mechanisms for intelligence-sharing and enhanced collaboration with allies and partners in response to the common challenges of tech transfer and industrial espionage.
  - Establish a regular working group among the "Five Eyes," as well as select allies and partners, to discuss best practices and lessons learned in responding to issues of tech transfer, as well as more rapidly exchange timely information about current threats.

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Currently, Elsa is a PhD student in Harvard University's Department of Government, and she is also a graduate of Harvard College (summa cum laude, Phi Beta Kappa). Her thesis was awarded the James Gordon Bennett Prize, and her dissertation will examine Chinese military learning and innovation in historical perspective. Her prior professional experience includes time with FireEye, the Department of Defense, Long Term Strategy Group, and the Carnegie-Tsinghua Center for Global Policy. While at Harvard, she has also worked as a research assistant at the Belfer Center and the Weatherhead Center. Elsa was a Boren Scholar in Beijing, China, and she maintains professional proficiency in Mandarin Chinese.

Endnotes

[1] [1] "Xi Jinping's Report at the Chinese Communist Party 19th National Congress" [习近平在中国共产党第十九次全国代表大会上的报告], Xinhua, October 27, 2017, http://www.china.com.cn/19da/2017-10/27/content_41805113_3.htm
[2] This assessment is consistent across a number of authoritative statements from Party and military leaders. See, for instance, these remarks from the director of the Central Military Commission Science and Technology Commission "Lt. Gen. Liu Guozhi: the development of military intelligentization is a strategic opportunity for our military to turn sharply to surpass" [刘国治中将:军事智能化发展是我军弯道超车的战略机遇], CCTV News, October 22, 2017, http://mil.news.sina.com.cn/china/2017-10-22/doc-ifymzqpq3312566.shtml. Xi Jinping's own comments and statements also highlight this ambition, which is implicitly an element of Xi Jinping's "powerful military objective" (强军目标). See, for instance Xi Jinping's remarks as quoted in this article: "Scientific and technological innovation, a powerful engine for the world-class military" [科技创新，迈向世界一流军队的强大引擎], Xinhua, September 15, 2017, http://www.gov.cn/xinwen/2017-09/15/content_5225216.htm.
[3] Pang Hongliang, a professor at the PLA's National Defense University, was among the earliest academics to start actively writing on the topic of intelligentized warfare, including publishing two books on the topic. Pang Hongliang [庞宏亮], "The Intelligentization Military Revolution Starts to Dawn" [智能化军事革命曙光初现], *PLA Daily*, January 28, 2016, http://www.mod.gov.cn/wqzb/2016-01/28/content_4637961.htm.
[4] See, for instance, this seemingly authoritative commentary emphasizing the importance of human-machine cooperation: Lu Zhisheng [陆知胜], "The Typical Style of Intelligentized Operations: Human-Machine Cooperation!" [智能化作战的典型方式：人机协同！] *PLA Daily*, October 17, 2018.
[5] For an initial analysis of this trend, see: Elsa B. Kania, "Learning Without Fighting: New Developments in PLA AI War-Gaming," *China Brief*, April 9, 2019, https://jamestown.org/program/learning-without-fighting-new-developments-in-pla-artificial-intelligence-war-gaming/
[6] This testimony builds upon and is informed by prior research that the author has undertaken since 2016, including: Elsa B. Kania "Battlefield Singularity: Artificial Intelligence, Military Revolution, and China's Future Military Power," Center for a New American Security, November 28, 2017, https://www.cnas.org/publications/reports/battlefield-singularity-artificial-intelligence-military-revolution-and-chinas-future-military-power.
Elsa Kania, "The PLA's Unmanned Aerial Systems – New Capabilities for a "New Era" of Chinese Military Power," U.S. Air Force China Aerospace Studies Initiative, August 10, 2018, https://www.amazon.com/dp/1724598112/ref=cm_sw_r_cp_ep_dp_1WSCBbDCCR3GX.
Elsa B. Kania and John K. Costello, "Quantum Hegemony? – China's Ambitions and the Challenge to U.S. Innovation Leadership," Center for a New American Security, September 12, 2018, https://www.cnas.org/publications/reports/quantum-hegemony
[7] "Xi Jinping: Accurately Grasp the New Trend in Global Military Developments and Keep Pace with the Times, Strongly Advancing Military Innovation" [习近平:准确把握世界军事发展新趋势 与时俱进大力推进军事创新], Xinhua, August 30, 2014, http://news.xinhuanet.com/politics/2014-08/30/c_1112294869.htm
[8] See, for instance, this accounting of Jiang Zemin's remarks: "Jiang Zemin and Military Transformation with Chinese Characteristics" [江泽民与中国特色军事变革] https://webcache.googleusercontent.com/search?q=cache:W4ONiqi73O4J:https://www.wxyjs.org.cn/sgdbzysxyj/201402/t20140217_147993.htm+&cd=5&hl=en&ct=clnk&gl=us
[9] "Xi Jinping: Accurately Grasp the New Trend in Global Military Developments and Keep Pace with the Times, Strongly Advancing Military Innovation" [习近平:准确把握世界军事发展新趋势 与时俱进大力推进军事创新], *Xinhua*, August 30, 2014, http://news.xinhuanet.com/politics/2014-08/30/c_1112294869.htm
[10] "Launching the Engine of Innovation for Strengthening and Rejuvenating the Military"[发动强军兴军的创新引擎——军队代表委员热议科技兴军], Xinhua, March 12, 2019, http://www.xinhuanet.com/mil/2019-03/12/c_1210079238.htm.
[11] See, for instance Xi Jinping's remarks as quoted in this article: "Scientific and technological innovation, a powerful engine for the world-class military" [科技创新，迈向世界一流军队的强大引擎], Xinhua, September 15, 2017, http://www.gov.cn/xinwen/2017-09/15/content_5225216.htm.
[12] Ibid.
[13] Ibid.
[14] See: "Xi Jinping: Launching the engine of military scientific research and innovation at full speed" [习近平：把军事科研创新的引擎全速发动起来]

[15] For the best review of the impetuses for changes in Chinese military strategy across its history, see: M. Taylor Fravel, *Active Defense: China's Military Strategy Since 1949*. Vol. 2. Princeton University Press, 2019. M. Taylor Fravel, "Shifts in Warfare and Party Unity: Explaining China's Changes in Military Strategy." *International Security* 42, no. 3 (2018): 37-83.

[16] Although the translation "smart" is used in the official version of this Defense White Paper, I choose to use the translations "intelligent" or "intelligentized."

[17] Ministry of National Defense of the People's Republic of China [中华人民共和国国防部], "China's Military Strategy" [中国的军事战略]," May 26, 2015. See also the official English translation of the white paper: http://english.gov.cn/archive/white_paper/2015/05/27/content_281475115610833.htm

[18] See also: Li Bingyan [李炳彦], "Major Trends in the New Global Revolution in Military Transformation and the Form of Future Warfare" [世界新军事变革大势与未来战争形态], February 24, 2016. Li Bingyan is a member of the National Security Policy Committee (国家安全政策委员会).

[19] Dennis J. Blasko, 'Technology Determines Tactics': The Relationship between Technology and Doctrine in Chinese Military Thinking." *The Journal of Strategic Studies* 34, no. 3 (2011): 355-381.

[20] For a noteworthy commentary from Lt. Gen. Gao Jin, then president of the Academy of Military Science and later the inaugural commander of the PLA Strategic Support Force, see: "Academy of Military Science President: Reforms Must Resolve the Restraints Upon Systematic Assurance for a Powerful Military" [军事科学院院长:改革要解决羁绊强军的体制性障碍], *PLA Daily*, November 2, 2015, http://www.chinanews.com/mil/2015/11-02/7600724.shtml. At the time, his remarks emphasized, "The mechanism of winning in warfare has changed profoundly. We must be aware of our own shortcomings… We must focus on solving the institutional obstacles, structural contradictions, and policy problems that have long plagued our military."

[21] For the definitive book on the PLA's reforms, see: Phillip C. Saunders, Arthur S. Ding, Andrew Scobell, Andrew N.D. Yang, and Joel Wuthnow (eds.), Chairman Xi Remakes the PLA: Assessing Chinese Military Reforms, ASSESSING CHINESE MILITARY REFORMS, National Defense University Press, https://inss.ndu.edu/Portals/82/Documents/books/Chairman-Xi.pdf?ver=2019-03-14-110008-073

[22] For the authoritative assessment of the PLASSF, see: John Costello and Joe McReynolds, "The Strategic Support Force: A Force for a New Era," National Defense University, October 2, 2018, http://ndupress.ndu.edu/Media/News/News-Article-View/Article/1651760/chinas-strategic-support-force-a-force-for-a-new-era/.
See also: Elsa Kania and John Costello, "The Strategic Support Force and the Future of Chinese Information Operations," *Cyber Defense Review*, Spring 2018, https://cyberdefensereview.army.mil/Portals/6/Documents/CDR%20Journal%20Articles/The%20Strategic%20Support%20Force_Kania_Costello.pdf?ver=2018-07-31-093713-580.
For primary source documentation highlighting the PLA's role in innovation, see: "How Can the Strategic Support Force Forge New Quality Weapons" [战略支援部队如何锻造新质利器], *PLA Daily*, March 11, 2016, http://www.chinanews.com/mil/2016/03-11/7792939.shtml.

[23] For a basic description of the CMC Science and Technology Commission's mandate, see: "Shoulder the functional mission of strengthening the military through science and technology" [肩负起科技强军的职能使命], *PLA Daily*, April 28, 2016, http://www.mod.gov.cn/topnews/2016-04/28/content_4651316.htm

[24] "Academy of Military Science National Defense Science and Technology Innovation Research Academy – Exploring the "Matrix" Research Model to Enhance Innovation Capability" [军事科学院国防科技创新研究院—— 探索"矩阵式"科研模式提升创新能力], April 2, 2018, http://www.81.cn/jfjbmap/content/2018-04/02/content_202957.htm.
See also: "Academy of Military Science National Defense Science and Technology Innovation Research Academy Has Taken Measures to Gather Top Talents" [军科院国防科技创新研究院多措并集聚顶尖人才], China Military Network, February 4, 2018, http://webcache.googleusercontent.com/search?q=cache:WDwIAWmc6agJ:www.81.cn/jwgz/2018-02/04/content_7931564.htm+&cd=8&hl=en&ct=clnk&gl=us

[25] "The Academy of Military Sciences has amassed and selected more than 120 urgently needed scientific research personnel from the whole military" [军事科学院面向全军集中选调 120 余名急需科研人才], Xinhua, January 1, 2018, http://www.xinhuanet.com/mil/2018-01/25/c_129798773.htm.

[26] See, for instance: "Four Departments Issued a Notice Regarding the ""Internet Plus" Artificial Intelligence Three-Year Action Implementation Plan" [四部门关于印发《"互联网+"人工智能三年行动实施方案》的通知], China Government Network, May 25, 2016, http://www.miit.gov.cn/n1146290/n1146392/c4808445/content.html. "State Council Notice on the Issuance of the New Generation AI Development Plan" [国务院关于印发新一代人工智能发

展规划的通知], August 20, 2017, http://www.gov.cn/zhengce/content/2017-07/20/content_5211996.htm"MIIT's Notice Regarding the Release of the Three Year Action Plan to Promote the Development of New-Generation Artificial Intelligence Industry (2018-2020) [工业和信息化部关于印发《促进新一代人工智能产业发展三年行动计划（2018-2020 年）》的通], December 14, 2017, http://www.miit.gov.cn/n1146295/n1652858/n1652930/n3757016/c5960820/content.html

[27] For the full translation, see: Graham Webster, Rogier Creemers, Paul Triolo, and Elsa Kania, "Full Translation: China's 'New Generation Artificial Intelligence Development Plan' (2017)," https://www.newamerica.org/cybersecurity-initiative/digichina/blog/full-translation-chinas-new-generation-artificial-intelligence-development-plan-2017/

[28] This is an estimate and approximation on the basis of the author's awareness of the range of mechanisms for funding and investment across military, government, and private investments in artificial intelligence and related technologies.

[29] "Five National New Generation Artificial Intelligence Open Innovation Platforms" [五家国家新一代人工智能开放创新平台], December 12, 2018, http://easytechchina.com/index.php?m=&c=media&a=show&id=3380.

[30] See again China's "New Generation Artificial Intelligence Development Plan."

[31] See this series in *China Brief*, organized by Peter Wood for early analyses on these issues: "China & the Third Offset," https://jamestown.org/programs/cb/china-third-offset/

[32] See: China Military Science Editorial Department [中国军事科学 编辑部], "A Summary of the Workshop on the Game between AlphaGo and Lee Sedol and the Intelligentization of Military Command and Decision-Making" [围棋人机大战与军事指挥决策智能化研讨会观点综述], *China Military Science* [中国军事科学], April 2, 2016. Note that the journal's own English language translation of the title of the workshop is not the direct or literal translation.

[33] The potential alternative spellings and translations of 智能化 include intelligent, intelligencization, smartification, and/or AI-ification. The notion of 'cognification' has also been used in English-language descriptions of a similar phenomenon. I have chosen to render this term "intelligentization" for consistency with some of the official translations of the term in authoritative journals, such as *China Military Science*, but I am open to debating alternative translations and conceptualizations with those concerned. Not unlike "informatization," the notion of "intelligentization" is difficult to define with precision and appears to be used in a varying and sometimes somewhat inconsistent manner by PLA writings on these issues. My understanding of this concept has evolved since I first discussed it in published writing and testimony in February 2017. See also: Elsa B. Kania, "Testimony before the U.S.-China Economic and Security Review Commission: Chinese Advances in Unmanned Systems and the Military Applications of Artificial Intelligence—the PLA's Trajectory towards Unmanned, "Intelligentized" Warfare," U.S.-China Economic and Security Review Commission, February 23, 2017, https://www.uscc.gov/sites/default/files/Kania_Testimony.pdf

[34] CMC Joint Staff Department [中央军委联合参谋部], "Accelerate the Construction of a Joint Operations Command System with Our Military's Characteristics [加快构建具有我军特色的联合作战指挥体系], *Seeking Truth*, August 15, 2016, http://www.qstheory.cn/dukan/qs/2016-08/15/c_1119374690.htm.

[35] "Xi Jinping's Report at the Chinese Communist Party 19th National Congress" [习近平在中国共产党第十九次全国代表大会上的报告].

[36] This concept (弯道超车), which often recurs in PLA writings, alludes to idea of two cars racing towards a corner, of which one cuts the turn more sharply and takes the inside track, thus passing by the other. I'm open to other suggestions on how to translate this term.

[37] "Lt. Gen. Liu Guozhi: the development of military intelligentization is a strategic opportunity for our military to turn sharply to surpass" [刘国治中将:军事智能化发展是我军弯道超车的战略机遇], CCTV News, October 22, 2017, http://mil.news.sina.com.cn/china/2017-10-22/doc-ifymzqpq3312566.shtml

[38] For an excellent academic evaluation of the challenges of catching up, see: Andrea Gilli and Mauro Gilli. "Why China Has Not Caught Up Yet: Military-Technological Superiority and the Limits of Imitation, Reverse Engineering, and Cyber Espionage." *International Security* 43, no. 3 (2019): 141-189.

[39] For an academic perspective on the notion of leapfrogging, see for instance: Takashi Hikino and Alice H. Amsden, "Staying behind, stumbling back, sneaking up, soaring ahead: late industrialization in historical perspective" *Convergence of productivity: Cross-national studies and historical evidence* (1994): 285-315.

[40] This is the author's attempt to provide the simplest possible definition of the concept, and I am very open to other suggestions and interpretations.

[41] For context, see: Andrew S. Erickson and Michael S. Chase. "Informatization and the Chinese People's Liberation Army Navy." *Phillip Saunders, Christopher Yung, Michael Swaine, and Andrew Nien-Dzu Yang, The Chinese Navy: Expanding Capabilities, Evolving Roles, Washington, DC: Institute for National Strategic Studies* (2011): 247-287.
On Chinese cloud computing, see: Leigh Ann Ragland, Joseph McReynolds, Matthew Southerland, and James Mulvenon, *Red Cloud Rising: cloud computing in China*, Defense Group Incorporated, 2013.

[42] This concept (弯道超车), which often recurs in PLA writings, alludes to idea of two cars racing towards a corner, of which one cuts the turn more sharply and takes the inside track, thus passing by the other. I'm open to other suggestions on how to translate this term.
[43] "Experts: Military Intelligentization Is Not Merely Artificial Intelligence" [专家：军事智能化绝不仅仅是人工智能], *People's Daily*, December 6, 2017, http://military.people.com.cn/n1/2017/1206/c1011-29689750.html
[44] Ibid.
[45] See: China Military Science Editorial Department [中国军事科学 编辑部], "A Summary of the Workshop on the Game between AlphaGo and Lee Sedol and the Intelligentization of Military Command and Decision-Making" [围棋人机大战与军事指挥决策智能化研讨会观点综述], *China Military Science* [中国军事科学],
[46] See: "Future wars, research on future wars, thinking innovation, rational treatment of disruptive technology" [未来战争丨研究未来战争需要思维创新，理性对待颠覆性技术], The Paper, August 16, 2016,http://www.thepaper.cn/baidu.jsp?contid=1514759
[47] Ibid. Some of those prominently involved in this seminar and related initiatives have included academicians, of whom are also dual-hatted in military research institutions: Maj. Gen. Li Deyi, Yang Xuejun, Lu Xicheng, Dai Hao, Shen Changxiang, Liao Xiangke, Yu Quan, Yin Hao, and Wang Shafei, among others. "Theory-Technology Fusion Innovation" New Year Seminar Successfully Convened in Beijing" ["理技融合创新"新春座谈会在京成功召开], "Theory-Technology Fusion Innovation" New Year Seminar Successfully Convened in Beijing" ["理技融合创新"新春座谈会在京成功召开],
[48] For a perspective on the process of innovation, see: Tai Ming Cheung, Thomas G. Mahnken, and Andrew L. Ross. "Frameworks for analyzing Chinese defense and military innovation," 2011, https://cloudfront.escholarship.org/dist/prd/content/qt5cr8j76s/qt5cr8j76s.pdf
[49] "Xi Jinping: Strive to build a high-level military scientific research institution to provide strong support for the party's strong military objective in the new era" [习近平：努力建设高水平军事科研机构 为实现党在新时代的强军目标提供有力支撑], Xinhua, May 16, 2018, http://www.xinhuanet.com/2018-05/16/c_1122843283.htm
[50] Potentially, the 61st Research Institute, which initially appeared to have been shifted from the Informatization Department to the new Equipment Development Department, may have been linked to or re-subordinated under AMS, but that assessment would be pending further evidence and confirmation.
[51] "President Xi came to the military school for the first time" [习主席第一次到军校视察就来到这里], China Military Online, March 20, 2018, https://new.qq.com/omn/20180320/20180320A1G5SK.html .
[52] "Chief Engineer Hu Xiaofeng, General Manager of China's Bingqi Program, Delivered a Lecture: the Challenge of the Intelligentization of Command information Systems" [中国兵棋工程总师胡晓峰少将演讲：指挥信息系统的智能化挑战], July 13, 2016, 2016, http://chuansong.me/n/434595151184
[53] The PLA does not describe what it is doing as an 'offset' per se, but that oculd be the effect in practice.
[54] Ke Zhengxuan [科政轩], "How to build a military scientific research system with our military's characteristics" [我军特色军事科学研究体系如何构建形成], *PLA Daily*, August 08, 2017, http://www.81.cn/jmywyl/2017-08/04/content_7703373.htm
[55] Hu Shengning [胡延宁], Li Bingyan [李炳彦], and Wang Shengliang [王圣良], *Light Warfare: The New Trend in the Global Revolution in Military Affairs* [世界军事革命新趋势], PLA Press [*解放军出版社*], 2015, p. 65-76. See also: Li Bingyan [李炳彦], "Major Trends in the New Global Revolution in Military Transformation and the Form of Future Warfare" [世界新军事变革大势与未来战争形态], February 24, 2016.
[56] This is the department that has had direct responsibility for the PLA's formulation of its equivalent to doctrine, operational regulations.
[57] Zhang Zhanjun [张占军], "How to compete for future maritime combat initiative" [如何争夺未来海上作战主动权], *PLA Daily*, October 24, 2017, https://web.archive.org/save/http://www.xinhuanet.com/mil/2017-10/24/c_129725534.htm
[58] The prior edition of the NDU's SMS dated back to 1999, and it is unusual for a revision of the text to occur so soon.
[59] Note: Although the 2013 edition of the Science of Military Strategy is often seen as more authoritative, it is the author's contention that the 2015 and this revised 2017 versions merit greater attention. Xiao Tianliang (ed.), *The Science of Military Strategy* [战略学], National Defense University Press, 2017. This is the second edition of the edition initially released in 2015.
[60] Please note that this is the author's personal translation and paraphrasing of the text in question.
[61] For context, see: Elsa B. Kania, "When Will the PLA Finally Update Its Doctrine?," *The Diplomat*, June 6, 2017, https://thediplomat.com/2017/06/when-will-the-pla-finally-update-its-doctrine/

[62] Wang Yonghua [王永华], "How to get through the whole link of combat concept development?" [如何打通作战概念开发的完整链路？], China Military Network, November 29, 2018,http://www.81.cn/jwgd/2018-11/29/content_9360140.htm.
[63] Chen Hanghui [陈航辉], "Artificial Intelligence: Disruptively Changing the Rules of the Game" [人工智能：颠覆性改变"游戏规则], China Military Online, March 18, 2016, http://www.81.cn/jskj/2016-03/18/content_6966873_2.htm. Chen Hanghui is affiliated with the Nanjing Army Command College. Please note that I do not assess this to be an official or entirely authoritative perspective, though I do believe that the recurrence of similar sentiments in a range of reasonably authoritative
[64] Ibid.
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PANEL I QUESTION AND ANSWER

VICE CHAIRMAN CLEVELAND: Terrific.

Senator Talent?

COMMISSIONER TALENT: Two questions.

Ms. Kania, your testimony suggests that the Chinese are moving pretty quickly in terms of military applications of AI.

Mr. Ding, your testimony suggested that -- you said that the United States laps the world in military applications of AI.

So first question is are you two disagreeing with each other or am I misinterpreting your testimony.

And then the second question for all three of you: all three of you touch on what I think is one of the real central problems here, which is that one of the tremendous strengths of America's scientific or national security innovation base in general, including with regard to AI, is that the openness of the system, the fact that the networks and players in the system coordinate freely rather than being controlled from above, that's a tremendous strength.

The down side of it, though, is that Beijing recognizes that and has a definite plan not only to come up with more advances on its own but to get the ones we come up with, which is really the brass ring for them because then they get the technology and they didn't have to spend the money to get it.

So the dynamic is how do we protect the openness of the system while also protecting the technology of the system.

So you all made suggestions. Do you both -- I guess my question is do all of you recognize that both of those equities are really important and our intention or do any of you, for example, think we don't really need to worry about China taking our technology?

So the first question is for the two of you and then the second for all of you.

MS. KANIA: Thank you. Great questions and tricky ones as well, given the complexity of these issues.

I would say that my assessment and Mr. Ding's are not necessarily at odds or irreconcilable. I look more at the military dimension of this including in terms of potential capacity for adoption and particularly military research and development, which is often quite a bit more opaque, so not necessarily reflected quite as readily in patents and publications, given some of the asymmetries of transparency between the U.S. and China.

I share the assessment that there are some major limitations in Chinese capacities in key and core technologies in the near term.

But I am -- I take very seriously the ambitions the Chinese leaders have articulated and how rapidly we have seen the PLA start to reform, launch a range of major new initiatives.

I would say that some of these do remain fairly nascent. A lot of what I can speak to is the activity and the momentum behind these projects.

It is hard at this point to evaluate what the actual results will be. So I think there is a lot of uncertainty, going forward, including, for instance, China's Ministry of Education has launched a new plan for AI in higher education and there is a massive scaling up of programs for talent recruitment and development.

In the long term, perhaps 10 or 20 years down the road, China could have a major advantage in talent, although the U.S. does indeed have some strengths today.

So I think how we assess the relative balance between the U.S. and China in AI depends upon the time frame we have in mind, how seriously you consider the current activities while also recognizing some of the potential inefficiencies and limitations.

I think, for instance, the experimentation with new guidance plans that blend venture capital investment and government funding do appear to be looking to catalyze innovation across a number of sectors.

I think there's also some of asymmetries between U.S. and Chinese capacities to access and incorporate commercial technologies that are, of course, challenging for both bureaucracies.

There has been occasionally some unwillingness on the part of American institutions to work with supporting the military, whereas in the China a number of the premier companies such as Baidu and seemingly Alibaba and universities like Tsinghua are actively supporting the PLA in some cases.

COMMISSIONER TALENT: Right. Let's let Mr. Ding -- no, that was really interesting. Let's -- do you agree that you two are not really disagreeing?

MR. DING: Yes, I agree that Ms. Kania and I are not necessarily disagreeing.

Yeah, I think -- I would defer to Ms. Kania's expertise in terms of looking at the opaque Chinese military system.

This seems like to be the start of a book on the subject. So the level of detail in terms of the government guidance funds and the funding that is going into this space is substantial.

What I was trying to do with my remarks was I was looking at -- trying to look at are there any comparative indicators that we can look to to try to assess the development.

So we can list a bunch of achievements and a lot of different aims on both sides. I like kind of hard metrics on how do we assess capabilities in this space, and I found Jon Schmid has an unpublished dissertation at Georgia State where he looks at military patents.

And, obviously, military patents aren't a perfect indicator. A lot of the most important systems are not going to be patented open source but a crucial caveat I'll add to that is a lot of these advanced military systems source components that are found in patents.

So a lot of the key military producers will actually patent the components of these systems. So he argues that looking at this metric of military patents is a good indicator and he looked at how many of these patents in their abstract cited autonomous or unmanned in the abstract, and from 2003 to 2015 the U.S. had a lead in terms of cumulative military patents related to AI of seven times more than China.

I definitely take Ms. Kania's points about this could change in the future and we should be looking at trends and we should also be looking at how these capabilities are deployed in the field as well.

I would argue that the U.S. has an advantage there just in terms of our infrastructural advantages in terms of we have used drones before in the field and we have that data to look at in terms of experimenting with these systems.

And then in my written testimony I also argue that the Defense Advanced Research Projects Agency, DARPA's, approach towards AI has made some good bets in the past.

It was a DARPA challenge that sparked a lot of the interest in unmanned vehicles today and now DARPA is working on ways to create more efficient AI chips as well as more secure AI systems. So --

COMMISSIONER TALENT: So you're not suggesting that we should not be concerned -- I am giving you another double negative -- about Chinese potential for advanced weapons research and applications in the area of AI? You're just noting one particular metric?

MR. DING: Yeah. I am not saying that this should not -- this is, obviously, a big deal for the military and it could be a revolution in military affairs.

I am saying that we should also have a good sense of where we stand because that could affect the types of approaches we take, whether we take much more hasty action or whether we take more deliberate action.

COMMISSIONER TALENT: Okay. I see my time is up, and so I don't know the -- you don't mind? Okay.

Well, I just want to see if all of you would agree that we do need to be conscious of a serious risk of the regime letting us develop all this foundational technology and then stealing it because it's been their practice in the past.

Although I fully recognize what you're saying is that if we try to stop that with measures that are not carefully enough directed we could end up shutting down our research ourselves, right?

So if any of you would think that we don't have to be concerned about Beijing getting our technology, go ahead and say it.

Otherwise, I'll just let you go on to the next question.

MS. TONER: If I might make a related comment.

COMMISSIONER TALENT: Yeah.

MS. TONER: I am concerned. I think it is -- should be a concern to the Commission and to Congress that China might use technology developed in the U.S. against the U.S.

However, I do think that the model that is, or the situation with AI is a little different to many technologies that we are used to thinking about.

So I think we are used to thinking about something like, well, if we develop a really outstanding formulation for rocket fuel and then a Chinese researcher is in a lab that is developing that fuel, they can take the formulation back to China and use it immediately.

And I think the -- it's a little hard to get into briefly but I'll try. I think the research atmosphere in AI in the way that the technology is built means that the U.S. can draw strength from having open systems that are used around the world that cannot simply be taken back to China.

So, for example, the strength of U.S. companies like Google, Facebook, Microsoft, and Amazon in AI is a huge benefit to the U.S. and is not something that China is able to simply steal.

So, for example, right now the fact that Google and Facebook have made research platforms for AI, so TensorFlow and PyTorch are the two -- by far the two most widely used software platforms that AI is developed with, and the fact that those platforms are used openly by researchers all around the world provides strength to Google and to Facebook and to the United States, and is not something that researchers using those platforms can then turn around and use for their own benefit, if that makes sense.

So I think this is absolutely something that should be a concern as it is with any technology. But I think we should also recognize that in AI research there are also in many cases network effects that can draw strength to the U.S. via this kind of openness.

If I may, I would also love to comment very briefly on the previous discussion, as I am familiar with Jeff and Elsa's research, and I believe that Jeff has done some really outstanding work looking at what we can know about current capabilities in AI, and Elsa has done outstanding research looking at China's intentions and hopes for AI.

And so I think we can very clearly know that China is actively paying attention to this research area while also looking at all the indicators we have of how successful they are so far, suggesting that they have not yet had significant success.

MS. KANIA: I would add, I suppose, that I think there is fairly robust evidence that some of these developments in defense technologies are starting to produce real results. China's strength in hypersonic weapons development is one prominent example there as are actual realization of capabilities to leverage machine learning and remote sensing, which is something the PLA is actually quite actively embracing, including the launch of AI in software-defined satellites.

So I think there are -- there is quite substantial evidence of these developments starting to take shape.

Quickly, on the point of platforms, I'd also add that we are starting to see the Chinese government try to compete with that strength by launching their own open-innovation platforms and with particular concentration on things like medical AI, self-driving vehicles, smart cities.

So I think in the long term some of these initiatives are starting to gain more traction as well.

VICE CHAIRMAN CLEVELAND: Thank you.

Commissioner Wessel?

COMMISSIONER WESSEL: Thank you all for excellent testimony. I thank our staff for great preparatory materials.

Let me follow up in part with Senator Talent's question, because I fear the risk is even greater than has been defined.

AI is a journey, not a destination. It'll be a continually evolving ecosystem over time fueled by enhanced sensors, whether it's LiDAR or any of a number of other data-gathering visualization technologies that you probably know a lot more about than I do, on a platform of algorithms and assessment technologies to help understand that or understand the data that is collected by those sensors.

So it seems to me that the critical concern here -- there are several. One is I think the ability for any nation state or actors to gain access to the data platforms as we have seen with the hack of Anthem, which was not about PII but it was about the underlying patient longitudinal data versus other data sets, whether it's from Waymo or Cruise or any of the others that are doing, you know, massive collection activities to be able to apply to the learning to understand, you know, when -- I heard last week when a branch falls in front of a AV vehicle it doesn't know how to assess it yet.

It doesn't have -- you know, it knows how to look at a picture of a person or somebody riding a bicycle but a branch that falls it seems that, you know, the AV companies have not yet figured out how to address that.

So we have these open systems. We have rather than a piece of equipment other than the sensors we basically have data sets and algorithms, et cetera, that can, unless they are embedded on a chip or it may be hard to gather, the underlying information is probably in algorithms or residing in somebody's computer that is, unfortunately, more accessible than I think we would like.

Am I right in terms of that being the core issue -- you know, data sets, of course, the sensors that collect? But unless we do much more about cybersecurity and address the IP theft that, you know, different countries have different standards -- China, in my view, having a standard that falls below international norms -- we are at huge risk.

So, you know, whether we are the ones developing the patents or China is, et cetera, you know, we are -- we have an open -- almost open lock box that is -- makes us vulnerable.

Can each of you respond?

MS. KANIA: Absolutely. I share those concerns and I think it's clear that Chinese leaders recognize data as a strategic resource of national importance.

In addition to the AI plans we have all discussed, there have been a number of plans aimed at big data and developing new centers in ways of enabling fusion among data resources, and this has great commercial relevance.

To some extent, China's data advantage can be exaggerated as a concept. It's not quite as simple as data is the new oil. But the value of data is really application dependent.

So we have seen great strengths in particular applications where access to massive amounts of data is a core comparative advantage.

I think a couple of areas to watch, going forward, will be the use of AI in health care, including precision medicine and biotechnology. It's an area where I think we need to think much more seriously about the security of our own data and --

COMMISSIONER WESSEL: And bio -- and bio hacking, potentially. Yes.

MS. KANIA: Yes, absolutely. Including American genetic and genomic information, and if you look at companies like Beijing Genomics, Inc., or BGI, which is -- aspires to be a Google for biodata, you can tell that the amount of information they are amassing could provide a comparative advantage in future developments in precision medicine and biotechnology and there are some nexuses between these initiatives and military research and development as well that are cause for concern when some of these Chinese companies in health care do have partnerships with American hospitals and universities.

So I think that will be important, going forward. And then when we think about the other sources of data that have been stolen over the years including some of the breaches you mentioned not to mention the OPM breach, also reasons for concern about how the Chinese military and intelligence could or perhaps already are leveraging these sources of information on Americans including perhaps for intelligence and counter intelligence or psychological operations in the future.

So I do think -- and I discuss it further at length in my recommendations -- we need to think about the security of our data and applying more robust standards for cybersecurity much more rigorously, going forward, and while trying to fully leverage our own data to advance American innovation.

COMMISSIONER WESSEL: Ms. Toner?

MS. TONER: Yeah, thank you. I think you've -- is this working? I think you have certainly identified a critical issue at the center of this whole topic and I think the clear implication is that the U.S. must invest in defensive cybersecurity and really cannot invest enough in that area.

I think as our lives continue to be more digital that will be critical for all areas of society, not just for this AI question.

I think it also has an interesting sort of flip side implication as well, which is that we can consider, if we do believe that our competitors or adversaries are fielding systems that are using this kind of technology but there may be opportunities for us to then also get inside those systems and use that as a potential counter.

COMMISSIONER WESSEL: I understand.

Mr. Ding, any comment?

MR. DING: Yeah. I fully share the concern that cybersecurity is very important. I'll just make two brief points on the example of self-driving cars that you mentioned.

I think it's an interesting question of who has the responsibility for cybersecurity for that data set that Waymo has.

I would assume that a company like Google would be investing in the necessary safeguards in cybersecurity for that valuable data set, especially given that's going to be their market in the future.

It's an interesting discussion to what extent the government can provide help in terms of cybersecurity protections, standards and protocols.

That's definitely a future initiative to explore. I'll make also a distinction here between collecting data and simulating data.

So Waymo does a lot of data collection on roads and public road testing. But actually a lot of -- millions of miles of Waymo's data came from simulated miles -- simulating driving.

COMMISSIONER WESSEL: Mm-hmm. Agreed.

MR. DING: So a lot of the -- a lot of the discussion about why China has the advantages, they have more mobile users. They just have a lot more people and their companies can collect more data.

If, in the future, simulated data becomes more important and you can throw a lot of compute power and just generate a lot of the relevant data, that advantage may be muted in the future.

So we need to understand -- as you were saying, it's a continuously developing technology. So we need to understand how different advances change the data advantage.

The other quick point I'll make in health care, as Ms. Kania mentioned, there's a lot of partnerships between universities in this space.

So actually what is viewed as a Chinese data set, for example, data on health care patients in China, you may do that as like a national China data set.

But, in fact, those partnerships U.S. universities and researchers often have access to those data sets and they publish papers based off those data sets.

So they are garnering advantages from those data sets. So we should question the extent to which data sets are purely national, in a sense.

COMMISSIONER WESSEL: Access to but not the ability to utilize without controls of the government?

MR. DING: Exactly.

COMMISSIONER WESSEL: Right. As opposed to what's been happening with our data.

MR. DING: Yeah.

COMMISSIONER WESSEL: Okay. Thank you.

VICE CHAIRMAN CLEVELAND: We have seven commissioners who want to ask questions in about 40 minutes. So please keep that in mind.

Commissioner Lee?

COMMISSIONER LEE: Thank you, Vice Chair.

So thank you so much to the panel. It's really interesting and deep, and I think it's been interesting to see how the three of you play off of each other where there are areas of overlap and so on.

I want to drill down on the policy recommendations and I feel like there is sort of two different -- two different paths here, and in terms of AI there is the difference between cracking down on China and sort of being more defensive in terms of cybersecurity concerns versus what the U.S. needs to do to step up and fund both research and kind of proactive implications there.

And I guess one question has to do -- and this is really for all three of you so I am just interested in your views -- is in terms of timing, you know, I think Mr. Ding and Ms. Toner were a little bit more sanguine in terms of what's going on and, you know, but you all do recognize that there's a danger at some point in the future.

And my question is, is there an inflection point and, if so, are we in a place where we can recognize that inflection point before it happens or will we wake up one day and realize that, you know, it's too late sort of.

And so what are the crucial elements that you would look at to understand what is the moment at which there should be more concern?

And I think it's pretty different issues in terms of security issues versus commercial issues. But also I am interested in the interplay of where government actions in terms of funding OTA or NIST, which I think are really important and the U.S. has chronically under-invested in some of these areas for a long time and that's something where we don't need to worry about what China's doing -- we need to do, you know, we need to take care of our own issues.

But the other issue is where the interplay of government and private sector interests and actions comes into play and I think that was a little bit on the last question, Mr. Ding, and I think you said that Google should take responsibility for some of these issues around self-driving vehicles. But are they and are there areas where maybe the government assumes the private sector is taking care of something and the private sector assumes that the government is, and if so?

So, again, just in terms of the policy recommendations, going forward, what are the crucial inflection points we should be looking for and what is the timing and the scale of the U.S. investment that you all think is needed to get the U.S. on the right path?

MS. KANIA: Those are a good start but I think the critical metric to look at, going forward, as we are thinking about what an inflection point might entail will be talent, and I think the most critical thing we can do is really sustain and increase our own initiatives in education including focusing on STEM education at all levels, expanding scholarships and opportunities for American students while continuing to remain open to talented students and scientists from around the world while encouraging them to stay and contribute here.

So China's ministry of education has launched a new initiative for AI and higher education in their attempts to leverage AI both to enhance education and promote education in AI at all levels of education in China today that are starting to expand.

I wish that the U.S. Department of Education was equally seized of the matter and I hope we can see more progress there, thinking about our own STEM education as really source of national competitiveness, going forward.

And I think when we think about what an inflection point might look like, another point I want to make is that there is an inherent level of uncertainty when we are talking about advancements in these military technologies since AI will often qualitatively enhance existing capabilities in weapons systems. So it's harder to measure. It's harder to have a very clear understanding of what the military balance is or looks like.

And, arguably, there can be a tendency on the part of the U.S. and Chinese militaries to be concerned with and tending to think in terms of worst case scenarios of overestimating each other's capabilities.

I've seen that in Chinese military assessments of where the U.S. might be, and vice versa from time to time. So I think the nature of AI is a general purpose technology -- that is, enhancing and augmenting weapons systems across a vast array of applications does create this uncertainty that could, at worse, drive our arms racing dynamics since it is so hard to evaluate and since the results are so uncertain. So I think that does make safety and surety important as we think about how to sustain stability in this long-term competition.

COMMISSIONER LEE: Thank you.

MS. TONER: I would actually, I guess, like to represent the perspective that there may not be a clear inflection point in the future. I think it can be useful to think of AI as simply a next wave of increasing -- continuing software improvements.

So if you think about how software has changed society and changed, certainly, warfare as well, there have been massive changes but I don't think there's a very clear inflection point that happened suddenly.

Instead, it was a question of continual investments, taking the foundation seriously. So, for example, on the military side my personal view is that the most important AI-related issue that, for example, the Pentagon faces is its software procurement process and the way that it stores and manages its data and that this -- if we can invest in that layer of the situation that will then pay dividends down the road in terms of AI capabilities.

So I think -- and then turning to the -- proactively building the U.S.'s own capabilities, I do think it's a real shame that two of the -- the two by far most obvious investments to make are so difficult for us to do politically, which are investing in basic research, so procuring, you know -- sorry, appropriating more dollars for that and even more importantly this immigration question is really a self-inflicted wound on the U.S. right now, that our immigration is not just vacuuming up all of the outstanding researchers who would love to work here if they could.

And I understand that there are real limitations to what we can do on that front. But I think -- I think we should really take seriously looking for every little small improvement we can make.

MR. DING: I'll just add two quick points, and I agree with both Ms. Toner and Ms. Kania's comments on sort of where we look for inflection points.

I think that you have to make a distinction between inflection points in the research and inflection points in the commercialization.

So in the research side with ImageNet, before, I believe, 2008 there was -- you could only get 80 percent accuracy in terms of identifying images.

With the advent of deep neural networks, that approach led you to get above 90 percent and now people are getting 99 percent, 98 percent, in terms of identifying images.

So that's a clear jump in terms of what IA can add in terms of qualitative improvement in past systems in image recognition.

You can look at similar competitions and metrics in natural language understanding as well. There are certain, like, data sets such as Stanford's question/answer sets and can compare different systems and measure where the leaps are happening.

In terms of commercialization, that might be, like, if you get a completely new domain such as autonomous vehicles where you actually get level four autonomous driving that might mark an inflection point where you have almost a completely new industry.

Then the other thing I'll add is just echoing that this is a long-term uncertain game. With general purpose technologies, the steam engine was invented but the effects only came to be seen 80 years later.

A similar story played out with electricity where you only had widespread adoption maybe 40 years later.

We have seen with biotechnology, which was hyped as this new general purpose technology. We haven't seem much of the big -- we may have not -- we might not have seen the big effects yet.

So continuing to pay attention to how these different inflection points are playing out will be important for the future.

COMMISSIONER LEE: Thank you. And I have just a quick lightning round follow-up question for the three of you.

In terms of commercialization, I am thinking about the job impact of AI, going forward, and, obviously, there's two different things.

One is, you know, displacing current jobs just in terms of the technology but the other is the location of AI investment, commercialization, any production, the, you know, future engineering.

Do you have any policy recommendations with respect to how the U.S. can take steps now to try to ensure -- beyond the immigration issues that you all have talked about -- that some of the good jobs of the future would be located in the United States?

Quick.

MS. KANIA: So I would say again, education, and I think investment in basic science, ensuring that investment is more evenly distributed across the country and including to localities that have the potential to emerge as major tech hubs but haven't received that investment to date.

MS. TONER: At risk of taking us a little bit on a tangent, I think an important issue here will be -- I think there is plenty of room to improve U.S. workers' ability to relocate between areas of greater and lesser productivity.

I think there could be, for example, housing policy relates to the extent to which people are able to move to a new location to take a new job.

So I think that is an under-discussed area here.

MR. DING: Not an issue I have looked at enough to offer any opinion. Thanks.

COMMISSIONER LEE: Thank you so much.

VICE CHAIRMAN CLEVELAND: Commissioner McDevitt?

COMMISSIONER MCDEVITT: Thank you. Fascinating discussion.

I have two questions. First, for Ms. Kania, I want to take you back to your opening sentence or two of your testimony here when you mentioned, certainly, Xi Jinping's avowed statement to be -- have a world-class military by 2049.

In about two weeks, we are going to have a panel that's going to take a look at -- try to understand what world-class military really means -- how do we define that breadbasket of things -- what will a world-class military look like.

And I am not going to ask you to answer that. But I am going to ask you to answer -- you said -- then you went on to say the goal is to surpass the United States.

And I need your evidence for that. Is that personal opinion or do you have in writing or a Chinese source from -- authoritative Chinese source that says the objective is to surpass the United States?

The second question is for all of you. Has anybody or are you aware of anyone who has done any research looking back to the post-Sputnik period of time to see what actions the U.S. government took in the wake of the Sputnik shock, if you will -- I am old enough to remember it -- to in terms of how it -- what it did to focus on education, talent, R&D investment, et cetera, et cetera, to see if there's any lessons that could be applied in the future?

MS. KANIA: I'll speak quickly to the first question. I think Chinese language writings of varying degrees of authoritativeness are often fairly explicit that the hope and ambition in the course of this revolution in military affairs is for China to leapfrog ahead of the U.S. military and to not only close the gap through catching up but also to surpass the U.S. to become that world-class military, going forward.

COMMISSIONER MCDEVITT: Now, are these think tankers or are these government officials?

MS. KANIA: These sorts of statements include remarks by Xi Jinping himself on a number of occasions, as well as those from Lieutenant General Liu Guozhi, who's the head of Central Military Commission Science and Technology Commission, which is, in some respects, the Chinese would-be DARPA, which is funding a lot of this next-generation research and development. I have nearly 300 footnotes in my written testimony and happy to discuss sourcing and also add that the "Science of Military Strategy," an authoritative textbook from the PLA's --

COMMISSIONER MCDEVITT: I am aware of that one, yeah.

MS. KANIA: -- University includes a new section on advancing intelligentization, the objective of the PLA as a latecomer military seeking to surpass the leader, implicitly, the United States.

COMMISSIONER MCDEVITT: Okay. I am not trying to badger you but I am trying to be informed myself because I have been looking for specific references to this very point that came from the lips or pen of Xi Jinping.

And so if you have those in your footnotes, I am delighted.

So then to the other question --

VICE CHAIRMAN CLEVELAND: Your second question.

COMMISSIONER MCDEVITT: -- all of you, any observations on the post-Sputnik?

MR. DING: Yeah. I think Sputnik is a good historical example to draw from. A lot of people have said China's AI advances represent another Sputnik moment for the U.S.

I think what's interesting is Sputnik might have been an example where we overestimated the Soviet Union's technological capabilities.

We could see that if you were to do a similar type of net technology assessment but across the U.S. and Soviet Union at that time, whereas maybe the Soviet Union had the lead in producing the satellite that was -- that some argue that -- the U.S. could have beaten the Soviet Union to Sputnik at the time, Walter McDougall writes a history on this, and it bears out through history that the U.S. had the sustainable leads in the innovation system over time. And perhaps our response to Sputnik increased the risk of miscalculation and war in this space.

I think there are lessons to draw from Sputnik. I think post-Sputnik led to establishment of the Advanced Research Projects Agency, the forerunner to DARPA, which I've cited as one of the U.S. advantages in this space in funding smart military innovation.

I think there are also things that have changed since Sputnik. The structure of innovation in U.S. leads in technology are more in the commercial realm. So whereas a lot of the policies that came out of Sputnik focused on the spin-off approach of producing military innovation, having that spin-off to the commercial realm, now the better approach is to produce spin-on type of approaches where we are leveraging the commercial advantages of U.S. companies.

So, yes, some lessons to take away but also some crucial distinctions we need to be aware of.

MS. TONER: I don't think I have much to add to what Jeff said.

MS. KANIA: I would -- I would just quickly, on the topic of the Sputnik moment, arguably, China has had theirs or they have had a couple of moments that really reinforced to them the imperative of investing in innovation.

You can point to, for instance, AlphaGo's defeat of Lee Sedol in the game of Go in the spring of 2016, which prompted a lot of Chinese military thinking on what artificial intelligence could mean for the future of command decision making.

And I'd also add that the launch of a new strategy for innovation-driven development, which has been a personal priority of Xi Jinping, is quite explicit as a high-level strategic document that innovation is an imperative and that responding to the challenges of this technological revolution is an opportunity for China to become a world-class power in science and technology.

So we think, arguably, China has had more of a Sputnik moment than we have so far, though I hope we can still find ways to mobilize and learn the right lessons from our own history on this front.

VICE CHAIRMAN CLEVELAND: Thank you.

Welcome to our new colleague, Commissioner Borgeas.

COMMISSIONER BORGEAS: Thank you, and good morning to our panelists and, of course, to my new colleagues. This is a wonderful opportunity. This is my first hearing. It's great to be here.

I am just going to pose some questions directly to our panelists and then ask that you answer them or address them in some fashion once I pose all three.

I think the first one I am going to pose is to Ms. Kania. Is the financial return on investment motive from our military producers hindering our military progress and making us more vulnerable to these leapfrog evolutions in tech? And, if so, would enhanced state sponsorship and subsidies be the way forward as a matter of policy?

And to Mr. Ding, we have talked at length about the seamless synergy between the commercial, military, and civic applications in China. Do you have any recommended structural reforms beyond the three recommendations that you have made in your -- in your position piece on where we can improve on the synergies between the commercial, military, and civic?

And to Ms. Toner, we have talked at length about the battle for talent, and do you have any thoughts on the restrictions of either admission or funding within institutions and universities of those who are known to have state sponsorship or are suspected of having state sponsorship, or the movement of faculty from the U.S. to China if we believe that the use of taxpayer dollars or university or institution dollars will go along with their intellectual property overseas, and do you think that a five-year or some period of time naturalization project for the attraction of foreign talent to stay here would be a way forward to deal with the, you know, H-1B issue?

MS. KANIA: On the question of relative trajectories and defense innovation, I'd say that in some respects it appears that the U.S. defense budget has tended to prioritize sustainment over innovation, and I think as we think about future capabilities that could change the character, perhaps even the nature, of warfare, investing in future capabilities and emerging technologies should be an imperative. And there can be some institutional impediments to fully resourcing and embracing that kind of innovation in any bureaucracy.

It does appear that the PLA, in part because they have fewer legacy systems, has perhaps been more inclined to pursue this kind of leapfrogging and prioritize these next-generation innovations.

I'd add quickly on the point of military-civil fusion, the system that China has today is not seamless yet. That is the intention and the aspiration, but when Xi Jinping is required to personally head up a commission advancing this agenda, it is a sign that there needed to be high-level impetus to overcome some of the existing inertia to making military-civil fusion a reality.

And some of the steps that China is taking that concern me the most in this regard are those they've learned from the study of the strengths of our own defense innovation ecosystem and the traditionally close relationships between defense, industry and academia in the United States, which are -- we should redouble our own public-private partnerships to sustain our competitiveness going forward, and also recognize that the PLA is experimenting with mechanisms, not unlike those we have used successfully in the past such as DARPA style challenges, small teams intended to leverage commercial technologies based out of Shenzhen, a major center for AI development and particularly strengths in hardware.

So I think military-civil fusion, in some respects, is inspired by American antecedents, and I think we can look back to the lessons from our own past of how we can start to rebuild these bridges to sustain future innovation.

MR. DING: Yeah, just quickly on your point about how to build our own civil-military fusion, I think I'll expand on the second point where I talk about building bridges across the valley of death.

And the two specific recommendations there are, one, by Joshua Israel, which is to start up a Department of Defense loan program modeled after the Department of Energy's efforts to coordinate with accelerators to fund high-risk high-reward startups in this space.

The second is echoing Ms. Kania's point on building up public-private consortiums. The example that I give is sharing translational research and data analysis capabilities across industrial partners, universities, and hospitals in the area of brain collection and drug discovery for brain disorders. That's one way that the U.S. could build these bridges.

MS. TONER: To your questions about immigration and the battle for talent, firstly, I definitely think there are some types of immigrants who potentially should not be allowed to -- should not be approved if they do have strong ties to institutions of concern.

But I believe that that is a very small minority of the total applicants, and having massive delays in processing for all of those applicants is harming the U.S. overall. And so we need to look for better ways to target and screen that -- for that risk.

In terms of your question about a naturalization project of some kind, I think that could certainly be productive. I think there are also other -- there are many different options at different stages in the immigration chain.

So, for example, creating a clearer path from being a student or a scholar here to permanent residency and eventual naturalization could be productive, reducing the processing times and application burdens overall, looking at the numerical limits on H-1B visas, which hit China especially hard and, again, CSET has a report that will be going into great detail on the situation and the policy options here that should be coming out in the next couple of months.

MS. KANIA: On the question of talent, I'd add quickly I think we should concentrate also on the organizations that are engaged in talent recruitment on behalf of the Chinese government and the Chinese Communist Party in the United States and around the world, including a range of talent bases, incubators, and innovation centers located in places like Silicon Valley and Boston, Massachusetts and, increasingly, really going global and what some Chinese officials have referred to as talent warfare.

So I think focusing on increasing capacity for effective screening while also identifying particular organizations that are targeting students and scientists for recruitment is one way to think about a more nuanced and carefully calibrated approach, going forward.

VICE CHAIRMAN CLEVELAND: Thank you.

Commissioner Lewis?

COMMISSIONER LEWIS: Thank you very much for helping inform us about the concept of artificial intelligence and how it's being used.

I have several questions for all of you, but I'd like to ask Ms. Kania one question right off the bat, which is in the first paragraph of your statement you state the PLA aspires not only to equal but also surpass the United States military by achieving an advantage in the course of the ongoing revolution in military affairs that is being catalyzed by today's advances in emerging technologies.

Could you give us a source for that?

MS. KANIA: That source is based on my reading of Chinese language materials, some of high levels of authoritativeness, back to 2014 when Xi Jinping first, at a Politburo study session on the topic, started to emphasize these themes of the revolution in military affairs and of the historic opportunity that China had to turn sharply to surpass or leap -- or undertake leapfrog development and this phrase, this language, these concepts, these strategic documents all are quite consistent across a broad range of sources that the ultimate ambition is to be at the forefront of designing future warfare, pioneering new concepts and capabilities, and this is consistent with strategists' statements from the PLA's Academy of Military Science, which actually is developing new doctrinal approaches to intelligentized warfare.

And I provided fairly extensive sourcing in my testimony and am happy to provide further documents and translation as part of an ongoing project.

I am also undertaking to make sure that I am conveying all of this in the direct words of Chinese military strategists and leaders at some of the highest levels of power.

COMMISSIONER LEWIS: That would be wonderful. Could you communicate in writing to our staff where you read these things and where you saw that in writing?

MS. KANIA: Absolutely.

COMMISSIONER LEWIS: Thank you very much.

MS. KANIA: A lot of footnotes. I am happy to provide any further details on these points and I think --

COMMISSIONER LEWIS: Thank you very much.

MS. KANIA: -- it has been consistent since 2014 in Chinese strategic thinking.

COMMISSIONER LEWIS: Thank you.

I have a question for all of you. Do we have any knowledge of how many students from China, both students or researchers, are involved in the United States in the work for artificial intelligence?

That's the number-one question. Number two, Ms. Toner, you mentioned about standards in -- setting AI standards. Could you give us an idea of what kind of standards you're talking about?

And then, finally, number three, you mentioned before about the Chinese use of artificial intelligence in what they are doing in -- with the Uyghurs in Xinjiang and how they are violating human rights. Should this be -- should that impact our cooperation with the Chinese with the use of artificial intelligence?

I guess we could start by saying how many -- how many Chinese students are here involved with artificial intelligence?

MS. TONER: I do not have a number for you offhand. I believe that it is -- the statistics I've seen of workers in Silicon Valley is around, I want to say, 20 percent. I could follow up with that number if you would like.

COMMISSIONER LEWIS: Twenty percent doesn't tell me anything.

MS. TONER: Right. I don't have an absolute number for you offhand. I am sorry.

COMMISSIONER LEWIS: Do you have any idea, roughly, of how many hundreds or thousands of students are here, or workers?

MS. TONER: Not offhand. But I can certainly follow up with the Commission.

COMMISSIONER LEWIS: And what's the advantage to the United States of having all these Chinese students and workers working in the field of artificial intelligence?

MS. TONER: The advantage is that they provide their talent and their human capital to U.S. firms, to U.S. universities, to U.S. industry, and they contribute to the fact that the United States is seen as the obvious choice for where researchers from China and from all around the world would like to come and work. And while they are -- while they are working here they are also not working in China.

COMMISSIONER LEWIS: Do we run the risk of them taking what they learn here and bringing it back to use against us later?

MS. TONER: It's possible that that risk applies in some specific applications. In general, the field of AI research is extremely open and most -- almost all interesting research advances are published freely on the internet. This is true even of labs that are in companies which, you know, usually would protect their own IP, companies like Facebook, Google, Microsoft, Amazon. Baidu and Tencent will publish freely online.

So while I certainly think that we should pay attention to specific applications of AI that are security relevant, for example, in weaponry or in other defensive systems, that is a very, very small minority of all work in AI and most of that work -- most of the non-sensitive work is being published freely anyway.

So it's not obvious to me that a student coming to the United States is sort of gaining a concrete thing that they are able to then take back to China that they would not be able to simply access on the internet from China.

COMMISSIONER LEWIS: And when you mention standards -- AI standards, what are you talking about?

MS. TONER: Yeah, it's a little unclear. So there's a lot of discussion of AI standards and people, I think, mean many different things by them.

One set of discussions is around ethical standards and principles, which is certainly an important issue but it can be difficult to make that concrete enough to be useful, and a different set of discussions, which I believe NIST is beginning to have, is also around the safety and reliability of these technologies.

So something that has just been mentioned briefly in our discussion today so far is the fact that AI and machine learning powered applications generally are not very reliable or robust, to say nothing of secure to hacking attacks.

And so -- and the methods that we have for producing robust software systems, for example, formal verification, are not well suited to the way that these technologies are structured.

So I think there's interesting and important technical work to be done in setting down how could you measure when a system like this is ready for a safety-critical application because the systems we have so far are not.

COMMISSIONER LEWIS: You just used the words ethical standards. Can you give us an example of that?

MS. TONER: Certainly. So the OECD, for example, recently put out, I believe, five principles for the use of AI. I don't have offhand what they are.

But, generally, standards of these kind -- there have been many releases. There came actually -- there was one out of Beijing recently noting standards they think should be applied to AI development and typically things that are included say that it should be used for the benefit of humanity, it should be used fairly, it should be possible to understand what the system is doing and why -- sort of relatively general, you know, certainly positive and important statements. But so far, they have mostly been relatively general.

COMMISSIONER LEWIS: So given that the Chinese are using it for human rights abuses, how should that affect our conduct?

MS. TONER: Yeah. I think -- I think the role of AI in the human rights abuses that China has been perpetrating in Xinjiang has been a little overstated.

I think China would really like us to think and the CCP would really like us to think that they have extremely sophisticated technology at their fingertips and that's what they are using.

In general, it's not clear to me that it makes sense to think of -- to closely connect the discussions of AI and the discussions of what is going on in Xinjiang.

I think to the extent that we want to respond to that situation, we should focus on the fact that -- I think the reason that that is happening is because the CCP is willing to make it happen, and they are using many methods including many not at all technologically sophisticated methods.

And so, therefore, I think our response, if we are going to respond, should be to try and discourage or condemn or otherwise sanction that action, and I think the technological angle is only one small piece.

MS. KANIA: I'd actually disagree on that point, if I may.

VICE CHAIRMAN CLEVELAND: Excuse me. Can we -- we need to move on because we have several commissioners that have additional questions, and we can follow up on the record if you have additional observations.

So, Commissioner Kamphausen?

COMMISSIONER LEWIS: Robin, may I just ask Mr. Ding how many people he knows are -- how many Chinese people he knows that are involved in this field?

VICE CHAIRMAN CLEVELAND: Can we do that on the record? We are running out of time.

COMMISSIONER LEWIS: Mr. Ding, could you give us your written record as to how many Chinese are involved in the United States in artificial intelligence?

VICE CHAIRMAN CLEVELAND: We can follow up with any number of questions for the -- on the record if you'd like. I mean --

MS. KANIA: I would just add that several thousand Chinese military scientists by some estimates, according to the research of my colleague, Alex Joske, in his report, have been sent to study abroad overseas including some proportion in AI.

So I think that there -- the numbers can be difficult to estimate. That's the subject of ongoing research that CSET is undertaking. So, hopefully, we can get back to you with a more authoritative accounting of that going forward.

VICE CHAIRMAN CLEVELAND: Commissioner Kamphausen?

COMMISSIONER KAMPHAUSEN: Thank you all for your really detailed testimony and for your written statements. We have learned a great deal. I have three questions that are really from a devil's advocate sort of perspective, and I will hope you will take that as a compliment as to the strength of your arguments to this point.

Mr. Ding, very quickly, I want to be persuaded, I want to be reassured that China is not poised, as you say, to overtake the U.S. But I've heard the arguments about the quality of the patents and the types. It's not just about numbers. I guess I would ask you to respond to an assertion that maybe you're doing special pleading on behalf of the West or the U.S. Or, put differently, what do Chinese scholars say in response to your arguments?

Ms. Toner, you very persuasively talked about the ecosystem -- the innovative ecosystem that the United States has, and you talked about how the innovations that take place in the AI space, especially when they occur in the United States, especially at some of the great companies that are headquartered here, that that is a benefit that redounds to the U.S. more generally.

The reality is, of course, as proud as we are of these companies and their achievements and the value that they've created, they are not American national champions in the same sort of way that we would see in places like China.

And so how do you -- how do you then build on the argument you have made that this is the right place? I love the arguments that you have all made about we need to rethink our approach to talent acquisition. But in light of the fact that these companies are global -- they may be headquartered here -- how do we -- how do you refine your response?

And then, Ms. Kania, very persuasive, exhaustive research. Thank you very much. But, frankly, China is the world's second largest economy. It's perhaps aspiring to be a global military on par with the United States.

The aspirations that you've outlined are very logical and normal for a military of a country of that sort. So what in particular about the application of AI to Chinese military modernization is of most concern to you?

And then maybe, secondarily, are they trying to cheat themselves on the pathway to modernization by leapfrogging? You've written about using technology to overcome the absence of combat experience. Is that -- is that a fool's errand?

Thank you.

MR. DING: Thank you for asking me to argue against myself.

(Laughter.)

MR. DING: It's a constant trouble of mine. So I am glad to be able to play that psychological struggle out in front of the Commission as well.

And so what do Chinese scholars say in response to my arguments? A lot of my work involves translating Chinese texts, and a lot of the testimony cites Chinese texts in terms of saying that they are behind in some of these spaces.

So the AI open source software statistics I cite come from a translation of a white paper from Chinese government officials there where actually Chinese analysis of this space tends to downplay Chinese advantages in this sphere.

Two arguments as to why there are opportunities for China to leapfrog the U.S. in this space. The first is that when there are new innovative technologies, it opens up more space for technological laggards to compete.

So I'll give an example in the realm of chips related to AI development, some of the chips that power the training of machine learning algorithms as well as the chips where machine learning algorithms are run on the end device.

You've seen that when there have been shifts in terms of chip technology from the Intel-dominated chips, to ARM, to now Nvidia dominating in terms of general processing units, GPUs, a next step in chips will be more customized chips that power AI algorithms.

That could be an opportunity where you get new players. Whereas, currently the U.S. chip designs have substantial advantages because of learning by doing events, cumulative advantages. These take long-term capital investments that rebound over time.

The second argument against myself is potentially we focus too much on invention and innovation and we don't focus enough on diffusion.

So it may be the case that the U.S. becomes -- sustains itself as the innovative leader. But some of these new innovations are diffused more quickly in China.

I think that two of the reasons why I am more sanguine towards the U.S. lead is I think we will have an advantage in sustainable diffusion, taking care to prevent accidents that decrease trust in the technology itself as well as we will take advantages to build these bridges across the valley of death and commercialize some of these promising ideas that are coming out from the U.S., and we benefit from cluster effects there as well.

MS. TONER: To your question about U.S. companies and the fact that they are not national champions in the same way as you're implying as some of Chinese -- China's companies have been designated explicitly as national champions, I mean, again, it comes back to this being just the strength of the U.S. system, and it's not an accident that these world-leading companies were founded here and have become big and successful in the U.S. That is a direct result of the commercial and political environment that the U.S. has deliberately built for them.

I think also there was a hint in your question of the concern around the possibility that U.S. companies will not work with the U.S. government as catalyzed, most notably, by Google withdrawing from the Project Maven contract or not renewing its contract with them.

And I think -- I think on the one hand that incident has come to characterize the relationship between Silicon Valley and Washington in a way that I think is overstated.

And if you look at the many ways that U.S. companies are in fact working directly with the U.S. government, there are many of them. I cite some of them in my testimony, for example, the fact that the Pentagon is looking to make this enormous cloud contract, which I think is, you know, a good example of the kind of underlying software and computing infrastructure that is needed if the U.S. is going to use AI to its advantage.

The fact that the Pentagon is looking at Amazon and Microsoft to provide that contract and that those companies have both bid on it is a huge advantage to the U.S. You know, we certainly could not imagine them doing something similar with any government body in China.

So I guess a final point that I'll just make is I think here the best thing that the U.S. can do to benefit from those companies is, as I say in my recommendations, to really hold firm to our principles and our values because that is a real advantage and something that these companies and all of the employees at those companies believe in and will be excited to work with.

So I think that is an underlying recommendation behind all my testimony. Thank you.

VICE CHAIRMAN CLEVELAND: We have another commissioner who wants to ask questions. So, Ms. Kania, if you could keep -- and we are already at the end of this -- theoretically at the end of this panel so if you could keep your answer to a minute, please.

MS. KANIA: When I first started looking to the question of Chinese military innovation, the prevailing consensus in the field tended to be deep skepticism of China's capacity to innovate.

I think today it's clear the PLA is fighting to innovate, and they are achieving some notable progress in the course of these ongoing reforms that have been quite far-reaching and the transformation of the PLA has been undergoing including, of course, the creation of the PLA strategic support force, integrating capabilities for information support in operations in ways that could be quite significant. So I think we shouldn't overestimate what the PLA has achieved.

I think, as I also discuss at length in my testimony, some of their persistent weaknesses and challenges also remain from issues of talent and human capital to training, even the attempts to adapt and revise their doctrine which has been an ongoing and very protracted process.

So I think the reasons for skepticism about whether the PLA can succeed, and I try to address those in much of my research, when we think about some of the applications the PLA is considering, for instance, data fusion and extensive development of undersea robotics and submarines to enhance dominance in the deep sea and augment antisubmarine warfare capabilities, some of these advances in cyber electronic warfare, swarming technologies that are becoming quite mature, I think there are reasons to continue to track quite seriously these developments.

COMMISSIONER KAMPHAUSEN: Thank you.

VICE CHAIRMAN CLEVELAND: Commissioner Fiedler?

COMMISSIONER FIEDLER: Just quickly, I want to point out a couple of things that -- the U.S. government has not been particularly good at estimating Chinese capabilities and the length of time it takes them to achieve anything. So, for instance, we were wrong about how rapidly they could modernize their military.

I am concerned -- general purpose versus dual use -- and by the way, governments generally in history have been not able to regulate science and scientific progress. I am concerned that we have to make decisions about what general use leads to what application we want to inhibit the spread of. And so that's where I would focus the U.S. government, and I would just look for whether you agree with that or not.

And I have a specific question for you, Ms. Toner. Would you bar U.S. companies from investing in companies in Xinjiang who are involved in surveilling, oppressing the people of Xinjiang? Would you bar investment, U.S. investment in those companies, those Chinese companies?

MS. TONER: I think that is a measure that we should certainly consider. I, unfortunately, don't feel informed enough about the situation and the potential implications to give a clear yes or no.

COMMISSIONER FIEDLER: Here's the problem. I've had this discussion with people for 20 years. Everybody can clearly see that a cattle prod should be sanctioned. Soon as you get a little more amorphous an impact and less direct and immediately painful, then you get all kinds of intellectual arguments that tend to be meaningless on effect on people.

So because -- this is where the policy problem is going to come in in a big time if the scientific community is hesitant to recognize impacts and is just trying to hold the government off, okay.

You know, to me it's clear as day. If a U.S. company is involved in a facial recognition thing, and that company predominates in Xinjiang, and it's U.S. money that's doing it, the U.S. company should not be doing it any more.

MS. TONER: Let me restate it. I think of the potential responses, that should probably be at the top of the list, and I think it's very plausible that that would be a good response.

COMMISSIONER FIEDLER: Okay.

MS. KANIA: May I chime in with an alternative perspective? I think the situation in Xinjiang today is deeply disturbing to an extent it does present a moral imperative as you highlighted, and I think I would disagree slightly with my colleague and point to the fact that by my assessment I think surveillance technologies are really at the heart of the CCP's repression in Xinjiang.

And even if in some respects those developments remain incomplete, the fear that those capabilities are causing is very real. And as I heard recently from --

COMMISSIONER FIEDLER: Yeah. Right.

MS. KANIA: -- an activist with Human Rights Watch, people in Xinjiang today are afraid to speak because --

COMMISSIONER FIEDLER: I would just make one other suggestion to those of you who are pursuing the science, and that is that AI strikes me as more rapidly -- empowering people with the ability to more rapidly conduct asymmetric warfare with the United States or to neutralize our capabilities.

Okay. And that is likely to happen much more rapidly than their actual capabilities in a conventional or a new conventional definition of warfare.

MS. KANIA: Absolutely, and in that context the fact that the Chinese defense industry is exporting a number of drones and semi-autonomous weapons I think it poses cause for concern.

The U.S. military could be fighting Chinese weapons on battlefields around the world used by non-state actors before we actually fight the Chinese military, which is a much more likely scenario. So I think the diffusion of these capabilities in asymmetric ways is a cause for concern.

COMMISSIONER FIEDLER: And pattern recognition AI, okay, enables less intelligent human beings who are leading troops to be more intelligent. We have plenty of those, by the way. All armies do. As a former soldier I can recognize that.

VICE CHAIRMAN CLEVELAND: I had a lot of questions, but our time is up. I will submit them for the record.

And very much appreciate the level of detail and expertise that each of our panelists presented. As I said, I have lots and lots of questions, but I will follow up with all of you on the record.

So thank you very much. We will take a 10 minute break and start again at 11:15.

(Whereupon, the above-entitled matter went off the record at 11:07 a.m. and resumed at 11:15 a.m.)

PANEL II INTRODUCTION BY COMMISSIONER LEE

COMMISSIONER LEE: Okay. Good morning. Good morning.

Thanks, and we are ready to start with our second panel, which will assess China's development of new and advanced materials as well as the security of the U.S. supply of critical materials.

And thank you so much to our three panelists for their testimony and for being here with us today.

We will start with Richard Silberglitt. Dr. Silberglitt is a senior physical scientist at the RAND Corporation. He has worked in academia, government, and private industry for over 40 years.

While at RAND, Dr. Silberglitt led a road mapping effort for the U.S. government's nano-enabled technology initiative and participated in the Nanotechnology Enabled Sensing Workshop. He is co-developer of a method for research and development portfolio analysis and management that has been applied for the U.S. Army, Navy, National Security Agency, National Institute of Justice, and Centers for Disease Control and Prevention.

Thank you, Dr. Silberglitt.

After him, we will hear from Dan Coughlin, vice president of composites market development at the American Composite Manufacturers Association.

Mr. Coughlin works to establish global markets for U.S. composites manufacturers, particularly in materials for aerospace and automotive manufacturing. He has more than 30 years of manufacturing and R&D experience and started his career with GE working in thermoplastics and silicones.

Finally, we have Alan Hill, government relations partner for the National Graphene Association. Mr. Hill has an extensive background in telecommunications and technology policy serving as senior vice president of government relations and strategic business development for INCOMPAS and director of legislative affairs at XO Communications. Prior to entering the private sector, Mr. Hill was legislative director for Congressman Cliff Stearns and served on the staff of the House Energy and Commerce Committee.

We are delighted to welcome the three of you and looking forward to your testimony. Please keep your remarks to seven minutes, and then we will follow up with questions for the panel afterwards.

Dr. Silberglitt, the floor is yours

OPENING STATEMENT OF RICHARD SILBERGLITT, PH.D., SENIOR PHYSICAL SCIENTIST, RAND CORPORATION; PROFESSOR, PARDEE RAND GRADUATE SCHOOL

MR. SILBERGLITT: Vice Chairman Cleveland, Commissioner Lee, and distinguished members of the Commission, my remarks today will address new materials and the dual-use applications, China's development of these materials, U.S.-China research collaborations, and China's position as a dominant producer of critical materials.

New materials have increasing multi-functionality and respond to complex and challenging environments. Nano, one billionth of a meter, scale materials are important because they can exhibit fundamentally different properties from those of bulk materials.

Nanoscale materials may provide new or improved properties in dual use applications that include drug delivery, wearable electronics, batteries with higher energy density, and energetic materials.

Nanoscale synthesis led to metamaterials. These are materials with structures that vary on a scale comparable with or smaller than that of electromagnetic wavelengths.

These metamaterials can exhibit properties that don't exist in nature such as negative refraction of light. Metamaterials enable several potential dual-use applications including hypersensitive lenses, perfectly reflecting or completely nonreflecting materials, micro antennas, and cloaking devices.

Functional nanomaterials and metamaterials were identified as priority areas in China's thirteenth five-year plan. China has a substantial research and development effort in metamaterials. There was a sharp increase in Chinese metamaterial patent filings around 2010 following a similar increase in U.S. patent filings about five years earlier.

Since filing a patent application requires investment in time and resources with the expectation of technology ownership, the increasing number of metamaterials filings indicate that both countries regard metamaterials as an area of potential value.

The concentration of focus of U.S. and Chinese filings was substantially different with 80 percent of U.S. metamaterial patents distributed three times more broadly.

This U.S. breadth of application provides the opportunity for innovative uses of metamaterials in new areas while China's increased focus might lead to more advances in already identified areas. Which approach yields greater value will depend not only ono the breadth of focus but also on the quality of metamaterials development and implementation in each country.

The largest number of Chinese metamaterials patents belong to Guangxi Innovative Technology Limited, a Shenzhen-based developer of products for the aviation industry. The founder and president of this company received his doctorate from Duke University.

Researchers from the United States and China collaborate on a variety of new materials areas. Two examples are pursuing advanced batteries for clean vehicles, an important application for nanomaterials, and wearable devices that use nanoscale materials to power small electronics. These collaborations appear to be productive with mutual benefit.

Another aspect of U.S.-China research collaboration is the training of Chinese nationals in U.S. academic research programs, some of whom may return to China and develop such commercial entities as Guangxi Innovative Technology Limited.

There is a tradeoff involved here. On the one hand, these collaborations support global innovation. On the other hand, they support transfer of technology know-how in dual-use areas.

They should be evaluated on a case by case basis to ensure that technologies controlled for national security reasons are not provided to prohibited countries through tacit knowledge.

Turning to critical materials, while the United States has extensive mineral resources and is a leading global materials producer, it is dependent on imports for many materials that are critical inputs to manufacturing. The most well-known examples are metals of the rare earth family. However, in 2018 the United States was relying on imports for 64 non-fuel mineral commodities.

China is by far the dominant producer of these critical materials, counting for more than 50 percent of world production of 12 different critical materials. China is also the only country upon which the United States is dependent for more than 50 percent of its imports of more than 18 non-fuel mineral commodities.

China achieved its dominance in global raw materials production with a large resource base, a long-term emphasis on mineral production, and relatively lax environmental and occupational health and safety standards. However, China's position as a reliable low-cost supplier of raw materials for manufacturing deteriorated as its market share and domestic consumption grew and controls of its minerals production sector contributed to significant price increases and volatility on the world market.

The negative effects on competitiveness of non-Chinese manufacturers led China's trading partners to successfully bring an unprecedented series of complaints before the World Trade Organization.

However, China continues to pursue resource protection strategies regulating its tungsten industry, for example, by limiting the number of mining and export licenses, imposing quotas on concentrate production, and placing constraints on mining and processing.

A dominant producer like China can contribute significantly to market distortions and supply disruptions that strongly affect the manufacturing sector.

RAND's 2013 report Critical Materials: Present Danger to U.S. Manufacturing, recommended two types of actions to mitigate the influence of market distortions on the global manufacturing sector: actions to increase resiliency and foresight actions that can provide early warning of developing problems.

Actions to increase resiliency include those that encourage diversified production and processing of critical materials and those that involve the development of alternative sources such as secondary production or alternative inputs to manufacturing.

Data on the production processing and trade of minerals are widely available. These data could be used to benchmark market activity with diversified commodity markets to allow recognition of increasing concentration of production before it leads to harmful market distortions.

Thank you for the opportunity to testify, and I am happy to answer any questions you may have.

PREPARED STATEMENT OF RICHARD SILBERGLITT, PH.D., SENIOR PHYSICAL SCIENTIST, RAND CORPORATION; PROFESSOR, PARDEE RAND GRADUATE SCHOOL

New and Critical Materials: Identifying Potential Dual-Use Areas

Richard Silberglitt

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Testimony presented before the U.S.-China Economic and Security Review Commission on June 7, 2019.

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New and Critical Materials: Identifying Potential Dual-Use Areas

Testimony of Richard Silberglitt[1]
The RAND Corporation[2]

Before the U.S.-China Economic and Security Review Commission

June 7, 2019

Thank you Vice Chairman Cleveland, Commissioner Lee, and distinguished members of the Commission for inviting me to testify today. I have divided my comments into four sections. The first provides some basic information about new materials, focusing on nanomaterials and metamaterials, their commercial applications, and the potential for emerging dual-use applications. The second describes China's current capabilities in metamaterials compared with those of the United States. The third contains information about recent collaborations between the United States and China on materials research. The fourth and final section reviews China's continuing domination of the production and processing of critical materials. In this section, I suggest possible actions for federal policymakers to consider to increase U.S. resilience to supply disruptions or market distortions and to provide early warning for problems concerning critical materials production. This final section is based on the results of a 2013 study conducted by the RAND Corporation at the request of the National Intelligence Council,[3] taking into account relevant developments and data since the publication of that report.

Development and Applications of New Materials

Since the evolution of materials science and engineering in the latter part of the 20th century as an interdisciplinary combination of physics, chemistry, and several engineering disciplines, materials have been developed with increasing multifunctionality and ability to survive in and respond to complex and challenging environments. Instrumentation to measure materials' properties at the atomic and molecular level, combined with theoretical analyses and computer

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1 The opinions and conclusions expressed in this testimony are the author's alone and should not be interpreted as representing those of the RAND Corporation or any of the sponsors of its research.

2 The RAND Corporation is a research organization that develops solutions to public policy challenges to help make communities throughout the world safer and more secure, healthier and more prosperous. RAND is nonprofit, nonpartisan, and committed to the public interest.

3 Richard Silberglitt, James T. Bartis, Brian G. Chow, David L. An, and Kyle Brady, *Critical Materials: Present Danger to U.S. Manufacturing*, Santa Monica, Calif.: RAND Corporation, RR-133-NIC, 2013.

simulations, has enabled great advances in our understanding of relationships between materials structure, processing, and properties and led to new applications.[4] Materials structured at the nanometer (one-billionth of a meter) scale are of special importance because they are very close to the molecular scale and can exhibit properties and interactions that are fundamentally different from those observed in bulk materials. For example, because of their much smaller size and much larger surface area, drugs encapsulated in or composed of nanoscale particles are significantly more easily absorbed into the bloodstream and more highly bioactive than conventional drugs, enabling therapeutic effects with lower doses and less risk of side effects.[5] Other applications in which materials of nanometer size may provide new or improved properties include wearable electronics,[6] batteries with higher energy density,[7] and energetic materials (materials with stored chemical energy that can be released, such as thermite—a mixture of powdered aluminum and iron oxide).[8] Wearable electronics and higher-energy-density batteries can be considered dual-use to the extent that they may be used by military personnel. Energetic materials are clearly dual-use.

The ability to synthesize materials with structural variations on the nanometer scale has led to the capability to develop a wide variety of metamaterials—materials with structures that are typically not found in the natural world and that vary on a scale comparable with or smaller than that of electromagnetic wavelengths. These metamaterials respond differently than ordinary materials, and in some cases exhibit properties that are not seen in nature, such as negative refraction of light.[9] Metamaterials have been shown to enable several potential dual-use applications, such as hyper-sensitive lenses;[10] perfectly reflecting[11] or completely nonreflecting[12]

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[4] For example, the U.S. Government's Materials Genome Initiative is a multiagency effort to combine experimental, theoretical, and computational methods and tools to discover and explore new materials and decrease the time to their use in commercial applications (Materials Genome Initiative, homepage, undated).

[5] See for example, the description of research on nanoparticle therapy for kidney disease at Francis Collins, "Building Nanoparticles for Kidney Disease," *NIH Director's Blog,* January 31, 2019.

[6] For a recent application that includes energy harvesting, see "Electronic Textiles Could Harvest Energy as We Move," *Nano: The Magazine for Small Science*, May 15, 2019.

[7] See Nature Reviews Materials, "Battery Materials and Technologies," September 6, 2017.

[8] Vladimir E. Zarko and Alexander A. Gromov, eds., *Energetic Nanomaterials: Synthesis, Characterization, and Application*, Amsterdam, Elsevier, Inc., 2016. For a review of worldwide energetics activity, see M.S. Firebaugh, B.M. Rice, Y. Horie, T.M. Klapötke, J.M. Short, R.D. Lynch, R.A. Kavetsky, and D.K. Anand *Topics in Energetics Research and Development*, College Park, Md.: CALCE EPSC Press, University of Maryland, 2013.

[9] For a detailed review, see Muamer Kadic, Graeme W. Milton, Martin van Hecke, and Martin Wegener, "3D Metamaterials," *Nature Reviews Physics,* Vol. 1, 2019, pp.198–210.

[10] Dylan Lu and Zaowei Liu, "Hyperlenses and Metalenses for Far-Field Super-Resolution Imaging," *Nature Communications*, Vol. 3, 2012, p. 1205.

[11] Parikshit Moitra, Brian A. Slovick, Wei li, Ivan I. Kravchencko, Dayrl P. Briggs, S. Krishnamurthy, and Jason Valentine, "Large-Scale All-Dielectric Metamaterial Perfect Reflectors," *ACS Photonics*, Vol. 2, 2015, pp. 692–698.

[12] Mohammad J. Moghimi, Guangyun Lin, and Hongrui Jiang, "Broadband and Ultrathin Infrared Stealth Sheets," *Advanced Engineering Materials*, 2018.

materials; and optical components with specific properties, such as micro-antennas and cloaking devices.[13]

Comparison of China and United States Metamaterials Capabilities

China is pursuing a substantial research and development (R&D) effort in metamaterials. Functional nanomaterials and metamaterials were identified as priority areas of advanced materials in China's 13th 5-year plan, which calls for breakthroughs in core technologies, including new materials, and explicitly identifies key new materials research, development, and application as a project area for science and technology innovation.[14]

Analysis of patents according to the technical classification systems used by national and international patent granting authorities [e.g., the United States Patent and Trademark Office (USPTO), the World Intellectual Property Organization (WIPO), the China National Intellectual Property Administration (CNIPA)][15] provides a window into China's metamaterials efforts and its application focus. Figure 1, which was compiled for the purpose of this testimony, shows the cumulative metamaterial patent filings in China and the United States from 1989 to 2017.[16]

We see emergence in the cumulative number of filings in both countries, starting about 2005 for the United States and about five years later for China. Since filing a patent application requires an investment in time and resources with the expectation of ownership of a technology area, the increasing number of metamaterials filings is an indication that both countries regard metamaterials as an area of potential value.

While the cumulative number of metamaterials patent filings in the United States and China were roughly the same in 2017, an examination of the application focus of the two countries reveals a substantial difference. Figures 2 and 3 show the technical areas in which each country's metamaterials emergence is concentrated.

While antennas are the largest application area for each country, the concentration of focus is markedly different (41 percent of applications for China and only 19 percent for the United States). The next most important technology areas (semiconductors and optics) are similar between the two countries, both in technology and in percentage of all metamaterial applications. However, the top 80 percent of U.S. metamaterial patents are distributed over a much wider application area than the top 80 percent of China's metamaterial patents, which may reflect a greater Chinese focus on applications consistent with government R&D plans. On one hand, the

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[13] For the theory and design of optical metamaterials, see Tie Jun Cui, David Smith, and Ruopeng Liu, eds., *Metamaterials: Theory, Design, and Applications*, New York: Springer, 2010.

[14] National Development and Reform Commission, "13th Five-Year Plan for Economic and Social Development of the People's Republic of China," March 17, 2016.

[15] Patent classification analysis uses the technical classifications to which patent examiners in national and international patent granting authorities assign patents to establish a network that links patents by technology area. Emerging technologies can be identified and analyzed through variations in the cumulative number of patent filings in this network. For a description and demonstration of this approach that includes nanotechnology as an example, see Christopher A. Eusebi and Richard Silberglitt, *Identification and Analysis of Technology Emergence Using Patent Classification*, Santa Monica, Calif.: RAND Corporation, RR-629-OSD, 2014.

[16] Because there is an 18-month delay in publication of patent applications, 2017 is the last year with complete data.

breadth of application in the United States provides the opportunity for innovative uses of metamaterials in new areas. On the other hand, China's increased focus might lead to more advances in already identified areas. Which approach will yield greater value will depend not only on the breadth of focus, but also on the quality of metamaterials development and implementation in each country.

The company responsible for the largest number of Chinese metamaterial patents is Kuang-Chi Innovative Technology Limited, a Shenzhen-based developer of metamaterial products for the aviation industry, including "novel electromagnetic metamaterial to meet user-defined functional requirements such as wave transmission, polar rotation, radiation pattern and shielding, new meta-RF satellite communication products, near space technology."[17] The founder and president of this company, Ruopeng Liu, received his master's and doctorate from Duke University in 2009; he founded the company in 2010.[18] Liu is in a strong position to lead the development of products such as those listed above for China's aviation and space industries.

United States–China Research Collaborations

The United States and China are the two largest sponsors of R&D in the world, with estimated 2018 expenditures of $566 and 486 billion, respectively.[19] In today's global R&D environment, researchers from the two countries collaborate in a variety of areas involving new materials. One example of a current collaboration is the U.S.-China Clean Energy Research Center (CERC), which is coordinated by the U.S. Department of Energy's Office of International Affairs. CERC's objective is to use collaborations between top researchers in both countries to accelerate the development and deployment of clean energy technologies in the United States and China. It is focused on five key research areas: advanced coal technology, building energy efficiency, clean vehicles, water and energy technologies, and medium- and heavy-duty trucks.[20] One of the principal focus areas for clean vehicles is advanced batteries—an important application for nanomaterials. Another area in which U.S. and Chinese researchers are working together to advance the state of the art is wearable devices powered by energy harvested from the environment, including human activities. Devices have been developed in both countries that use nanoscale materials to generate sufficient electricity to power small electronic devices, either from piezoelectric materials (in which pressure generates electricity) or triboelectric materials (in which friction generates electricity).[21] These both appear to be productive collaborations of mutual benefit.

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[17] Bloomberg, "Aerospace and Defense: Company Overview of Kuang-Chi Innovative Technology Limited," May 30, 2019.

[18] Bloomberg, 2019.

[19] "Government and Industry Continue to Grow Global R&D," *R&D Magazine*, Winter 2019 Supplement, p. 5.

[20] See U.S.-China Clean Energy Research Center, homepage, undated.

[21] For a review of the triboelectric portion of this work, see Jianjun Luo and Zhong Lin Wang, "Recent Advances in Triboelectric Nanogenerator Based Self-Charging Power Systems," *Energy Storage Materials*, in press. Luo is at the Chinese Academy of Sciences in Beijing and Wang is at Georgia Tech. See also Professor Zhong Lin Wang's Nano Science Research Group, homepage, undated.

Another aspect of U.S.-China research collaboration is the training of Chinese nationals in U.S. academic research programs, some of whom may return to China and establish academic research programs or develop such commercial entities as Kuang-Chi Innovative Technology Limited. There is a tradeoff involved in such academic research programs. On the one hand, they support innovation in and between the two countries. On the other hand, they support transfer of technology know-how in dual-use technology areas of possible relevance to U.S. national security. These programs must be evaluated on a case-by-case basis, with the objective of ensuring that technologies that are controlled for national security reasons are not provided to prohibited countries either directly or through tacit knowledge.

China's Domination of Critical Materials Production and Processing

While the United States has extensive mineral resources and is a leading global materials producer, it is dependent on imports for many materials that are critical for manufacturing. The most well-known examples are metals of the rare earth family, which are essential to many technologies essential to both civilian and defense applications, such as chemical catalysts, lasers, high-power magnets, batteries, light-emitting diodes (LEDs), night-vision goggles, and computer hard drives.[22] However, U.S. import dependence is not limited to rare earth metals. In 2018, the United States was reliant on imports for 64 nonfuel mineral commodities—fully dependent on imports for 18 of these and more than 50 percent dependent for another 30.[23] This included such semiconductors as indium, gallium, and germanium; metals used in high-temperature alloys, such as vanadium and rhenium; antimony, which is a critical component of flame-retardant plastics and textiles; and tungsten, a critical component in materials used for drilling, cutting, and machining in industries that include mining and construction, oil and gas exploration, and tools and dies. It is these materials—critical inputs for manufacturing—that I refer to as critical materials in this testimony.

China is by far the most dominant producer of these critical materials, accounting for more than 50 percent of world production of 12 different critical materials—antimony, aluminum, bismuth, fluorspar, gallium, germanium, magnesium, rare earths, silicon, tellurium, tungsten, and vanadium.[24] By comparison, there is no other country that produces more than 50 percent of world production of more than one critical material. China is also in a class by itself as the only country upon which the United States is dependent for more than 50 percent of its imports of more than 18 nonfuel mineral commodities.[25]

China achieved its dominance in global raw materials production because of its large resource base, its long-term emphasis on mineral production, and its ability to produce raw

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[22] Definitions of the rare earth family of metals vary slightly. I use the definitions from K.A. Geshneider, Jr., "The Rare Earth Crisis—The Supply/Demand Situation for 2010-2015," *Material Matters*, Vol. 6, No. 2, 2012, pp. 32–37. The metals are lanthanum, cerium, praseodymium, neodymium, samarium, europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium, lutetium, and yttrium.

[23] U.S. Geological Survey, *Mineral Commodity Summaries 2019*, Washington, D.C., 2019, p. 200.

[24] U.S. Geological Survey, 2019.

[25] U.S. Geological Survey, 2019.

materials at lower cost because of its relatively lax environmental and occupational health and safety standards. Figure 4 shows how China's dominance in materials production grew from 1990 to 2010, as mines and processing plants in other countries closed because of their inability to compete with China's low-price exports.

However, China's position as a reliable low-cost supplier of raw materials for manufacturing deteriorated as its market share and domestic consumption grew and a combination of production controls, export restrictions (e.g., quotas, tariffs), mine closings, and company consolidation contributed to significant price increases and volatility on the world market.[26] For example, prices of some rare earth metals spiked by thousands of percent between 2010 and 2013.[27]

The negative effects on competitiveness of non-Chinese manufacturers led China's trading partners to bring an unprecedented series of complaints before the World Trade Organization (WTO), beginning in 2009 and culminating in May 2015 with China's removal of export restrictions on rare earths, tungsten, and molybdenum.[28]

In 2009, the United States and the European Union (EU) brought a complaint against China's trade restrictions on various forms of bauxite, coke, fluorspar, magnesium, manganese, silicon carbide, silicon metal, yellow phosphorus, and zinc. When the WTO ruled in favor of the United States and the EU, China appealed and lost, then took full advantage of the "reasonable period of time" allowed under WTO rules before finally removing export duties on these materials on January 1, 2013, the very day the time for compliance expired.

In 2012, before China had acted on the dispute just described, the United States, EU, and Japan brought an additional complaint against China's trade restrictions on rare earths, tungsten, and molybdenum. This dispute was also settled in favor of the United States, EU, and Japan. China appealed again and lost, and finally removed export duties and export quotas, as well as restrictions on trading rights of enterprises exporting rare earths and molybdenum. China again acted on the very day the time for compliance expired (in this case, May 2, 2015).

The relatively long timeline for resolution (more than three years) of these disputes and the fact that export restrictions on three critical materials were retained for over two years after they had been ruled inconsistent with WTO rules, highlights the vulnerability of U.S. manufacturers dependent on Chinese exports of critical materials. In fact, an analysis of global industrial supply chains and trading strategies concluded that among major traders, only China pursued strong resource protection strategies, defined as export and production restrictions, consolidation of industry, and investment restrictions.[29] China continues to pursue resource protection strategies. For example, China regulates its tungsten industry by limiting the number of mining and export

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[26] Jeonghoi Kim, "Recent Trends in Export Restrictions," Paris: OECD Publishing, OECD Trade Policy Paper No. 101, 2010.

[27] Richard Miller, "Materials Challenges for a Transforming World: Developments for a Sustainable Future: The Example of Rare Earths," *Johnson Matthey Technology Review*, Vol 61, No. 2, 2017, p. 127.

[28] WTO, *China—Measures Related to the Exportation of Various Raw Materials*, Dispute Settlement DS394, January 28, 2013; WTO, *China—Measures Related to the Exportation of Rare Earths, Tungsten and Molybdenum*, Dispute Settlement DS431, DS432, DS433, May 20, 2015.

[29] Eva Barteková and René Kemp, "Critical Raw Materials Strategies in Different World Regions," United Nations University and Maastricht University, UNU-MERIT Working Paper No. 2016-005, 2016.

licenses, imposing quotas on concentrate production, and placing constraints on mining and processing.[30]

As China's export restrictions and the WTO disputes illustrate, a dominant producer can contribute significantly to market distortions and supply disruptions that strongly affect the manufacturing sector. What is most important here is not the level of import dependence but rather the level of availability of these materials at a fair market price. It is important to note in this respect that there are dominant materials producers that eschew export restrictions and allow market forces to largely determine supply and demand of the materials they produce. One such example is Chile, producer of 55 percent of the world's rhenium.[31]

RAND's 2013 report recommended two types of actions to mitigate the influence of market distortions on the global manufacturing sector. These are: (1) actions to increase resiliency to supply disruptions or market distortions; and (2) foresight actions that can provide early warning of developing problems concerning the concentration of production.

Increasing Resiliency to Supply Disruptions or Market Distortions

Actions to increase resiliency can take two different forms: those that encourage diversified production and processing of critical materials and those that involve the development of alternative sources such as secondary production or alternative inputs to manufacturing. Market forces have already encouraged efforts at diversification, for example, new production and processing of tungsten in Vietnam, exploration and development projects for rare earths in the United States and in other countries, and renewed rare earth production from the mine in Mountain Pass, California.[32] However, the uncertainty created by a highly concentrated market is a barrier that must be overcome by actions at the local, national, regional, and global levels to create a favorable and sustainable climate for the investments and time needed to bring diversified supplies into place. Coordinated actions by importing countries can be effective here, such as the actions by the United States, EU, and Japan described earlier. Other areas in which coordination is possible include the formation and maintenance of stockpiles and the establishment of agreements about sharing limited resources in the event of supply disruptions.

Over the long term, actions to increase resiliency may include the development of new methods of extraction, processing, and manufacturing that promote the efficient use of materials; increased recovery of materials from waste and scrap (i.e., secondary production), from which the U.S. obtains approximately half of its tungsten; and research and development of alternative materials and new product designs that use smaller amounts of scarce materials.

Foresight of Developing Problems

Data on the production, processing, and trade of minerals are widely available from government organizations such as the U.S. Geological Survey and the British Geological Survey, as well as industrial organizations and the United Nations' Comtrade database. Using these data,

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[30] U.S. Geological Survey, 2019.

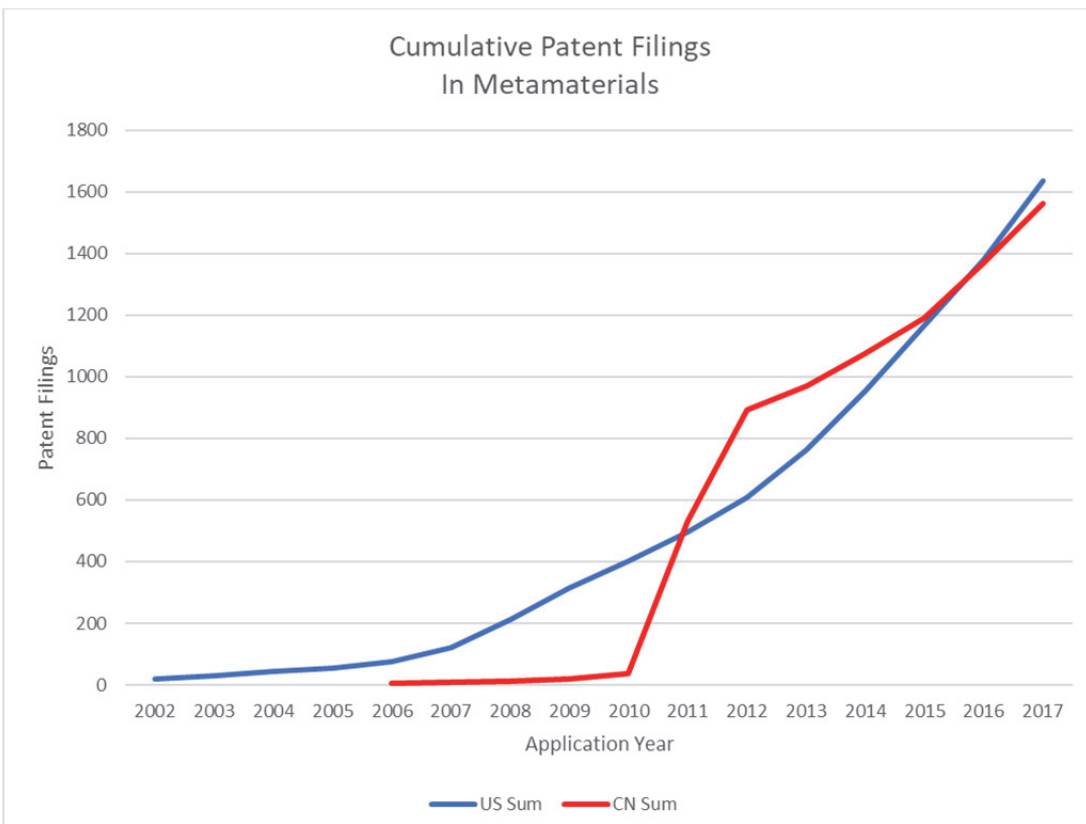
[31] U.S. Geological Survey, 2019.

[32] U.S. Geological Survey, 2019.

how might we recognize a developing pattern, such as increasing concentration of production, increasing export restrictions, two-tier pricing, price spikes, or price volatility before it creates harmful market distortions? One approach may be benchmarking of market activity with diversified commodity markets. For example, the Horizontal Merger Guidelines for firms established by the U.S. Department of Justice and Federal Trade Commission use changes in the Herfindahl-Hirschman Index of market concentration as a measure of market power.[33] When changes in the location of production of critical materials cross the threshold of these guidelines, international coordination and cooperation could prevent market concentration from reaching the level of concern that led to the WTO disputes against China. The goal of such coordination and cooperation should be to smooth market distortions while allowing for the natural economic development of producing countries.

Thank you for the opportunity to testify and I am happy to answer any questions.

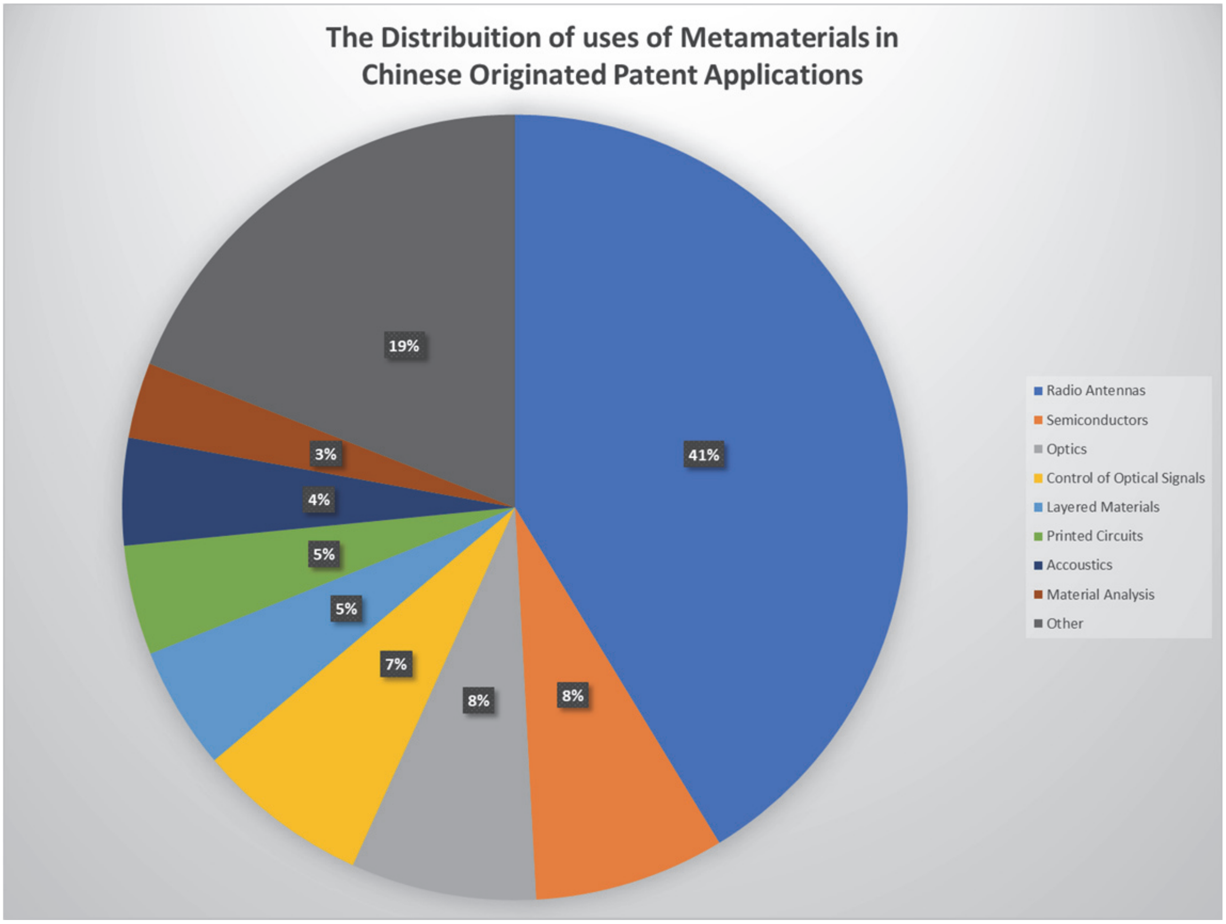
Figure 1. Cumulative U.S. and China Metamaterial Patent Applications



Source: Compilation of data published by USPTO and CNIPA by Christopher A. Eusebi.

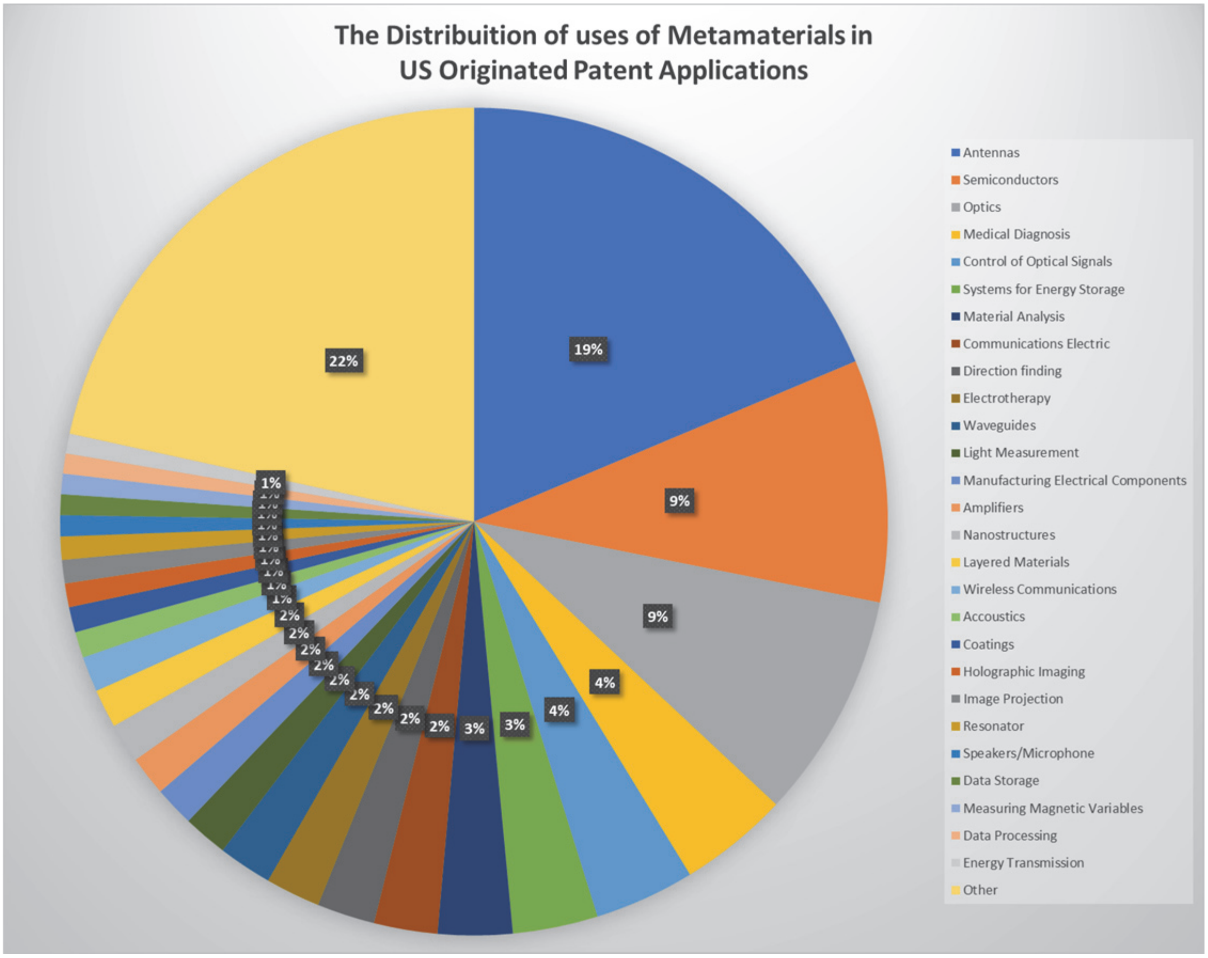
[33] U.S. Department of Justice, "Herfindahl-Hirschman Index," webpage, undated.

Figure 2. Application Areas for Chinese Metamaterial Patent Applications



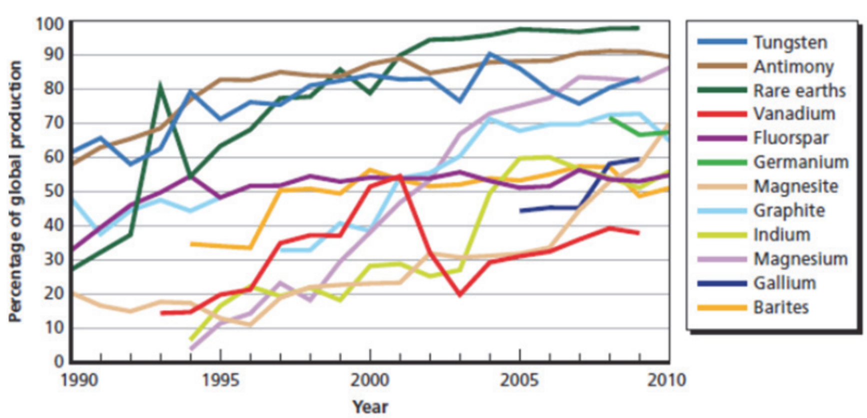
Source: Compilation of data published by USPTO and CNIPA by Christopher A. Eusebi.

Figure 3. Application Areas for United States Metamaterial Patent Applications



Source: Compilation of data published by USPTO and CNIPA by Christopher A. Eusebi.

Figure 4 Growth of China's Raw Materials Production



SOURCES: U.S. Geological Survey, 1996–2011; International Organizing Committee for the World Mining Congresses, 2011.
NOTE: Data unavailable on Chinese market share for germanium prior to 2008. Gallium data are from International Organizing Committee for the World Mining Congresses, 2011.

OPENING STATEMENT OF DAN COUGHLIN, VICE PRESIDENT OF COMPOSITES MARKET DEVELOPMENT, AMERICAN COMPOSITES MANUFACTURERS ASSOCIATION

COMMISSIONER LEE: Thank you so much, Dr. Silberglitt.

Mr. Coughlin?

MR. COUGHLIN: Commissioners and staff, on behalf of the American Composites Manufacturers Association and our members, I appreciate the opportunity to testify before you today.

ACMA represents an industry of more than 3,000 companies. Most are small to medium-sized organizations that offer competitive wages in a growing industry with manufacturing located in every state.

Composites are combinations of fiber-reinforced polymers which result in a material that is strong and light. This combination results in long-lasting lightweight materials which enable a diverse range of sustainable innovations. These include efficient wind power, fuel-saving planes, electric vehicles with longer range, and bridges that don't rust.

The domestic composites industry contributes more than $50 billion in direct economic benefit to the U.S. economy annually. As a key component in end-use applications, the total economic value based on the industries served by composite materials is much greater.

The United States has led the world in development of composites such as those made from fiberglass and carbon fiber. However, we are failing to harness the full potential of federally-funded early stage research and to translate that research into jobs and growth.

If unaddressed, this path could allow other countries including China to gain the upper hand in the composites marketplace and, by extension, all of the industries that rely on composite materials.

China is investing in composites technology to gain market share and technology leadership in a diverse range of markets such as aerospace, automotive, industrial, infrastructure, and construction.

Our members view China as a key export market. But the current trade environment is not balanced. For example, China has an import duty of 15 percent to 17.5 percent on carbon fiber products. However, the United States has no duty on carbon fiber products coming from China.

An area of particular concern are the manufacturing technologies such as tooling, automation, and process equipment. With the Chinese economy largely state directed, their industrial policy is highly integrated. Rather than continuing to manufacture component parts, China seeks to expand domestic supply chains and broadly enhance their technology portfolio.

These efforts have also included strategic Chinese acquisitions of several manufacturing technologies including a billion-dollar acquisition of a major German tooling manufacturer, KraussMaffei.

In addition, China has also acquired critical aerospace composite technology companies. China is already producing composite raw materials. These manufacturing technology acquisitions provide preferred access to vital process technologies needed to convert carbon and glass fibers into value-added parts and finished goods.

We must consider whether these technology acquisitions could limit the access needed for American manufacturers to serve the growing aerospace sector.

The United States is falling short in translating promising research into commercially viable products. The federal government is a world leader of funding for early stage research through agencies such as Department of Energy, Department of Defense, National Institute of Standards and Technology, and the university system through the National Science Foundation.

Our old model of relying on military translational research to trickle down into commercial innovation leaves the U.S. at a competitive disadvantage in the global marketplace.

This is particularly acute in the area of manufacturing technology. Manufacturing innovation focuses on increasing scale while reducing costs for commercial applications which, in turn, increases the number of military applications that can benefit from the use of composites. Therefore, increasing support for translational research benefits both the private and public sectors.

Many key advancements in composites are first driven by the aerospace sector and then find an application in other markets. The development and commercialization of high-volume process technologies is a critical need to support the growing aerospace market.

The scale needed to support emerging markets such as urban air mobility will require step changes in productivity and process technology. Urban air mobility includes the applications of last mile delivery, air metro, and air taxi systems.

Many countries have more robust government-backed systems that promote commercialization of early-stage research.

For instance, the Fraunhofer system based in Germany aligns public funding with private investment to drive research and development in technologies with high commercial viability across a range of markets.

This ecosystem brings together diverse stakeholders to address the challenges needed to bring new technologies to market. The Fraunhofer system is among the best developed translational research programs but is not unique.

Today, Japan spends about 7 percent of its government R&D budget on translational research. Germany spends about 12 percent. South Korea spends about 30 percent. The U.S., in contrast, spends just 0.5 percent of its R&D budget on translational research.

This imbalance of support for translational research means that there is a significant potential that promising research coming out of our labs will first be commercialized overseas.

In a step in the right direction to address this gap, Congress passed the RAMI Act to support the Manufacturing USA network of innovation institutes.

IACMI, the composites institute, has the mission of translating early-stage research to make these innovative manufacturing technologies accessible to industry.

Federal support for this public-private partnership is essential to attracting matching funds from industry, academia, as well as state governments.

Likewise, industry collaborative programs through NASA to support rapid manufacturing and advanced thermoplastic composites is also a critical need.

Stable long-term support is needed to ensure that these programs remain viable. To ensure the long-term health of the U.S. economy, ongoing federal support for these industrial precompetitive programs is essential to maintaining our leadership and manufacturing technology.

We are no longer facing competition just between companies. Entire countries are acting in a coordinated way to ensure their manufacturing sector thrives through smart policy, strategic investments, and partnerships.

The federal government needs to provide consistent investments that foster innovation and the retention of vital technologies which the manufacturing sector relies upon.

By building stronger ecosystem of collaboration we can achieve a safer future, greater prosperity, and energize America's entrepreneurial spirit.

Thank you.

COMMISSIONER LEE: Thank you very much, Mr. Coughlin. Mr. Hill?

PREPARED STATEMENT OF DAN COUGHLIN, VICE PRESIDENT OF COMPOSITES MARKET DEVELOPMENT, AMERICAN COMPOSITES MANUFACTURERS ASSOCIATION

Statement of Daniel Coughlin
Vice President, Composites Market Development
American Composites Manufacturers Association

Written Testimony to the Hearing:
"Technology, Trade and Military-Civil Fusion: China's Pursuit of Artificial Intelligence, New Materials and New Energy"
U.S.-China Economic and Security Review Commission

June 7, 2019
Washington, DC

AMERICAN COMPOSITES MANUFACTURERS ASSOCIATION

Members of the U.S.-China Economic and Security Review Commission,

I am Daniel Coughlin, Vice President of Composites Market Development at the American Composites Manufacturers Association (ACMA). Thank you for the opportunity to provide perspectives from the composites industry on "Technology, Trade, and Military-Civil Fusion: China's Pursuit of Artificial Intelligence, New Materials, and New Energy."

Composites are combinations of fiber reinforcements, most commonly glass or carbon among many other materials, and tough engineered polymers. The resulting material combination is lighter, stiffer, and stronger than the constituent materials individually. Composites are formulated to provide characteristics specifically tailored for maximum performance in a host of different applications. Their performance characteristics allow for delivery of greatly improved performance relative to other material options while reducing long term costs and extending service life.

The domestic composites industry contributes more than $50 billion in direct economic benefit to the US economy and is growing at more than twice the national Gross Domestic Product. When looking at the litany of other sectors that are enabled by key composite technologies, like aerospace, electric vehicles, rail, defense, renewable energy, and longer lasting infrastructure to name a few, the economic contribution of these materials and component products is much greater.

ACMA represents an industry of more than 3000 companies in the domestic composites industry. While the Association represents many large corporations, the majority of the industry is made up by small-to-medium sized companies that offer highly competitive wages in a growing and technologically evolving industry with manufacturing located in every state.

Glass fiber reinforced polymer composites (GFRP or fiberglass) have been used in military applications since World War II. GFRP was originally developed as a replacement for molded plywood for use in aircraft radomes because the material is transparent to radio frequencies. The additional benefits of the material – high strength, light weight, durable, and blast and corrosion resistance – have allowed GFRP to be used in numerous additional applications. Fiberglass recreational boats are a well-known and instructive example of composites. Saltwater destroys traditional metal and wood hulls for boats, but fiberglass remains unscathed after decades of high salinity contact and has come to dominate that sector due to its superior performance.

Carbon fiber reinforced polymer composites (CFRP) were developed in the 1950s and began to see significant use in military aircraft in the early 1960s, initially in engine fans and then more widely in other structural and equipment applications. CFRP offers an ideal solution for aerospace and other applications that require extremely high strength and light weight.

Every composite is a highly engineered material, designed to meet specific load requirements with consistent durability and performance throughout its service life. There are some material combinations and manufacturing processes that yield outputs better suited to high intensity structural stress than others. For example, composites used in space applications have higher load requirements and therefore higher performance and higher cost than those used in sporting goods.

The structural performance of composites relative to traditional materials is a key driver of industry growth. Because they are strong, corrosion-proof and long lasting, composites are increasingly used in infrastructure and construction applications like bridges, water systems, utility structures and more. Because they are lightweight without compromising safety, composites are increasingly used in automotive and aerospace applications to provide superior performance while reducing fuel consumption costs. Composites are an important enabling technology for autonomous vehicles, urban air mobility, drones and a host of new transportation innovations because of the ability to embed sensors and self-healing technologies directly into the material system.

The United States has led the world in the development of composite materials from the very beginning, but the gap is closing rapidly. As this testimony will elaborate on, the United States is failing to harness the full potential of federally-funded initial stage research and translate it into jobs and growth in a key industry that supports nearly every major industrial sector. If left unaddressed, this path could allow China to gain the upper hand in the composites marketplace, and by extension the breadth of markets the industry serves including key transportation and defense technologies.

The U.S.-China Relationship in Composites

The composites industry has a complex, global supply chain. Many companies manufacture composites in multiple countries and do so with raw materials that compete on a global basis. The major raw materials needed to produce composites such as resins, reinforcements, fillers, and additives, have a solid base of supply from U.S. manufacturers. U.S. raw material suppliers are facing increasing foreign competition, most notably from glass fiber manufacturers. An exception to the solid U.S. base of raw material supply chain is PolyAcryloNitrile (PAN) pre-cursor needed to manufacture carbon fiber. There is limited domestic production of PAN, and carbon fiber manufacturers rely heavily on imported PAN, largely from Japan.

Regarding the import of glass fibers, the listing of various glass fiber formulations to the Section 301 tariffs list has had a negative impact on some manufacturing companies in the composites industry. ACMA surveyed members in 2018 for their perspectives on the trade escalation with China to better inform our efforts in this area. Their responses were wide-ranging and the majority of members did not respond. However of those who did respond, the majority indicated that they support efforts by the Administration to pursue a balanced trading relationship with China based on free and fair trade. A key concern for U.S. manufacturers are subsidies for Chinese producers which can create incentives for increased exports to the U.S. This concern is particularly focused on high volume component parts, like composite building materials.

Our members view the growing Chinese economy as a key export market as well, but the current trade environment is not balanced. For example, China has an import duty of 15% to 17.5% on carbon fiber products, however the United States has no duty on carbon fiber products coming from China. This imbalance provides China greater access to the American carbon fiber and carbon fiber composites market than is equally afforded to American firms in China.

An area of concern is leadership in tooling and manufacturing technology. Efforts by the administration to address dumping of steel and aluminum have not fully addressed end products produced from those materials. For example, CNC machinery can come in without any duty. Some European governments even provide a tax rebate for companies in their countries exporting that equipment. ACMA members also report Chinese machining technology products are sometimes first exported to Europe, rebranded, and sold in the United States under an 'Imported from Europe' moniker.

Further, it is important to note that there have been significant Chinese efforts to gain market share and technology leadership in key sectors that are supplied by the composites industry. This is especially true in aerospace and vehicles, particularly in newer innovations. For example, the Chinese have far greater state investment in technology development and a more focused policy framework for the broader deployment of electric vehicles. For instance, KDX Group, BAIC Group, and Changzhou Hi-Tech Group jointly invested $1.8B in 2017 to produce a "new-energy vehicle carbon fiber body and components project[1]."

Risks

One area where the United States is falling short is the failure to foster promising research into commercially viable products in key growth sectors. The federal government invests significant funds into early stage research at programs at DOE, DOD, NIST, and NSF, among several other agencies. The DOD does create market pull for military goods that rely on composites and as noted above this was the spark that started the industry. However, we cannot rely on military applications alone if the U.S. wants to remain competitive in the years to come. We are increasingly seeing that composites innovation is driven from non-military applications in sectors such as commercial aviation, electric vehicles, and advanced infrastructure and construction applications. Therefore, our old model of relying on military applications to drive commercial innovation alone leaves the U.S. at a competitive disadvantage in the global marketplace. Many large companies who once had the ability to commercialize early stage research now rely on research collaboratives and acquisitions to pull new technologies into their portfolio. Therefore, a lot of promising early stage research is first commercialized overseas where there are more active and vibrant public-private partnership programs.

Whereas United States industrial policy does not widely commit public resources to the commercialization of nascent technologies for non-military applications, the same is not true of competitive economies. Many countries have government-backed apparatuses to commercialize promising innovations. The Fraunhofer system based in Germany aligns public funding with private investment to drive research and development in technologies with high commercial viability across many markets. This ecosystem brings together diverse stakeholders, including companies that may ultimately compete in the end market, to address the challenges in bringing new technologies to market.

The Fraunhofer system in Germany is among the best developed, but not unique. The VTT Technical Research Centre of Finland is another example which was started in 1942 and continues to operate with 36% of its funding from the public sector in Finland. The Netherlands and the UK have effective networks of Public-Private Partnership institutes. Today, Japan spends about 7% of

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[1] http://www.jeccomposites.com/knowledge/international-composites-news/china-driving-whole-car-supply-chain-electric-vehicles-are

its government R&D budget on this translational research. Germany spends about 12%. South Korea spends about 30%. The U.S., in contrast, spends just 0.5%[2]. Since most of the U.S. basic science research is done in the public domain, other countries such as China have access to the results of $60.8B (2015) spent in the U.S. to feed the pipeline of innovations in their translational research programs[3].

Among the key technology areas that are vital to US competitiveness in composites in the future:

1. Tooling, machining, automation, and process equipment technologies
2. Carbon fiber production including PAN precursor production
3. Non-destruction testing, inspection and evaluation technologies including big data analytics
4. Embedded sensors and multi-functional composite materials
5. High performance thermoplastic composite technologies
6. High volume composite additive manufacturing technologies
7. Composites recycling technologies
8. Technological breakthroughs in resin feedstocks

In this testimony, I will focus on item (1) - Tooling, machining, automation, and process equipment technologies as one example which is currently at risk to illustrate the need for a revised U.S. manufacturing policy needed to sustain US manufacturing over the long term to compete effectively on a global basis.

The U.S. has relied on a higher degree of technical and engineering knowledge and capability, but this disparity is diminishing. With the Chinese economy largely state directed, their industrial policy is far more aggressive. The Made in China 2025 Initiative has already committed $300 billion dollars to producing higher-value products in key sectors including aerospace and robotics. Rather than continuing to manufacture component parts, the plan seeks to expand domestic supply chains and broadly enhance technological research and development. These efforts have also included significant Chinese investment in overseas manufacturers of machining technologies, including a billion-dollar acquisition of major German tooling manufacturer KraussMaffei.

In addition to KraussMaffei, critical aerospace composite technology companies have also been acquired. These include composite tooling company FFT Group by Fosun, the robotics company Kuka by Midea Group, Brötje Automation (process automation) by Shanghai Electric. Since China is already producing basic raw materials, these acquisitions provide China with vital process technology to turn the raw materials into value-added parts and finished goods. The tooling and equipment suppliers share technology and manufacturing with global partners to ensure access the best available technology for a given application. Acquisitions by China in this area suggest a need to look critically at whether a shifting supply base could limit access needed for American manufacturers to continue to be leaders in the end-use markets they serve, like aerospace.

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[2] https://science.house.gov/imo/media/doc/03.25.19%20CStevens%20OS%20Advanced%20Manufacturing%20Hearing.pdf

[3] https://fas.org/sgp/crs/misc/R44307.pdf

Tooling and machining companies provide key enabling technologies for high performance defense and aerospace applications. Many key advancements in composites come from the aerospace sector and trickle down into other markets. In addition to our existing commercial aerospace market, emerging markets will be important to the growth of the aerospace industry. Urban Air Mobility (UAM) which includes such applications as last mile delivery, air metro, and air taxi[4]. As these products are developed, this will spur the development and commercialization of high-volume process technologies. Improved process technologies will also benefit the production of single and multi-aisle commercial aircraft. Although estimates vary widely in this developing market, volumes of UAM production are on the order of 1000 vehicles per month, as compared to single aisle commercial aircraft volumes on the order of 100 per month. Therefore, the tooling, automation, and process equipment suppliers are key to maintaining competitiveness globally.

Leadership in aerospace composites will enable China to grow composites technology in other markets such as automotive, infrastructure, construction, medical devices, rail, renewable energy, and sporting goods. Composites are a key enabling technology for all these markets. U.S. leadership in composites technology is vital not only to the composites industry, but to all of the industries we serve. Support for translational research is a vital component of an integrated manufacturing policy. As other countries like China are increasing their targeted research efforts and making strategic acquisitions of technology companies, America runs the risk of maintaining technological superiority in key sectors.

China is looking hard toward the future as well. The Chinese government financially backs significant numbers of students to attend American and European universities in key STEM fields. This is particularly visible to our industry in material and mechanical engineering and may be the case in others. Many of these students become part of research teams working on promising early stage technologies in composites, robotics, and other key strategic areas. Much of this research does not see commercial light as noted previously, however students can return to China and are provided resources to take these technologies to the next level.

Advanced composites manufacturing is used in aerospace, automotive, energy, marine, sporting equipment, health care, infrastructure, and other industries to produce strong, light weight products. Jobs are high tech, involve working in clean environments, and require specific training.

STEM programs focused on advanced composites will provide the skills needed to innovate systems, processes, and material development critical to assure our technological superiority for decades to come, as well as, familiarize students with dual use technologies for both military and commercial application.

Lucintel, a global market research firm, found in a study commissioned by IACMI, The Composites Institute, that the composites industry is expected to experience substantial growth in the coming years. Carbon fiber composite applications are expected to grow more rapidly than glass fiber – an indication that advanced training is required to fill the need for advanced composites manufacturing technicians.

[4] https://www.nasa.gov/sites/default/files/atoms/files/uam-market-study-executive-summary-v2.pdf

In manufacturing, for every job that requires a master's degree or more, two jobs require a four-year degree, and seven jobs require a one-year certificate or two-year degree according to the Manufacturing Workforce Development Playbook[5]. In order to attract the next generation needed to fill the technician level positions requiring less than a four year degree, it is important to gain the interest of students before they exit high school.

As we know, not every child is pre-disposed to go on to college. Of the 16.4 million credentials needed by 2025 to meet workforce demands, more than one-third will be drawn from individuals with some college credit and no degree according to a report published by the Education Commission of the States in 2017[6].

Creating STEM programs that grant dual credit towards a certificate or a national certification, such as ACMA's Certified Composites Technician program, with local community and technical colleges is a model that would close that gap while providing the student with a portable, validated credential enabling that individual to accelerate his or her entry into the workforce. IACMI is teaming with Davis Technical Institute and other community colleges aligned to the DOD manufacturing enterprise to deploy such a model on a national scale to establish a talent pipeline for the advanced composites industry.

Pathways Forward and Policy Recommendations

The closest the United States has to an organized commercialization apparatus is in defense and space, where a form of innovations developed in NASA or DOD research programs can trickle into civilian markets. For example, the use of carbon fiber composites as a structural material in the Boeing 787 Dreamliner was preceded by numerous military jet programs. But in an era of rapid innovation, this paradigm leaves far too much on the table.

Around the world, governments are organizing and leading supply-chain stakeholders in the form of public-private partnerships to commercialize basic research. The United States needs a similar approach.

A step in the right direction has been the advent of the Manufacturing USA network of innovation institutes. The Institute for Advanced Composites Manufacturing Innovation (IACMI) has made tremendous strides in taking very early stage research originating at national or university laboratories and translating it up the commercialization chain. It is successful because it brings together stakeholders from industry, academia, and government to collaborate on promising technology. Other institutes in the Manufacturing USA network are doing the same thing in other industries.

Stable long term support is needed to ensure that these institutes remain viable. The authorizing legislation directed government funding for an initial five-year period only. The industry financial and in-kind commitment to IACMI far exceeds the federal share, and the easy answer is to say that large corporations have large research budgets that can fund early stage research. Unfortunately,

[5] https://www.nist.gov/sites/default/files/documents/2017/04/28/Manufacturing_Workforce_Dev_Playbook.pdf
[6] https://www.luminafoundation.org/files/resources/state-innovations-for-near-completers.pdf

this is not borne out. Other countries with successful translational research programs recognize that a core of public funding is needed to attract industry and state funding. Since many companies are global, their research funding can be shifted to those countries which embrace this model. Matching public resources mitigate financial risk and illustrate a commitment by government to see development of technology in the relevant area. This has a magnifying effect on industries. If it is clear that the government is committed to the viability of a key sector, greater investment will flow into that sector and America has a better chance to achieve or maintain a comparative advantage.

A good start in the development of a needed comprehensive industrial policy would be continued funding to those Manufacturing USA institutes with demonstrated ability to commercialize viable research. A next step is aligning the resources of the National Laboratories network to develop basic research further toward commercial viability, rather than leaving it at a low level of technology readiness and moving to the next project. Not every project will yield overwhelming success, but assuredly more new products will enter the flow of commerce and benefit the American economy as a whole.

To assure America maintains superiority in key industries including, but not limited to, composites, Congress needs to look holistically at the manufacturing ecosystem. The government should do a better job of promoting manufacturing trades as a career pathway. Products are needed and even in an era of increasing automation, they cannot be produced without people. Ushering more people into the high-tech manufacturing workforce will assure the United States has the capacity to lead the world in key sectors.

There are also regulatory drags that stymie innovation. As new vehicle technologies become more mainstream like autonomous vehicles, electric vehicles, and drones, America is behind because we lack the regulatory framework for their broad and safe introduction and the infrastructure to support them. Similarly, lacking a unified vehicle emissions standard for the whole domestic market makes it difficult for automakers to manage innovation in a consistent fashion. The same situation is equally pronounced in the infrastructure sector, where the development of codes and standards as well as the length of time needed to permit new starts has slowed growth of deployment of innovative construction materials and techniques. China and other countries are faster to clear these hurdles and are already reaping the benefit.

Conclusion

It is no longer enough to rely exclusively on American entrepreneurial spirit to maintain dominance in the world economy. The world has changed. We are no longer facing competition just between companies, entire countries are acting in a coordinated way to ensure their manufacturing sector thrives for through strategic investments and partnerships.

The federal government needs to provide consistent, long term investments based on smart policy choices that foster innovation and the retention of vital technologies which the manufacturing section relies upon. In turn, industry needs to provide its share of support for collaborative, pre-competitive research. By involving industry, the research will be more focused on programs which have commercial value. By building a stronger ecosystem for public-private collaboration, we can achieve a safer future, greater prosperity, and a renewed entrepreneurial spirit all Americans can be proud of.

Attached: Supplemental Materials Submitted for the Record *(next page)*

Competitive Positioning of USA vs China in the Composites Industry

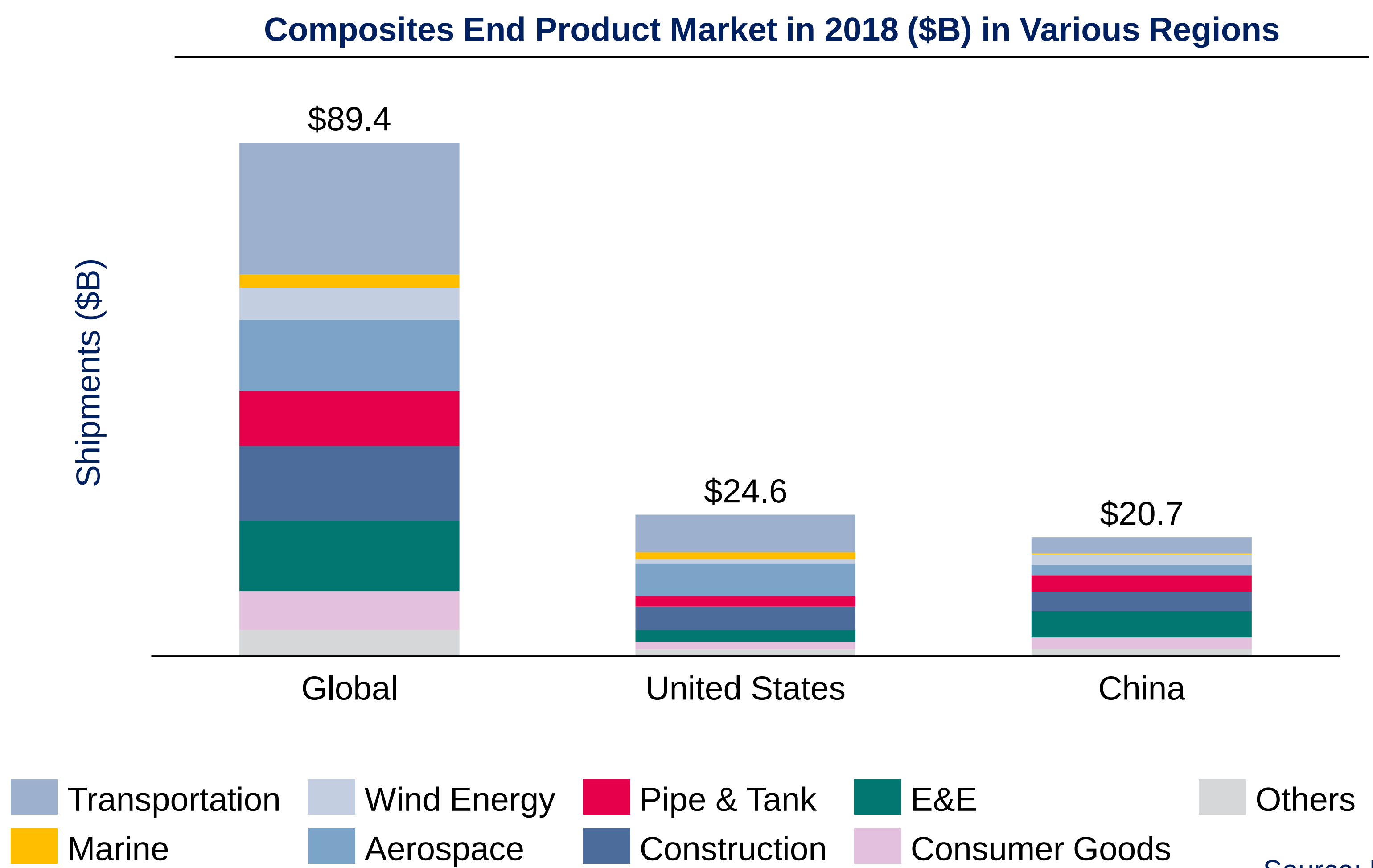
PRESENTED TO

ACMA

PRESENTED BY / DATE

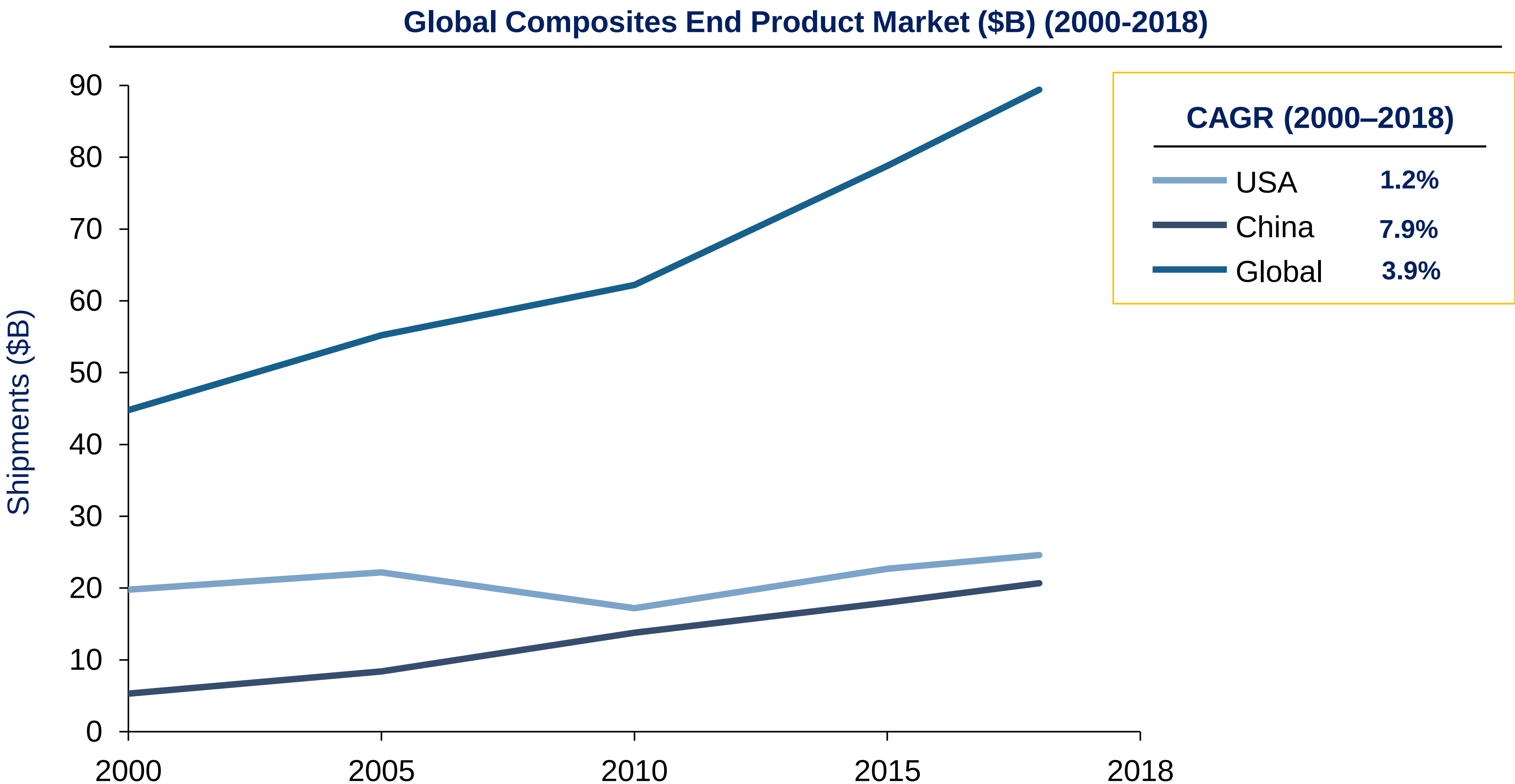
Lucintel / June 6, 2019

In Last 20 Years, China has Grown Rapidly and Became Second Largest Market After the US



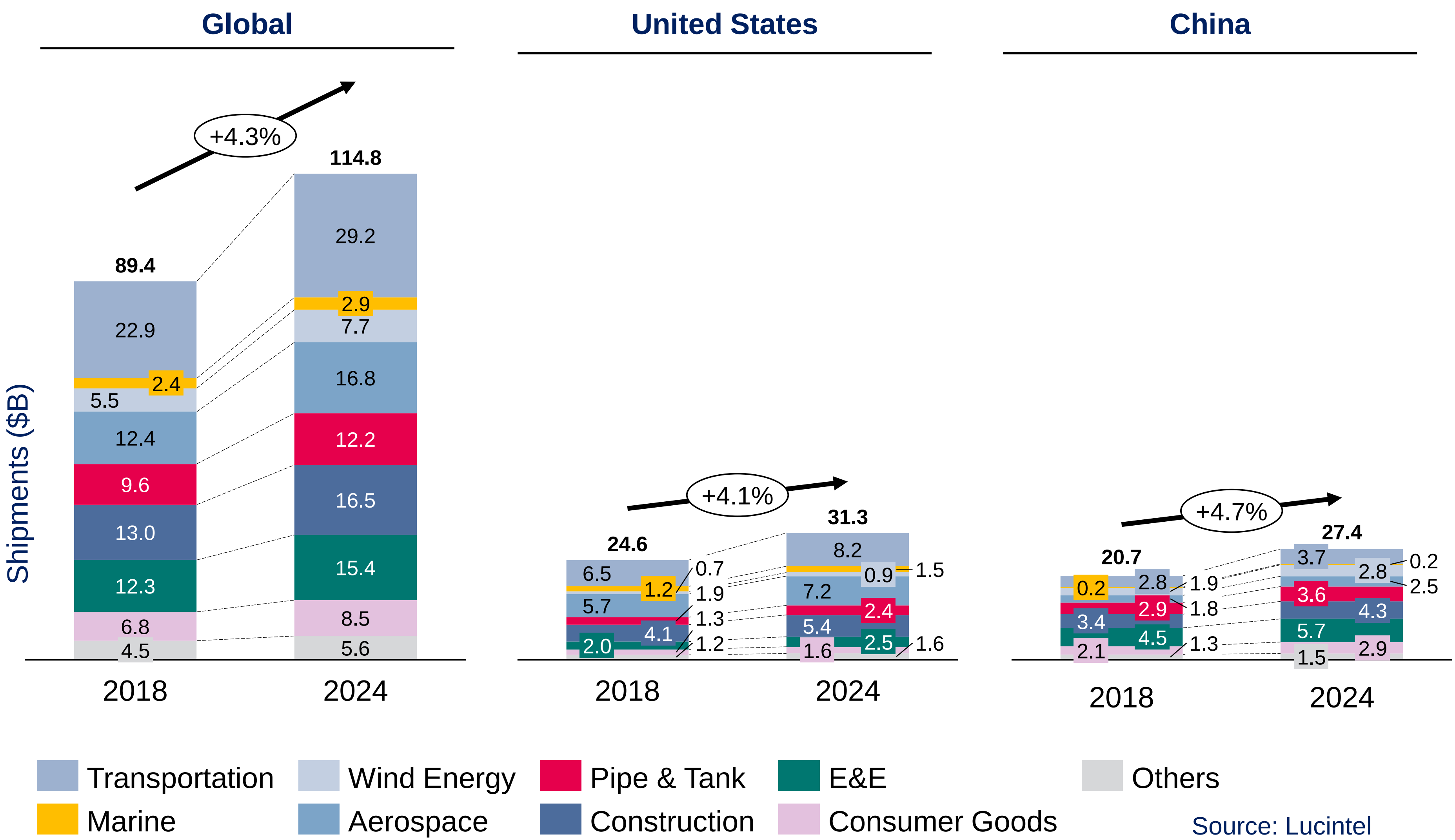
Source: Lucintel

Chinese Composites End Product Market Grew 6.5 times More than the USA During Last 18 years



Source: Lucintel

Transportation is the Largest End Use Market of Composites



Source: Lucintel

Wind Energy, Aerospace, and Consumer Goods Industry are Expected to Register Highest Growth Rate in China during 2018-24

Market Size and CAGR of Composites End Product Market during 2018-2024				
Industries	The USA		China	
	2018 ($B)	CAGR 2018-24	2018 ($B)	CAGR 2018-24
Transportation	6.5	4.0%	2.8	5.0%
Marine	1.2	3.6%	0.2	3.7%
Wind Energy	0.7	5.0%	1.9	7.2%
Aerospace	5.7	3.9%	1.8	6.2%
Pipe & Tank	1.9	4.4%	2.9	4.0%
Construction	4.1	4.5%	3.4	4.1%
E&E	2.0	3.8%	4.5	3.9%
Consumer Goods	1.3	3.2%	2.1	5.5%
Others	1.2	4.5%	1.3	3.3%

CAGR

Less Attractive : 3.0% -4.0%
Moderately Attractive : 4.1% - 5.0%
More Attractive : >5.0%

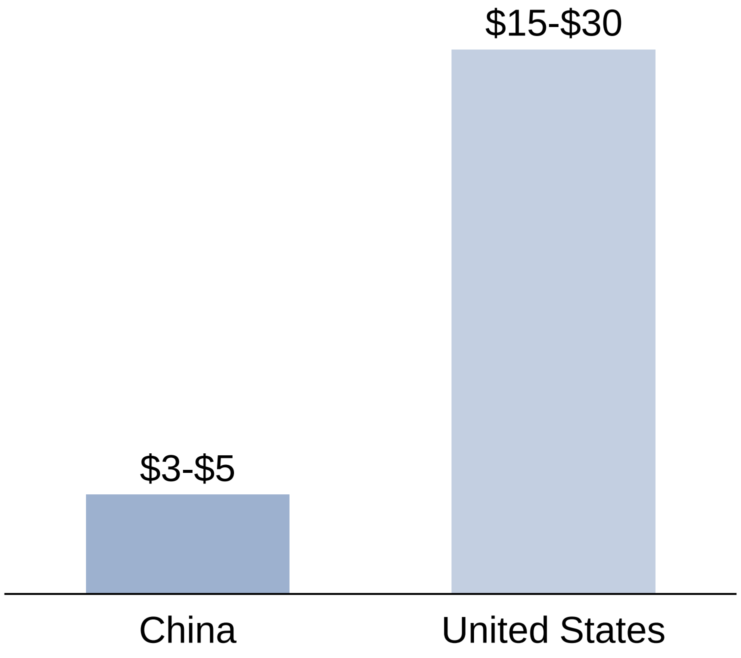
Market Size

Less Attractive : < $2.5 B
Moderately Attractive : $2.6- $5.5 B
More Attractive : >$5.5B

Source: Lucintel

China's Main Competitive Advantage is Low Labor Cost Compared to the US to Win Over New Opportunities

Average Factory Labor Cost in 2018 ($/Hour)

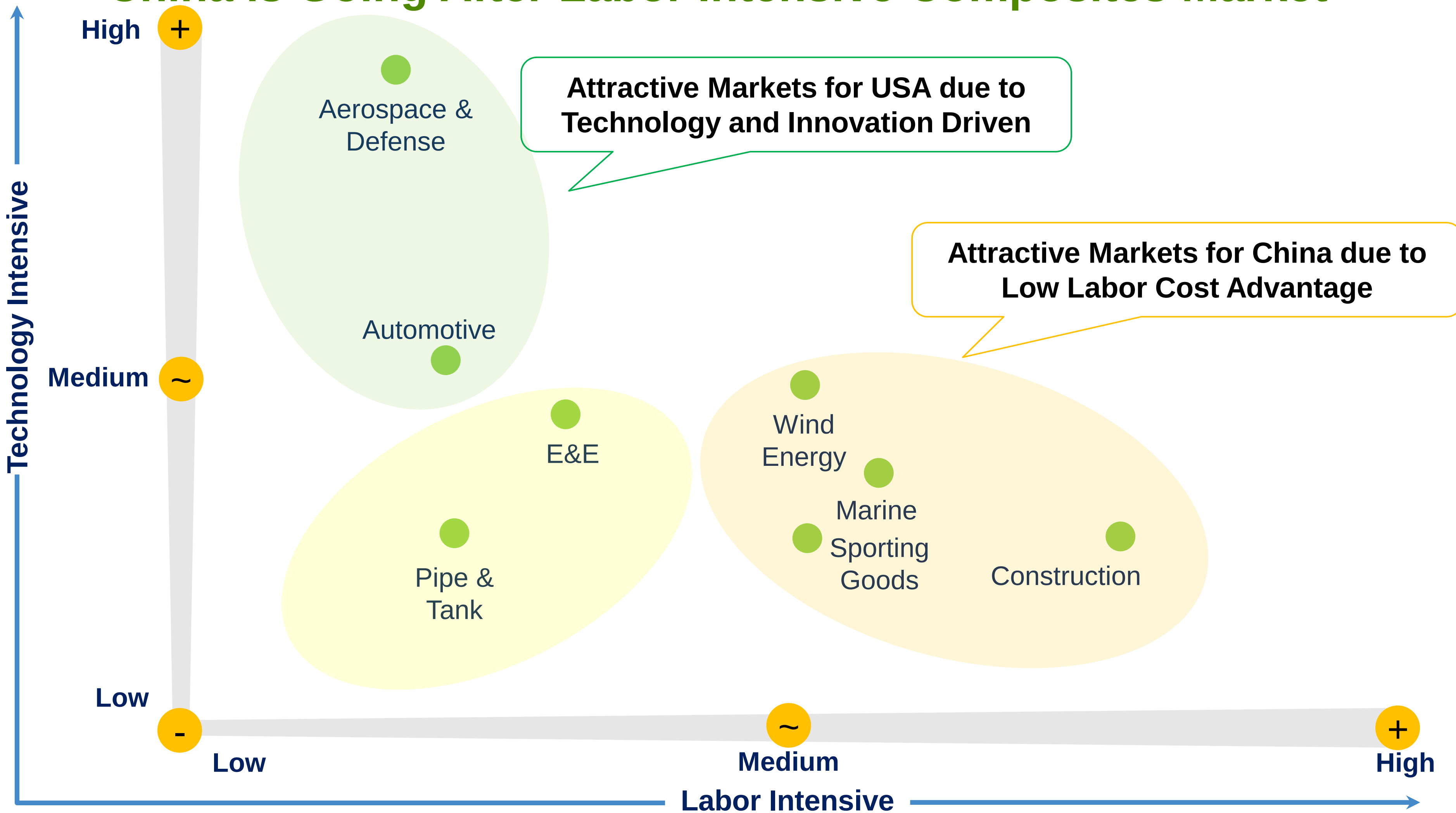


Key Insights

- China has advantage of low labor cost (almost five times lower than the USA) over the USA which is one of the major reasons for companies shifting their production base from USA to China for labor intensive industries such as sporting goods, E&E, construction, etc.

Source: Lucintel

USA has good Position in Aerospace and Automotive whereas China is Going After Labor Intensive Composites Market



Source: Lucintel

OPENING STATEMENT OF ALAN HILL, GOVERNMENT RELATIONS PARTNER, NATIONAL GRAPHENE ASSOCIATION; PRESIDENT, J.A.HILL GROUP, LLC

MR. HILL: Thank you, Vice Chairman Cleveland, Commissioner Lee, and members of the Commission, and thank you for the opportunity to appear before you today to discuss the two-dimensional material graphene and China's efforts to what we see as establish dominance in this space.

So what is graphene and why is it important? Graphene is a two-dimensional single atomic layer of carbon and is the thinnest and strongest material ever discovered.

It's 200 times stronger than steel, conducts electricity 20 times better than copper, it's transparent, allowing 97 percent of light to pass through, flexible, stretching up to 25 percent of its length, and conducts heat better than any other metal.

Graphene has the capability to affect every sector of our economy: energy, defense, health care, communications and technology, manufacturing, transportation. You name an industry, and graphene is likely to play a significant role in revolutionizing it.

For energy, graphene is demonstrating increased output, performance, and longevity for lithium ion batteries and energy storage.

Graphene can reduce the weight and increase strength for composites, construction, and other structural materials. It's being used for filter systems membranes for safe drinking water.

It's also anti-corrosion coatings, conductive inks, sensors, and we do see some enhanced retail products that have made it to market such as sporting goods, apparel, protective gear.

And just this week there was a report surfaced that they've actually tested a small drone out in the U.K. that had graphene-enhanced composite wings, about a three times increase in strength for that material.

So graphene is real, and its commercial impact is beginning to appear.

And as far as the global focus on graphene, I know there was a discussion about patents on the previous panel, but there's been over 50,000 patents that have been filed on graphene with half of those filed in the last three years. The study that analyzed this was 2015 to 2017. It was a three-year period.

So the U.S. holds about 6,000 patents in graphene. China dominates the field with about 32,142 patents, 60 percent of the total patents filed. South Korea comes in second with about 7,000 patents.

Now the U.K. where graphene was discovered has established a National Graphene Institute and just recently opened a Graphene Engineering and Innovation Center, a firm they call the GEIC.

Europe has also allocated 1 billion euros to establish a graphene flagship which I believe is about 21 countries, 145 academic institutions, which is the biggest research initiative designed to take graphene from the lab to European industries.

Now, as far as China, their strategic interest in graphene is well known. Also in the thirteenth five-year plan graphene is specifically mentioned in its strategic emerging industries section of the plan.

In 2018, China formally established the Beijing Graphene Research Institute, which will focus on technological research and industrialization.

Now, we mentioned dual use, and that is an ongoing concern, especially when you look at all the commercial applications it can be easily assumed that you can take those applications and apply them to military use.

And, in fact, in 2017 the European Defense Agency commissioned a study to determine the potential dual-use graphene-based technology such as sensors, biomedical, filters membranes, optoelectronic devices, energy, and camouflage signature management.

There is media coverage that's clear -- that's touting some of China's defense capabilities with graphene such as bulletproof vests, armor. There was an article on its new attack helicopter having armor plating with graphene.

We do want to take those with a grain of salt. But it's clear that at least in experiment if you're looking at low weight, reducing the weight of something, increasing the strength, it's clear that there is graphene experimentation within the defense capabilities.

We know the government is offering monetary support. And a lot of this is anecdotal. There is not a lot of hard source data.

But when we were talking to researchers or other companies, China is offering millions of dollars to locate to another Chinese province, either open up a new facility or start a new facility for graphene applications.

They have -- the one thing the graphene companies and scientists are seeing is that these graphene cities is what China is trying to create. So some of these cities that have been destitute from other industries and are looking to reinvigorate, graphene tends to be the one that they are gravitating to.

So we also know that with China we talked about the materials -- source materials. Since graphite exfoliation, which means basically breaking apart graphite to discover -- to get the graphene is the predominant commercial process to produce it, China maintains a significant domestic graphite resource presence and a competitive advantage in the development of its own graphene and graphene-based technologies.

In 2018, China produced 70 percent of the world's graphite. The U.S. produced none, and between 2014 to 2017, China accounted for 37 percent of U.S. imports of graphite.

So the question is, as China possesses a significant lead in graphene patents, dominates the supply and production of the critical source material for graphene production, and is actively attempting to procure the best foreign minds in graphene science, that should pose a serious concern for U.S. policy makers.

Briefly, on two of the recommendations that I had for the committee -- excuse me, for the Commission -- is one, we really need to develop a -- kind of a grand strategy for commercialization of graphene.

It is a -- there is no -- U.S. has invested substantially in the research, in the fundamental science of graphene and supporting it. But there's no high-level U.S. government policy similar to what you see in the U.K. or the EU or China dedicated to infrastructure that allows for the integration of graphene into already existing technologies or exploring new technologies.

The National Graphene Association has established an industry council. It has established an academic council. So in kind of furthering collaboration efforts and trying to develop a broad commercialization program, we are trying to reach out with industry, academia, and federal policy makers to do these first steps to establish some broad U.S. policy in commercializing graphene.

We had -- there was language in the 2019 National Defense bill asking DOD for a report on the efforts that are going on department wide. We think we need probably broader information from across the federal government as to what's going on in graphene.

We know in DOE, the labs, NASA, all the other agencies have been exploring it but to what extent and to what benefit for commercialization is unknown.

And then we need the basic tenets of U.S. policy. In the CJS appropriations in FY '19 we were able to get the committee to recognize the importance, both economic and national security, of graphene and also encouraged National Institutes of Science and Technology to continue to do graphene research, especially towards commercialization but also to kind of designate industry and academic institutions with expertise and existing capabilities and infrastructure related to the commercial application of graphene.

So now that we have a solid base of graphene knowledge and have established the science of graphene, and it's being explored in detail, the next few years are going to be very pivotal for graphene commercialization.

Failure of the U.S. to develop a comprehensive strategy to lead and support the commercialization and continued development of graphene technologies could create a strong dependency on graphene technologies developed by U.S. competitors as well as the source materials.

This is something that should pose a significant concern but I think with some of the steps the NGA has begun with and what we laid out in the testimony should begin to mitigate some of those concerns. Thank you for the opportunity and look forward to answering your questions.

PREPARED STATEMENT OF ALAN HILL, GOVERNMENT RELATIONS PARTNER, NATIONAL GRAPHENE ASSOCIATION; PRESIDENT, J.A.HILL GROUP, LLC

STATEMENT OF ALAN HILL

PRESIDENT, J.A.HILL GROUP, LLC

GOVERNMENT RELATIONS PARTNER, NATIONAL GRAPHENE ASSOCIATION

BEFORE THE

U.S.-CHINA ECONOMIC AND SECURITY REVIEW COMMISSION

"TECHNOLOGY, TRADE, AND MILITARY-CIVIL FUSION: CHINA'S PURSUIT OF ARTIFICIAL INTELLIGENCE, NEW MATERIALS, AND NEW ENERGY"

JUNE 7, 2019

Vice Chairman Cleveland, Commissioner Lee, and Members of the Commission, thank you for the opportunity to appear before you today to discuss the two-dimensional material, graphene, and China's efforts to establish dominance in this space.

The National Graphene Association (NGA) is the sole trade association in the U.S. advocating for the commercialization of graphene. With twenty corporate partners and over two thousand members, NGA is expediting the commercialization of graphene through an ecosystem that spans industry, academia, national and international standards bodies, and federal policymakers. Most recently, the NGA held a high-level two-day summit here in Washington, D.C., with Senator Roger Wicker (R-MS), Chairman of the Senate Committee on Commerce, Science, and Transportation, supporting the summit and providing the opening keynote on the second day. This was the first conference where industry, academia, and government were all represented and discussed the imperative need for U.S. leadership in graphene commercialization.

Graphene Overview

Though graphene is generating a lot of excitement and attention presently, the existence of this material has been known to the scientific community for over 70 years. However, it was not until 2004, when graphene was first isolated by researchers from the University of Manchester, that its true significance was discovered. So, what is graphene? It is a two-dimensional, single atomic layer of carbon and is the thinnest and strongest material ever discovered. In fact, graphene's properties were considered so revolutionary upon its isolation, that the two research scientists, Konstantin Novoselov and Andre Geim, were awarded the Nobel Prize in Physics six years later. Below are some of the key properties identified:

- 200 times stronger than steel;
- Conducts electricity better than copper;
- Transparent – allowing 97.3% of light to pass through;
- Flexible – stretching up to 25% of its length;
- Conducts heat better than any other metal;

Though graphene's discovery was revolutionary, the process used to isolate graphene was relatively simple in its execution. The researchers used flakes of graphite (the same material used in pencils) and sticky tape to isolate graphene. The sticky tape was placed on the graphite, peeled off and then applied to a separate surface. Tape was reapplied to the remaining graphite, and the process repeated until a single layer of graphene was all that remained. A great visual for understanding this is to think of a deck of playing cards. The full deck represents the graphite and each card represents a single layer. Peel off each card (or layer) until the bottom card representing the single, atomic, layer is all that remains. This process is a form of exfoliation and it produces the most artisanal form of graphene; yet it is also the most uneconomical process for making graphene commercially.

There are two primary forms of graphene – graphene film and graphene powder. Graphene film is suitable for high tech sensors, electronics and photonic and photovoltaic devices while graphene powders are suitable for composites and other applications where graphene powders are used as structural additives. For commercial production, there are two primary methods to make graphene – exfoliation, the process originally used to isolate graphene, and chemical vapor deposition (CVD). These processes are referred to as "top down" and "bottom up" methods. Exfoliation (top down) is the predominant method used to produce graphene. The process starts with bulk graphite, breaking it down until you get nanoplates, which are small pieces of graphene. However, instead of using sticky tape as the Nobel Prize researchers did, the top down process uses electrochemical exfoliation, high pressure milling, or incorporating oxidizing agents to make graphene.

CVD (bottom up) uses a gas (i.e.; methane) that contains carbon. The gas is super-heated to nearly 1,000 degrees and blown over a metal surface, usually copper. This process aids in separating the carbon and hydrogen in the gas allowing the carbon to settle onto the metal. Interestingly, as the carbon settles onto the copper, it begins assembling atom-by-atom to form a layer of graphene. Once the metal is covered, the chemical reaction ceases. CVD is the method used to produce graphene film for use in electronic devices. The difficulty with CVD, in the past at least, has been scaling the process in a manner to make it cost effective for the end-user. However, scalability is becoming less of an obstacle than it once was given technological advances in the manufacturing process.

Potential Graphene Applications

Energy

Graphene-enhanced lithium-ion batteries are shown to have superior performance, increased output, longer lifecycles, and greater operating tolerance at higher temperatures than "plain" lithium-ion batteries. Graphene-based supercapacitors offer energy storage at higher levels and can hold hundreds of times the amount of electrical charge as standard capacitors, providing a suitable replacement for electrochemical batteries in many industrial and commercial applications. Graphene's superior conductivity also makes it a feasible candidate as an alternative to the rare and expensive cadmium telluride typically required for photovoltaic panels.

Water Desalination

Graphene membranes have proven to be quite effective in desalination of seawater, with commercial products on the market showing promise to produce safe drinking water with less energy than the reverse-osmosis technique currently used to treat seawater.

Automotive

Graphene's use in automotive applications gained prominence in 2018 when XG Sciences announced that its collaboration with Ford Motor Company had yielded graphene enhanced polyurethane foam parts. The addition of graphene resulted in improvements in noise reduction, heat endurance, and strength of these parts. Graphene is also showing the potential to reduce the weight and increase the strength of automotive composites and tires.

Communications

Samsung is currently investigating the use of graphene for handset batteries. In addition, Huawei is currently using graphene as part of the cooling system for the newest version of its "Honor" handset line.

Infrastructure

Graphene is showing significant promise in the both concrete and asphalt. Data consistently shows that a small addition of graphene can reduce the weight, increase the strength, and increase the overall life of roads and other critical infrastructure.

Aerospace

Graphene's properties are showing unique applicability for composite parts, fire retardant technologies for aircraft interiors, and conductive coatings to provide better protection against lightning strikes. Furthermore, graphene is showing promise in space applications such as using a solar sail as a propulsion system.

Coatings

Graphene can improve the anti-corrosion properties of coatings by a factor of five. Of its many properties discussed previously, graphene is also impermeable, lending a significant benefit to coatings used in harsh environments. This is particularly important for the maritime industry. Moreover, conductive ink has been developed using graphene that allows for the creation of electronic circuits on a variety of surfaces.

Sensors

Graphene-based sensors can be used to detect gas and other biological agents as well as explosives. Its heat and conductive properties can be used in coatings to detect changes in temperature and wirelessly submit those changes to a handheld receiver. Biomedically, graphene can be used to detect changes in the human body.

Apparel and Sporting Goods

Many retail graphene enhanced products have surfaced over the past 18 months. Callaway Golf balls, Head tennis rackets, Inov8 running shoes, Anker wireless earbuds are but a few. Great Britain even used a graphene-enhanced sled for the Skeleton event in the 2018 Winter Olympics.

This is not an exhaustive list of potential applications, but only a sampling of what is currently being investigated and commercially developed. Given graphene's unique properties, its ability to impact nearly every sector of the economy cannot be understated.

Global Focus on Graphene

The realization and proof of existence of the first truly two-dimensional material launched one of the fastest paced research topics in history. The resulting massive global investment in graphene research has established an extensive base of knowledge and a large intellectual property and patent pool for this material and its myriad applications. In fact, since its discovery in 2004 and subsequent Nobel Prize award in 2010, graphene has advanced from initial discovery to commercial development at a tremendous rate.

This rate of progress in the graphene industry is nothing short of astonishing. In December of 2018, a team of researchers published an extensive analysis of patents filed in the field of graphene providing evidence of how quickly this field is advancing and which country is leading. The research team determined that over 50,000 patents have been filed in the graphene field, with over half of those patents filed in the last three years (2015-2017).[1] While the U.S. holds just over 6,000 patents in graphene, it is China that dominates the field with 32,142 patents - over 60% of total patents filed. South Korea is second with just over 7,000 patents. It is worth noting, however, that the U.S. and South Korea are believed to hold more "high-value" patents with leading companies such as IBM, Lockheed Martin, and Samsung holding a number of these patents.[2] The researchers also point to a number of other key factors in the patent analysis. First, the U.S. and Japanese patents are mainly held by companies while China and Korea patents are tied more to "universities or research institutes". Second, when looking at the various stages of a technology (emerging, growth, maturity, saturation), the analysis points to China with a distinct advantage among the top 20 patentees in the growth stage of graphene.[3]

Though the U.S. has invested substantially in understanding the fundamental science of graphene and supporting academic research - many government agencies (National Science Foundation, Department of Energy, Department of Defense, National Institute of Standards and Technology, and many others) have developed an extensive base of scientific knowledge - the path from the laboratory to developing viable commercial products is not as well coordinated nor developed in the U.S. with some criticism pointing to siloed efforts in research and development and a lack of

[1] Yang, X., Yu, X., Liu, X., (2018) Obtaining a Sustainable Competitive Advantage from Patent Information: A Patent Analysis of the Graphene Industry. Sustainability 2018, 10, 4800.
[2] Ibid.
[3] Ibid.pp 16-17.

general information on what the U.S. is really doing commercially.[4] Furthermore, there is no high level U.S. government policy on the strategic and economic importance of building and supporting a stable U.S. graphene industry.

In contrast, the U.K. and Europe have undertaken significant steps to transition graphene from the lab to commercialization. In 2013, the United Kingdom and European Union's European Regional Development Fund provided £61 Million to create a National Graphene Institute (NGI). That same year, the European Commission allocated €1 billion to develop the Graphene Flagship, the E.U.'s biggest research initiative designed to take graphene from the lab into European industries and generate economic growth through commercialization of graphene. Furthermore, the United Kingdom recently dedicated another facility called the Graphene Engineering and Innovation Center (GEIC) to "rapidly accelerate the development and commercialisation of new graphene technologies."

China's Focus on Graphene

China's interest in graphene is well known. In 2015, President Xi Jinping visited the National Graphene Institute as part of his state visit to the U.K. while Huawei had previously entered into a partnership with the NGI to conduct additional graphene research.[5] Graphene is also specifically mentioned in China's 13th Five-Year plan (2016-2020) as part of its goal to develop strategic emerging industries. Finally, in 2018, China formally established the Beijing Graphene Research Institute which will focus on "technological research and industrialization".[6]

China's progress in graphene is equally as astonishing as the development of the graphene industry itself. As previously mentioned, China holds just over 60% of all patents filed in the graphene field. The number of Chinese companies focused on graphene is estimated to be in the thousands. Furthermore, a large body of published graphene research continues to grow year over year with Chinese researchers dominating the amount of global publications in the graphene space – garnering 44% of world-wide publications between 2012 – 2015.[7]

An ongoing concern in examining China's pursuit of advanced materials like graphene is the issue of dual-use – that a technology or application will have military as well as civilian uses. For graphene, the immediate identification of specific dual-use technologies is not as easily recognized. Nearly every potential commercial application that has been identified for graphene's use can be easily translated to potential military applications as well. Anti-corrosion coatings could be used on naval vessels. Composite armor could be made lighter and stronger with the addition of graphene. Graphene based inks that allow for electronic circuits could be

[4] It wasn't until Ford announced in 2018 that it had collaborated with XG Sciences on graphene enhanced polyurethane foam parts that graphene's commercial viability became "real".
[5] https://www.manchester.ac.uk/discover/news/chinas-president-xi-jinping-visits-the-national-graphene-institute/
[6] http://www.chinadaily.com.cn/m/beijing/zhongguancun/2018-10/30/content_37173414.htm
[7] Shapira, P., Gök, A., Yazdi, F. (2015) Graphene Research and Enterprise: Mapping Innovation and Business Growth in a Strategic Emerging Technology

imbedded in battlefield clothing as antenna for communications or flexible sensors that could detect the presence of biological or chemical agents.

The difficulty in easily identifying graphene technologies in terms of dual-use is not unique. Commercial technologies are advancing at such a rapid pace and scale that the line between civilian and military use is no longer easily identified. There is a reason why the Defense Department created its Defense Innovation Unit to work with commercial industries in identifying new technologies for military purposes. Europe has shown concern regarding dual-uses of graphene and in 2017, the European Defence Agency commissioned a study to determine potential dual-use graphene-based technologies. The areas identified for study are the same areas where graphene has significant commercial possibilities such as "sensors, biomedical, filters/membranes, optoelectronic devices, energy, and camouflage/signature management." The first working group meeting for EDA's study was held in May 2018.[8]

It is clear, at least in media coverage, that China is touting graphene's use for defense purposes. In 2016, it was reported that China was testing graphene for armor and bullet proof vests. Just last year, reports surfaced with graphene touted as a significant part of the armor for China's new attack helicopter.[9] While it is possible the reports may exaggerate what role graphene is playing in a particular weapons platform, the likelihood is that it is being used for weight reduction and/or an increase in strength of the armor material. But it does beg the question of strategic priorities – is the U.S. focused more on retail applications of graphene while China is focused on defense applications?

As far as distinct commercial products, one product, in particular, stands out in the area of coatings. The Sixth Element (Changzhou) Materials Technology Co used its graphene-zinc anti-corrosion paint "to cover several bridges and wind-turbines steel towers." The significance is described in the use of graphene – "adding 1% of graphene, one could reduce the zinc content in current anti-corrosion coatings from ~80% to 25%, and the corrosion protection time is doubled."[10] The Sixth Element is also the same company supplying the graphene for Huawei's handset technologies.

Chinese companies are also actively engaging in commercial collaborations with institutions like the National Graphene Institute or with foreign graphene companies directly. For instance, U.K. based graphene company, Versarien, has entered into two separate collaboration agreements with unnamed Chinese aerospace companies. The Chinese government is also offering monetary support to encourage municipalities and provinces to create graphene cities or industrial parks and identify foreign companies or researchers to relocate or create a graphene-based startup in these areas. Chinese companies, individual investors, and financial holding companies are

[8] https://www.eda.europa.eu/info-hub/press-centre/latest-news/2018/05/29/work-starts-on-graphene-roadmap-in-defence

[9] http://www.defense-aerospace.com/articles-view/release/3/196658/china-adds-graphene-armor-to-z_10-attack-helicopter.html

[10] https://www.graphene-info.com/graphene-enhanced-anti-corrosion-system-deployed-bridges-and-wind-power-towers-across-china

actively pursuing U.S. and other foreign graphene companies and scientists offering millions of dollars and state of the art facilities to relocate or establish graphene manufacturing facilities in China. One significant result of these directed efforts by China is a reduction in the talent pool available in the U.S.

Dr. James Tour of Rice University, one of the top experts in graphene, has testified before Congress and has recently spoken at NGA's American Graphene Summit, about the real threat of losing the next generation of great scientific minds to China and other countries that are able to provide funding and resources to support continued work in this field. He spoke of a "brain drain" in the U.S. – some of best and brightest research minds choosing to go back to their home country. And he contributes this exodus to the limited amount of funding for the younger researchers. For example, Dr. Tour stated that he used to have 1 out of every 3 proposals funded. Today, the figure is about 1 in 10. If a senior research scientist is facing such reductions, the younger researchers are facing as much as 1 in 20 proposals that may receive funding. The last comment Dr. Tour made is he expects that in less than 10 years, U.S. students will choose to go to China for graduate school.

Dr. Tour's remarks are indicative of the potential problem the U.S. would have in gaining a leadership role in the commercialization of graphene. If the best and brightest research minds are, indeed, leaving the U.S. for other countries – that knowledge translates directly into commercialization efforts. I have had some personal conversations with young researchers, two of whom are studying here in Northern Virginia and are doing some interesting work in the sensors space. They're U.S. students and are eager to move their research to commercial application here in the U.S. The ultimate question from Dr. Tour's perspective is – will there be any funding for them?

Lastly, China maintains significant domestic graphite resources providing a competitive advantage in the development of its own graphene and graphene-based applications. According to the U.S. Geological Survey, in 2018, China produced 70% of the world's graphite and between 2014 and 2017, China accounted for 37% of U.S. graphite imports. In contrast, the U.S. produced no graphite and North America (Canada and Mexico) only accounted for 5% of the world's graphite production in 2018.[11] In examining China's rapid growth in graphene patents, its large domestic graphite supply clearly provides Chinese companies and researcher institutes greater opportunities for new advances and developments – especially as exfoliation from graphite remains the most common form of producing graphene. As the U.S. graphene market continues to develop, the requirements for graphene powder will naturally increase resulting in continued commercial dependency on imports of graphite from foreign sources. It is not difficult to imagine that the percentage of graphite imported from China would increase.

A China that possesses a significant lead in graphene patents, dominates the supply and production of the critical source material necessary to produce graphene, and actively attempts to

[11] https://www.usgs.gov/centers/nmic/graphite-statistics-and-information

procure the best foreign minds in graphene science, should pose a serious concern to U.S. policymakers.

The real obstacle to the advancement of graphene in the United States is a lack of coordinated focus from the U.S. government and a dedicated infrastructure that allows for the integration of graphene into already existing technologies and industries. There are many companies in the United States (and worldwide) that can manufacture graphene raw material by the ton annually. Price and scale of production are no longer impeding factors for the use and advancement of graphene. However, there is a dire need for technology transfer assets to support market entry for both small businesses and corporations.

Recommendations:

The U.S. government must adopt a grand strategy for graphene commercialization - a large-scale integrative and collaborative effort amongst industry, academia, and government to support and accelerate commercialization of graphene in the U.S. This will require the development of, and sufficient funding for, a commercialization program similar to what the U.K. and EU have undertaken. It is an effort that will require conjoined work and parallel efforts to develop international standards, best practices, assessment of environmental and safety studies, development of a national commercialization roadmap, and dedicated outreach efforts with large U.S. end-user industries to foster acceptance and industrial use of graphene.

A critical component of this strategy will be support for emerging companies focused on graphene production. Most U.S. graphene companies are startups, or very small businesses, with insufficient resources compared to their international competitors who are subsidized by their respective governments. A comprehensive incubator program would provide critical resources such as a physical base of operations or access to technical expertise and testing equipment and funding. Critical information could be shared amongst these small companies with research institutions, end-user industries, and government agencies to further commercial advances.

Fortunately, the U.S. can rely on its allies' experiences to inform how to construct a large-scale well-funded commercialization program. To assist the U.S. in moving forward with this type of large-scale program, NGA is actively working with industry, academia, and policymakers to implement the first steps necessary to get this type of program on a proper footing. Specifically, the U.S. should:

1) Develop increased situational awareness of the graphene efforts that are already ongoing at the federal level and what potential applications (or problems to be solved) may require graphene and graphene-based technologies. A common refrain from graphene companies is that they can produce the material in various forms, but they are unaware of what the end-user, especially at the federal level, is looking for in terms of applications. Senator Roger Wicker (R-MS) took the first step in this area by requiring the Department of Defense, in the 2019 National Defense Authorization Act (NDAA), to report on department wide efforts in the graphene field. The report is expected in the near term, but a comprehensive look at all federal work in this field is still needed.

2) Formally establish U.S. policy focused on the economic and national security importance of graphene commercialization. Similar to the FY19 NDAA, Senator Wicker also took a first step in this area and included report language in the FYI9 CJS Appropriations bill that recognized "the emergence of graphene as an innovative material with significant commercial and national security potential." In addition, the language encouraged the National Institute of Standards and Technology (NIST) to continue to fund and pursue graphene research activities and designate industry and academic institutions with expertise, existing capabilities, and infrastructure related to the commercial application of graphene.

In May, the National Graphene Association took the initiative to establish a Graphene Academic Council to assist in beginning these collaborative efforts. This follows on NGA's creation of a Graphene Industry Council in 2018 and a Standards Committee to collaborate on efforts to ensure international standards, which play a crucial role in ensuring that the development of new technologies and the improvement of existing technologies, are consistent in terminology and definitions.

Conclusion

Now that a solid base of graphene knowledge has been established and the science of graphene has been explored in detail, the next few years will be pivotal for commercialization as the material is prime for utilization by many large-scale industries. Graphene-based companies and other supporting organizations will be in the most need of federal support and funding. Failure of the U.S. to develop a comprehensive strategy to lead and support the commercialization and continued development of graphene technologies will create a strong dependency on graphene technologies and source materials developed by U.S. competitors. This should pose a significant concern for U.S. economic and national security in future years – a concern that can be addressed by taking the actions mentioned above in short order.

PANEL II QUESTION AND ANSWER

COMMISSIONER LEE: Thank you so much, Mr. Hill and the panelists, for your excellent presentations and for your testimony.

This seems like an area which is a little bit daunting in terms of the technological detail. But it also these -- kind of intriguing.

We have these magical and mysterious materials with a dizzying array of potential uses but also, clearly, a lot of policy concerns around supply, both supply of raw materials and supply disruptions, as some of you said, and also the fact that all these materials are, obviously, key inputs into other pretty important areas. And so we have both trade and technology issues that seem of interest.

I am going to turn first to Vice Chair Cleveland for her question.

VICE CHAIRMAN CLEVELAND: Thank you. I have questions, actually, for each of you.

You mentioned in your testimony, Dr. Silberglitt, critical materials and that the U.S. is dependent on China for more than 50 percent of imports and that you viewed the low cost of production as the principal driver in driving out competitors.

Are there other issues besides just cost or environmental and health, and are there other factors that have contributed to how China has dominated this market, and what would you suggest in terms of solutions besides the WTO, which takes some time?

MR. SILBERGLITT: Indeed. Thank you, Vice Chairman Cleveland, for the question.

Yes, the main way in which China has controlled markets of many of these critical materials is not just by producing more than 50 percent of the world's production of these materials but also by controlling the processing.

So, for example, with rare earths you produce the ore from the ground, but then you need to go through many steps of processing to separate those materials from each other and then finally to process them into forms that manufacturers can actually use.

All of this processing goes on in China, even though China produces maybe 70 or 80 percent of the rare earths, but they process 100 percent.

So one of the really important things to do is to diversify not only the production but the processing of these critical materials.

For example, Australia, you know, has very good production capability for rare earths, and we should be working with Australia to develop more processing capability.

VICE CHAIRMAN CLEVELAND: So Australian-mined rare earths are processed in China? Is that what I am hearing?

MR. SILBERGLITT: Yes.

VICE CHAIRMAN CLEVELAND: And that's because?

MR. SILBERGLITT: Because China has developed the processing capability over the years in the same way they developed the production capability. In fact, we did a case study of tungsten in our 2013 report, and we found that while China produced something like 70 or 75 percent of world's tungsten, the rest of the world sent all the tungsten they were producing to China.

So China, basically, produced 100 percent of it, and the commodity that is shipped around the world is called ammonium paratungstate, and that is the -- this APT is the material that manufacturers buy and use.

And China had cornered the market on this APT. Thus, they could set the tungsten price.

VICE CHAIRMAN CLEVELAND: Would you say that they uphold reasonable environmental standards when they are processing?

MR. SILBERGLITT: No, they don't.

VICE CHAIRMAN CLEVELAND: Okay.

Mr. Coughlin, you mentioned that there is an industrial policy that the Chinese have engaged in where there is an overseas investment strategy, Krauss, Kuka, a number of companies that have been the target of investment.

Who is next? What are they looking at in terms of possibilities for investment?

MR. COUGHLIN: I don't know what their next move will be. I do know they are looking to bolster their domestic aerospace industry with these acquisitions.

They have access to the manufacturing technologies. They have access to the supply chain. They have a huge internal market for commercial aviation as well as the emerging aviation market.

So they really have most if not all of the ingredients they need. Avionics may be an area where they are behind. So there are some items they are probably going to have to source from overseas.

But I have not -- I am not aware of the next acquisition, if you will.

VICE CHAIRMAN CLEVELAND: But you've identified the area of the sector which is what I was interested in.

And finally, Mr. Hill, the U.K. developed graphene. Is that right? A U.K. lab developed graphene?

MR. HILL: Right. It was discovered by two researchers at the University of Manchester.

VICE CHAIRMAN CLEVELAND: It certainly sounds like a wonder material. I am curious in terms of sort of looking at the critical materials problem where China has dominated the processing, are there partnerships, are there countries that we should be collaborating with now to sort of preempt the space that the Chinese have ended up in when it comes to processing of rare earths and critical materials?

MR. HILL: There is definitely some ongoing collaboration, especially with the U.K. and Europe, clearly, as they have been leading in graphene commercialization.

VICE CHAIRMAN CLEVELAND: I am talking about with the U.S.

MR. HILL: But with the U.S. -- with the U.S. it's been difficult. The NGA has been -- was essentially a startup association back in 2016, and so we have been gathering as much detail as we can about what the U.S. is doing.

So we do know U.S. companies are actively collaborating with U.K. and Europe. We do have companies that have been approached to collaborate with China as well.

The issue stems from is that we just don't have a coordinated effort here in the U.S. to establish our kind of domestic collaboration where industry, academia, and government are really getting together as they are in the U.K. and the EU with their centers.

We do know, whether it's Los Alamos or whether it's DARPA or whether it's universities like Rice or MIT or anybody else, everybody is working on the research side of graphene, and the running joke amongst a lot of the folks in the community is graphene can do everything except get out of the lab.

And I think that's one of the things in terms of collaboration is we need to collaborate domestically to figure out what the technologies and applications are that we are thinking about.

There's a lot of people that can develop graphene in the United States. The problem is -- is they don't know where the applications are or the problems to be solved.

And so that was one of the reasons we are looking for kind of a broader commercialization program that if we set up something what the U.K. and the EU are doing that gives a better ability, one, to know what our capabilities are and what we are developing domestically, and also really to take the leadership role in things like standardization and other things throughout the world because it really is being led by the U.K., Europe, and China in terms of what they will be able to produce and commercialize.

VICE CHAIRMAN CLEVELAND: Well, I don't know that it's cocktail party conversation, but 20 things you can do with graphene was one of the documents that the staff provided, and I never thought I'd be reading Physics World. But it's certainly a promising field.

Thank you.

COMMISSIONER LEE: Thank you very much.

Commissioner Wessel?

COMMISSIONER WESSEL: Thank you, all. An exciting field. I fear in part, though, that we've been shooting ourselves in the foot.

Dr. Silberglitt, you talked about -- not that you've been shooting us in the foot, don't worry -- policymakers.

Magnequench, which was the firm that transferred or transformed rare earth basic ore into useable product, was a U.S. company.

It was sold to the Chinese in 1996 under a CFIUS approval with a requirement under, I believe it was an NSS agreement, that they retain all of the productive equipment in Valparaiso, Indiana.

Several years later, as you may recall, in 2002 I believe it was, China took the productive equipment and moved it to China, therefore robbing us of any domestic capability to transform it.

Mr. Coughlin, you may recall that in composite materials, I believe it was Boeing that engaged in a joint venture in China that helped China dramatically accelerate its development of composite materials.

Again, we've been shooting ourselves in the foot, doing a great job at developing the R&D but not having the wherewithal or the policies to be able to transfer those critical materials for the future.

So, a couple of questions, I think policymakers and industry have woken up that there's a challenge here, both economic and national security and we need to find the policies to respond to that.

So, a couple of questions, one, do you believe our export control provisions address this critical sector?

As you know, under the CFIUS rewrite from last year, FIRRMA, Commerce in coordination with other agencies is supposed to come up with a critical materials list. It has not yet fully done that.

Are the products that you are concerned about contained in current definitions or current governmental plans?

Or would it be helpful to make sure that these new materials, which are so critical, graphene all the way through, are in fact dealt with under export controls? Number one.

Number two, you talk about we do great R&D, which we do, our R&D tax credit stops at the point when the technology has been developed but does not go forward in terms of product testing commercialization.

A critical problem has been for U.S. manufacturers that want to prototype. So, you're going to do 500, 1000 prototypes to be able to get it right.

Very few U.S. companies, whether it's foundries or anyone else, in fact, basic foundries all the way through semiconductors, are willing to take low-lot prototyping. The Chinese are willing to do it.

Should we expand the R&D credit to the RD&D, research development and deployment, to be able to help U.S. firms commercialize here without running afoul of WTO subsidy rules to make sure that we can take things from the lab bench to the shop floor?

And finally, what can we do to help, beyond export controls, convince many of our greater manufacturers that America's the place to do this, that investing in China will potentially be adverse to our long-term interests? And I appreciate the answers from all three panelists. Dr. Silberglitt, do you want to start? Sorry.

MR. SILBERGLITT: I guess I'm in the right place here, or the wrong place. So, let me address the export controls first.

The presence on the export control list of various technologies are static and they should be dynamic. So that's the first problem we have.

I don't make up the export control list, so whoever makes up the export control list ought to be thinking about current and future applications and not classifying something when it starts and then assuming it's classified forever there.

And that goes both ways because some things are on the export control list that were put there years ago and it's stifling innovation. And other things are on the export control list and they haven't been dynamic enough.

Should I continue, or are we past seven minutes?

COMMISSIONER LEE: It's okay but maybe make it quick so we can get to all three of you.

MR. SILBERGLITT: Okay, I'll quit there because that's where my expertise is. I'll go to the manufacturers for the other.

MR. COUGHLIN: I agree with your comment, Dr. Silberglitt, that we should have the export controls be more dynamic and less static.

COMMISSIONER WESSEL: Are you or your organizations participating in any of the ITACs or any of the other groups in the administration to help advise?

MR. COUGHLIN: I'm not aware of that. We do get involved from time to time in working across, for instance, from the U.S. to Europe. And sometimes, there are export controls on things which might be historically not really in the realm that should be managed, and vice versa.

One thing we've seen in terms of manufacturing technology that I talked about is we have good systems in place but China goes and acquires those technologies in Germany, which in a way is not helpful to us because that strengthens both China and Germany and weakens our manufacturing technology sector.

With regards to extending the R&D tax credit to deployment, I think that would be a great idea, especially if you could get the deployment piece as part of an integral translational research public-private partnership with agencies such as NASA, Department of Energy, Department of Defense.

Extending that tax credit and combining it with some seed money from federal funds would really greatly enhance commercialization of technologies.

MR. HILL: So, on the export control, with graphene the export control is not relevant at the time. There is no specific technology that would exist only if graphene was a part of it.

Right now, graphene is essentially making things better. So, for concrete you can increase the strength by 50 percent and you can increase the resistance to water by four times.

So, you can increase the longevity of asphalt 250 percent. So, it's a structural additive, it's an additive for electronics as well but we could see a future, whether it's a specific graphene-based technology that's developed that may have to fall under that.

Specific to the R&D tax credit, similar to the composites folks, graphene folks are extremely small, maybe 1 million, 2 million. The biggest issue is the tech transfer.

We do research very well, it's that tech transfer where we're falling down. And being able to really collaborate commercially to take things out of the universities, out of the military research labs, out of the national labs and really put forward something we can use commercially.

So, I think extending that would be a good idea.

COMMISSIONER LEE: Thank you. Commissioner Goodwin?

COMMISSIONER GOODWIN: Thank you, Commissioner, and thank you all for your time this morning. Mr. Coughlin, I wanted to ask you about regulation.

You indicated in your written testimony that there are some regulatory drags that might stymie innovation here. Yet it occurs to me that some sensible regulations on autonomous vehicles and drones are something that most Americans would welcome and appreciate.

But at the same time, obviously, in countries and jurisdictions where social regulations are more lax, they might have an acute advantage in developing entire cities where roadways are restricted to autonomous vehicles and so forth.

How do we thread that needle?

MR. COUGHLIN: Senator Goodwin, I do not claim to be an expert in this area. I think we can submit some supplemental testimony regarding things that we can do to accelerate the regulatory environment.

We do have members like Spirit AeroSystems who are heavily involved and interested in this market.

We are pulling together a group of UAM companies later this summer and next year to promote the education of composite materials and application in those systems.

So, really, we're just at the beginning stage of developing our network in that area.

But certainly, we do know that the regulatory environment here in the U.S. is robust, it does take more time, and of course, countries like China can step in and say this city is going to do this by caveat, by fiat. So, we are at a bit of a disadvantage in that area.

COMMISSIONER GOODWIN: Any suggestion on how we navigate that challenge?

Like I said, I think it's unlikely and as you would admit it's unlikely we're going to get rid of a lot of those safety regulations that are in place for the health, safety, and welfare of American citizens.

But at the same time, they pose real challenges for our competitiveness and research and development in these critical fields. So, what do we do?

MR. COUGHLIN: Bring industry, government, state and federal and local governments together. I don't think there's any problem we can't solve if we work together and if we set a goal of doing it quickly.

It doesn't have to take forever and this is an important market. This market has the potential to really drive the entire aerospace field, which aerospace is our number-one export.

It's one that we really should protect very, very carefully. So, it's vitally important that we accelerate the regulatory process, not deteriorate it, but accelerate the regulatory process.

And I think that's through, again, collaboration between industry and government.

COMMISSIONER GOODWIN: Thank you. Just to follow up, and I'll open it up to the panel for the conversation about export controls, in our first panel this morning there was some discussion about comparable controls, not on exports directly but on international research collaboration.

And Helen Toner actually cited a framework, a three-prong framework that another scholar had provided for where to apply controls on technology.

The concern being, of course, overreach and being unduly reactive and restrictive in an attempt to bolster American competitiveness.

But it establishes a three-prong framework that might make sense for identifying instances in which we should impose export controls or restrictions on collaborative research.

It includes whether it's essential to military technology, whether there's a scarcity of knowledge about the technology, except for a small group of experts in the United States and that the U.S. is truly ahead of the curve.

She then posited that the vast majority of AI research, which was the topic of our first panel, simply wouldn't meet this criteria.

My question is are there any in the fields that we're discussing in this panel that do, where certain restrictions like that would make sense.

MR. HILL: I can start from the graphene perspective. One of the interesting things is graphene is unique in this kind of space.

Everybody has access to the science, the science is what it is, the equipment to make graphene, whether you're exfoliating or you're doing chemical vapor deposition, whatever you're creating, pretty much everybody knows how to do it.

The question then becomes what are the applications and how is graphene used? So, there's a lot of collaborations ongoing worldwide.

I haven't had any conversations with any researchers or companies involved in this that see a risk at this point in terms of international research collaboration.

Given the patent landscape, I think one concern I did hear from a couple is that within the patents, there is generally enough information that, especially in concern to China, you could reverse-engineer what was patented. But as far as the points you're getting at, I don't see that ahead just yet with graphene. But the U.S. is not ahead of the curve in terms of commercializing that, and that's a fact right now.

COMMISSIONER GOODWIN: Anything to add?

MR. SILBERGLITT: Yes, I would add just one small point and that is my colleague used the word application and I think that's the key. Technologies on their own are nothing, it's how the technology is applied and used.

So, rather than trying to control research, I think one has to look at what the technology application is and it's those applications that have national security problems that ought to be the things we control.

COMMISSIONER GOODWIN: Thank you.

COMMISSIONER LEE: Thank you very much. Commissioner Borgeas?

COMMISSIONER BORGEAS: Thank you, please forgive me, not having a science or engineering background, I'm going to probably ask some fairly basic questions.

Anyone can step up. But in terms of graphene and its related graphite products, are these recyclable? Do they have any recycling capability?

MR. HILL: That's a good question. I think it depends. I don't know all the specifics about composites and what happens with composites recycling but graphene is usually an additive to this.

Most of the products that we're looking at are enhancing existing products on the market.

So, if there is a recyclability part of it -- graphene is carbon so it's not like there's not an environmental concern in terms of graphene. It's carbon-based.

As far as the involvement in electronics, same thing, there's a lot of other metals and other things that go into electronics that graphene could be a part of.

COMMISSIONER BORGEAS: So, if you were to have that in cement, for example, you could recycle the cement and graphene as the byproduct additive would exist in its secondary form as it did in its primary?

MR. HILL: That's a good question on secondary form. What I understand from those who are involved in the environmental side, graphene is carbon. It's only added to the material.

So, the material's recyclable, whatever happens to material, graphene, it goes back to carbon. Somebody can answer more directly than I can in terms of science. I'm not a scientist as well.

COMMISSIONER BORGEAS: I went to law school. I'll jump ahead.

Regarding the circumstance we find ourselves in between the U.S. and China in terms of trade, I've read some material that talked about whether that would be the nuclear leverage, the raw materials and the valued materials that China has large domain over.

Do you have any thoughts on whether or not that is part of this tariff war, that we could see some of these rare materials and rare metals being brought into the fold?

Or is the trade ecosystem in such a state that the technology that we transfer to China would be a counterbalance to that? Based on the response, is that a nuclear option?

Let me rephrase, is that considered below the belt too much?

MR. SILBERGLITT: I'm not sure I understand what you mean by a nuclear option. Could you explain --

COMMISSIONER BORGEAS: There's always gradations in terms of trade wars. Is this down at a level that we don't foresee?

MR. SILBERGLITT: Trade is not really my area of expertise so I would defer to my colleagues who are involved in industry on that one.

MR. HILL: I think the only point, what I mentioned earlier in my testimony is similar to what we're dealing with with rare earth materials and what China's doing. And it's kind of a retaliation with the back and forth. We do posit that given the reliance on graphite exfoliation for the predominance of producing graphene -- China maintains 70 percent of the market; we import 35 percent -- the U.S. gets to a point of expanding its use of graphite, not only for graphene but clearly I would say for energy use, batteries, et cetera.

That could be a sufficient concern in terms of access to the material, but in terms of the trade area, that's the only experience we have at that point.

COMMISSIONER BORGEAS: Where do we know the other -- please, sorry, go ahead.

MR. COUGHLIN: I'll comment.

I think the tungsten story was illustrative in that it's not just where you find the material but it's the manufacturing technology to turn that material into a useful raw material for manufacturing.

And that's why the public-private partnership translational research and fostering the manufacturing technology here in that U.S. is important.

Because undoubtedly, a number of the rare earths in the materials that we get from China are available from other sources.

Some are available here in the U.S., they're underdeveloped, but we also need the manufacturing technology to turn those materials into the useful raw material.

So, both ingredients are really needed. And so in terms of trade leverage, yes, it probably could be used as trade leverage because it would take some time to build up that industry.

COMMISSIONER BORGEAS: So, I'll finish with this but what I'm hearing from all three of you and from some of the questions posed earlier is that this translational research, this application stage, is one of the areas, the key areas, that we are faltering in in terms of strategy.

So, in terms of a policy recommendation, those partnerships, the collaboration between the federal, the state, and the local industry and policymakers, we're all on the same page that this is a deficit that warrants attention not just in the areas you're talking about but across the board, and others from the earlier panel as well.

But we'd all agree that this is a glaring deficit.

MR. HILL: Yes, I think in terms of commercialization of graphene, yes, there is a deficit.

We're very good at thinking up what it might be able to do and translating that into actual applications is where we're falling behind.

COMMISSIONER BORGEAS: Thanks.

COMMISSIONER LEE: Thank you very much. Commissioner Fiedler?

COMMISSIONER FIEDLER: First, let me follow up Commissioner Cleveland's question on rare earths. It's not so much that the manufacturing technology on rare earths is held by the Chinese and nobody else can get it.

It's that there is no suitable environmental technology to go along with the processing, which is why it's not processed here, all right?

So, the money should be going to the development of environmental technology for us to process it so we are not foolishly dependent on an adversary for our rare earth access. Am I wrong about that?

MR. SILBERGLITT: No, you're absolutely right. I think that the Department of Energy has established a Critical Materials Institute, which maybe you're familiar with. It's right out of Iowa State University, the Ames Laboratory, which is a really, really good long-term materials laboratory.

And one of the things they're looking at is how do you more efficiently, in a more environmentally-friendly way process these materials?

They're also looking at substitutes, new designs so that you can manufacture things with less of these materials.

And also, most importantly, which is something we saw in the case of tungsten, secondary production, reclaiming these materials from waste and scrap.

And also, in the case of rare earths, you can get them from processing other materials. Rare earths are not rare, they're very abundant. The rare earth name came from chemistry, right? It doesn't refer to geology.

So they're not rare, they're pretty abundant. They're expensive to mine and process because they're together with a lot of other things and some of those things are nasty, some of them are radioactive even.

Thorium is in there with the rare earths. So, we do have a lot of rare earths, both in materials we've already made and that we could recycle and reclaim.

And also, when we process some other materials we throw away the rare earths because it's not worth the money to reclaim them, and we could reclaim them.

So, waste and scrap, secondary production from waste and scrap and other materials would also be very important.

COMMISSIONER FIEDLER: The point being, policy-wise, here that being held up on access to rare earths is not necessary and if the private sector is not willing to do it, then the government for national security reasons perhaps ought to. So, that's just my comment.

On the graphene thing, I strikes me that what's happened here in the failure to commercialize is we didn't just lose manufacturing jobs when people went to China and elsewhere, we lost manufacturing technological ability.

The remaining companies don't have the -- they're not producing the stuff you want to mix with, okay? Number one.

Number two, in our financing world, we have the private equity companies of the world, take Carlyle, Blackstone, they don't create companies, they buy them. So, if they're not existing they can't buy them.

Venture capital is 90 percent, perhaps, involved in high-tech investments. So, here you have a relatively rudimentary discovery that is clearly revolutionary.

But you don't have the market in the United States to go to the companies to say, okay, I'll add it to my cement because Lafarge, CEMEX in Mexico are all of the companies.

And they say I don't need to strengthen, the cement is strong enough now. They're not innovative. Now, the Chinese on the other hand recognize that it is, wow, we can really do a lot with it to modernize our military, say. Right?

So, again there's a short-sightedness in our system that if it exists, who's going to solve that problem? So, obviously, sort of capitalists who like money don't see the money in this country.

And so where's the government intervention? And I'm not talking about massive government intervention, I'm just talking about -- I'm not talking about the government creating state enterprises in the United States.

But it's a complicated solution. I'm sorry that you're facing this problem. In the end you're going to commercialize it with people who have the base manufacturer, that's why the Chinese have the advantage.

MR. HILL: If I may respond just real quick to that, we are a little bit farther along and I think what's significant -- and you're right, venture capital, they're used to high-tech, they're used to three to five years return on investment.

Here in materials research, you're going out maybe ten years for something viable. I think in the last 18 months we've seen some significant movements to where end-user industries are realizing this is actually something I can use.

So, yes, Callaway golf ball has graphene inside it. I think it's the core soft. Ford has put it in its polyurethane foam parts for under hood.

There has been collaborations with AECOM, there's been some discoveries with cement like you're saying. I think what the end-user industries are realizing is more or less, maybe, the cost savings in a lot of cases.

So, in a lot of cases when you're talking about reducing the amount of material that you have to make cement with, if you can increase the strength by 50 percent you can use less material.

Same thing with composites. If you can reduce water intrusion in cement and I believe as well as it's with composites too with the water, then you have a significant savings.

In aerospace, you can save billions of dollars by reducing the weight. So, we're starting to make that education and I think from the government perspective, I agree with you, it's not the U.S.'s modus operandi to actually create state-run corporations.

But I think what we've seen many times is if U.S. policy at the high level says this is important, this is what we want to do because of China or whatever else, end-user industries tend then to start paying a little bit more attention. But I think we're out of the proof of concept phase because it's R&D hell for a lot of companies. So we're making progress but I think we have an opportunity to accelerate it.

COMMISSIONER LEE: If either of you want to make a quick remark, please go forward.

MR. COUGHLIN: I think the overall observation that you need a support ecosystem in order to sustain a manufacturing sector is really important.

Dr. William Bonvillian of MIT talks about this home alone concept that once critical parts of a manufacturing ecosystem move overseas, and I've seen this in the forest products industry, where the process equipment technology gradually migrated to Germany and Finland and Sweden, and that restrained the ability of domestic industry to innovate.

So, I think that point is very well taken, that we need an integrated manufacturing policy that integrates and supports the critical technologies that you talked about, including rare earth processing which is environmentally sustainable.

MR. SILBERGLITT: I agree that we should support the science and technology base for rare earths, and I think we're doing that. The institute I talked to you about is in fact doing just that, and they are collaborating with industry.

So, I think that's to be encouraged and supported.

COMMISSIONER LEE: Thank you. Was it on this issue?

COMMISSIONER GOODWIN: Yes.

COMMISSIONER LEE: Okay, a quick follow-up from Commissioner Goodwin.

COMMISSIONER GOODWIN: A quick question about the rare earths, are you familiar with the study that the Department of Energy announced last year about trying to assess the ability to extract rare earths from coal waste and coal ash?

And if so, do you know what progress they've made on that or where it stands?

MR. SILBERGLITT: Yes, I know they've done that study. I haven't really reviewed it so I can't say anything about progress, but it's a good idea for sure.

COMMISSIONER LEE: Interesting, okay. Commissioner Kamphausen, you're next.

COMMISSIONER KAMPHAUSEN: Thank you, Chair. Thank you to our distinguished panel. Dr. Silberglitt, I thought your discussion with Vice Chair Cleveland was remarkably understated with regards to the environmental question.

And Commissioner Fiedler's gotten to this point. I'd like to go a little bit further.

It's been my impression that it's precisely because China has been willing to bear the environmental cost that it controls 100 percent of the processing of I think it was tungsten, maybe, you said and so many other of the critical materials.

We've seen recently, it's not directly parallel but the Chinese have said we're stopping our process of taking the world's trash, for instance.

Is there a point at which, in your opinion, if you've thought about this or done some research on it, whether cost of processing will exceed the value that China has in dominating the processing of so many of these materials?

And then relatedly, you mentioned that there are some intermediate steps that we might do in terms of recovering or recycling rare earths in particular.

And the process of then building a more competitive future with the Ames Lab and so forth, it sounds like that's some years out.

Are there policy steps in between that might need to be taken that we might actually consider to sort of make up this gap, this period of time between when those can take effect?

MR. SILBERGLITT: Thanks for the question. Yes, for sure it takes time for all these things to happen but the secondary production from waste to scrap, that can happen really quickly.

In the case of tungsten, if you've looked at our report you know that in one year we reduced our dependence, foreign dependence, for tungsten to 60 percent to 40 percent. In one year, just from secondary production.

It's back up to 50 percent so the issue with secondary production, which was pointed out to me by Professor Eggers, who's one of the experts in this area, is that if you're producing for materials that you already have, that you've had for a long time and you've manufactured, then that's going to go away eventually.

You're going to get run out of that. If you're using the secondaries from the stuff that you're currently bringing in, that's sustainable.

And so I guess the reason why it went down and came back up a bit is because we probably used up a lot of what we had.

But in the case of rare earths, we haven't really done much at all in terms of secondary production and we've also just started to refill our defense stockpile.

So, there are things we can do, and plus, with rare earths, China is using a lot of the materials that they're producing. Part of the reason they produce all these materials is for domestic consumption.

So, it's really the amount that they're not using for their domestic consumption that they're controlling the world market with. And so the bar is lower than bringing them down all the way to where everybody else is equal to them.

The bar is to produce what the rest of the world needs outside of China and process it outside of China. And I think that there's no shortcut to that, we just need to develop those methods as your colleague had suggested.

COMMISSIONER KAMPHAUSEN: And on the environmental question, anything further?

MR. SILBERGLITT: Not really.

COMMISSIONER KAMPHAUSEN: Mr. Hill, then, I apologize if this is a science question but to make graphene you have to have graphite, correct?

MR. HILL: Yes.

COMMISSIONER KAMPHAUSEN: And you say in your testimony China produced 70 percent of the world's graphite.

Is that a function of its extractive ability or are there costs related to that production that they were willing to bear, maybe similar to the question we were just having, that others were not for environmental or other reasons?

In other words, do they have capture of the resource or are they just willing to bear the costs of production?

MR. HILL: I'm not sure if I have a specific answer to that.

It's, essentially, mined graphite so you take just a lump of graphite is what you have and so when you go back to the original discovery, they just took lump graphite flakes and sticky tape and just peeled off and reapplied, peeled off and reapplied.

The processing goes into the exfoliation, the actual taking of the graphite itself. So I don't have a clear answer on from the mining to the actual laboratory production of graphene.

I can go back and try to get a specific answer for you, if there's an advantage that they have in terms of mining, but I don't believe so.

COMMISSIONER KAMPHAUSEN: Okay, I was asking maybe a more basic question. Do they have more resources?

MR. HILL: They clearly have more resources graphite-wise, yes. Their resources in graphite are extensive. This information came from the U.S. Geological Survey, their last report.

They are providing 70 percent of the world's graphite so clearly their domestic resources -- I don't know the exact tonnage -- gives them a significant advantage domestically.

COMMISSIONER LEE: Thank you. Commissioner Lewis?

COMMISSIONER LEWIS: Mr. Silberglitt, you mentioned in the beginning of your presentation that something that we're exporting to China has a 15 percent tariff there and when we import the same item from them, there's no percent tariff on that.

What was that item?

MR. COUGHLIN: That was carbon fiber.

COMMISSIONER LEWIS: Is there no constituency -- I mean I don't understand how this comes about.

Is there no constituency in the United States to equalize this situation?

MR. COUGHLIN: Well, we as the American Composites Manufacturer's Association certainly are interested in equalizing that situation.

There was an environmental goods agreement which was being negotiated through the World Trade Organization a few years ago. I was part of that and promoting the free and fair trade of composite materials including carbon fiber.

So, it might have been addressed in that had it moved forward. China was not particularly supportive of it and it eventually did not pass the 17 countries who were part of it.

COMMISSIONER LEWIS: And that's still the situation today?

MR. COUGHLIN: That's correct, and this is particularly a problem for, for instance, export of pultruded plate into China for wind power.

U.S. companies can compete on a global basis, wind energy is definitely a growing area of technology. We have both the technology in terms of the wind energy itself and the raw materials that go into wind.

And we can export and compete successfully across the world but not when you have 15 to 17 percent tariff, plus other commercial barriers that are in place to exporting product.

COMMISSIONER LEWIS: How did it come about that there's no tariff in the United States on an item from China when they impose a tariff on us?

MR. COUGHLIN: I don't have the answer for that, Mr. Lewis, today. I can do some research and get back to you on that.

COMMISSIONER LEWIS: Thank you.

COMMISSIONER LEE: Commissioner Talent?

COMMISSIONER TALENT: Mr. Coughlin, what are the characteristics of a good translational research program?

If I were still in the Senate and I wanted to introduce a bill to create such a program, what is it I should be certain to include and what should I be certain not to include if I want to have a successful program?

MR. COUGHLIN: I would start with industry support, make sure there's industry pull on any translational research. You want to make sure that there are applications out there that can pull the technology into commercialization.

We have excellent fundamental research that can go in a number of different directions. So, translational research is more application and market-focused.

And I think there's been a good report written just in this past year about this, about the various areas that need translational support, that was published through the White House.

I think Lloyd Whitman was an author of that report. We reviewed that last year and it cites a number of areas of technology that need translational research support.

COMMISSIONER TALENT: Great, and could you, for the record, give us -- and we can do this after the hearing -- an example where you get pretty granular about how something really worked?

In other words, there was this consortium and this grant put in pursuit of this application, and they succeeded and now it's been commercialized.

I'd like to have some specific example maybe, if the rest of the Commission agrees, included in the report. So, could you follow up and let us --

MR. COUGHLIN: Yes, certainly we'll do that.

COMMISSIONER TALENT: Thank you. Madam Chair?

COMMISSIONER LEE: Thank you very much. Commissioner Wessel has a quick follow-up.

COMMISSIONER WESSEL: Thank you, and a follow-up on Senator Talent's comments.

If you could provide us your assessment of the NNMIs out of the manufacturing and composite, or I guess it's advanced materials is the one in Detroit as I recall, as well as the advanced manufacturing partnership, AMP 2.0, which was to try and enhance the translation between research to the production.

Each view, if you have any views on, again, AMP 2.0 and the NNMIs, that would be helpful.

MR. COUGHLIN: We'll definitely respond to that.

In terms of AMP 2.0, I will point out there were three technologies that were cited as cross-cutting technologies in that report, composites was one, as being an enabling and foundational technology for a lot of the industries that we rely on for both domestic supply and --

COMMISSIONER WESSEL: I served on the Working Committee, but it's several years old now and, again, the NNMIs, now that they've been stood up, are they working and what would you do with the AMP materials?

MR. COUGHLIN: We'll respond to that, thank you.

COMMISSIONER LEE: Anybody else? Okay, I have sort of a wrap-up kind of question for all three of you.

This has been a really great, really interesting panel with a lot of insights into these different areas. And we've talked about a bunch of different things in terms of policy going forward.

And a couple of phrases have come up, the manufacturing ecosystem, a grand graphene strategy.

In the earlier panel we talked about building a bridge across the valley of death, which I think is similar to what you're talking about, the translational research, that key missing point in terms of both U.S. Government and U.S. business failing somehow to get at that key moment.

So, I guess for all three of you, if you step back a minute, what do you think are the key obstacles that are preventing the U.S. from having some kind of a coordinated strategy across business and government that would help both the development, the technology, but especially the commercialization and the manufacturing of some of these really important products going forward?

And how can the U.S. -- what steps should the U.S. be taking now? Is it in trade policy, is it in technology, is it the R&D tax credit?

What are the key things that are needed to create that ecosystem that would be supportive of these important materials going forward?

I invite each of you.

MR. SILBERGLITT: I'll start. So, I'm a scientist, I've certainly worked in private industry for a long time and I've been involved in some development efforts.

But I think that one of the most important programs we have is the small business and innovation research program.

And I think that another really big issue that I've been involved with over my whole career is transition of technology from government research labs.

So, I think that what's most important is connections between people and we ought to be establishing more of these kinds of connections between the people who are doing the research and developing the early versions of what could be useful technologies and people who are actually manufacturing things and making money from them or supplying our soldiers with them.

And so I think the important thing there is that we actually define what a product is. What is a result? If you're talking about graphene, you should be talking about how is graphene used in a particular product?

Graphene is embedded in most things. Graphene is today where nanotechnology was in 2000 when we started the National Nanotechnology Initiative, and now nobody talks about nanotechnology because it's in everything. Materials and products are made and they're processed at that one-billionth of a meter scale today and it makes them better products. That multi-functionality I was talking about at the beginning of my testimony.

So, I think it's connections between people, programs that connect people, and real definitions of how these kinds of advanced materials are going to be used.

So, not letting a researcher in a lab get away with saying, oh, I have a patent and I have so-and-so, I'm doing a CRADA with that person, cooperative R&D agreement.

No, you should be saying, I'm going to develop this product with the properties so it can go into this product, this unmanned system that our soldiers are going to use, or this battery that our soldiers are going to use.

COMMISSIONER LEE: Isn't that in the interest of any business to sort of define the product and how it will be used and so on? So, is there a market failure here?

Why would the private sector not be providing that kind of information and guidance?

MR. COUGHLIN: Well, there's a failure of connectivity so these kinds of public-private consortium partnerships that are being suggested I think are very good things.

But they need to actually define the connections between the research and the product, that's my point.

You talked about the valley of death and, actually, I took that out of my testimony because I wasn't sure if it was a term that would need explaining. But apparently, it does not.

So, if you look at the testimony starting by allocating a percentage of our R&D budget towards translational research, technology readiness level 4 through 7 would be a huge step because researchers respond to the funding opportunities that are available.

And the funding opportunities that are available are mostly for early-stage research, and so they respond to that.

So, if you created a certain percentage that was allocated towards translational research -- and this is pre-competitive research, this is before you turn it into a product so it's in that critical juncture you talked about which is the valley of death. You incentivize researchers to go after funding if you allocate a percentage of funding in this area. They're going to collaboration more with industry and industry is going to support our research institutions more.

It's going to work both ways. We've seen that happen in other countries so I think that's a useful model.

MR. HILL: To follow on that, I agree with the failure of connectivity and the connections between people. I think that's been a hallmark for what the U.K. and the EU are doing with their graphene centers.

I think to kind of simplify it from translational research is really to put it in context.

In the high-tech world, we have incubators and especially with graphene in particular, I think that is something where you take the connectivity between people, you take the ability for funding, but you really want to put together industry and academics and government altogether.

So, when you have researchers coming out of the university that have a new patent or have a new process that they want to engage and go forward, there's an ecosystem that supports them there.

And I think, I honestly do, graphene is very unique. They outlined the properties, there's no other material like it in the world. It's even being tested in terms of quantum computing.

So, you see graphene has endless applications, if you will, if we start really focusing on what it is.

The interesting thing about the funding for research is Dr. James Tour who is probably one of the foremost graphene scientists out of Rice University.

He had some sobering comments at our summit back in May. As a senior researcher, he used to get one out of three proposals funded, he's about one in ten now.

And so for the younger researchers that are coming up, they're lucky to get 1 in 20 of these proposals funded. So, there's a significant disconnect in terms of really focusing on the new research that's coming out. And as high-tech as we're getting, as that continues to expand, we're at the point where we're towards the end of Moore's law, what's next for computing, there are going to be a lot of new advances.

And I think it takes a wider lens in terms of saying, okay, what do we make policy-wise? What is that strategic policy for these new materials? And how we put that ecosystem together.

And so it does take a little bit of bold strategy but it does take funding, and it takes connectivity amongst researchers, industry, and government as well.

COMMISSIONER LEE: Thank you very much. We are more or less at the end of time, but I invite any of the Commissioners who have a follow-up question.

COMMISSIONER TALENT: One quick follow-up, do you all have a sense of which federal agency is best at managing this sort of thing?

My sense is DoD and DoE probably have the most experience, but do you have any -- is your opinion similar? You mentioned NASA, I don't really know how good they are.

MR. SILBERGLITT: I think you're on the right track. I think DoD and DoE have a lot of experience and have done some really good things in these areas.

COMMISSIONER TALENT: Okay.

MR. COUGHLIN: I think DoD and NASA at different points in time have been very effective because they're also customers and --

(Simultaneous Speaking.)

COMMISSIONER TALENT: That's true.

MR. COUGHLIN: -- for the technologies. So, that has been a critical element.

I don't think inherently DoE or any of the other departments are incapable of it, they just don't have it as baked into their mission, pulling things through into commercialization, as NASA and DoD have been.

So, it's something that could be addressed again with allocation of research funding towards the translational research.

COMMISSIONER TALENT: Thank you.

MR. HILL: I agree with DoD, that's one of the reasons why we targeted it for the report to find out exactly what's going on department-wide.

Like I said, AECOM is phenomenal in its graphene research in terms of standardizations, thing that you're going to have to have for new technologies like graphene.

But, yes, DoD, DoE are the predominant ones that I think can make the most bang for your buck if you will.

COMMISSIONER LEE: Well, with that, thank you so much to our three panelists for sharing your expertise, your experience, and your thoughts about what we need to think about going forward in this pretty important set of areas. So, we really appreciate your time and your testimony and with that, we will break for lunch and reconvene at 1:45 p.m. sharp for our last panel which is on new energy, nuclear power, and energy strategy.

Thank you all very much. I look forward to seeing you for that final panel.

(Whereupon, the above-entitled matter went off the record at 12:36 p.m. and resumed at 1:46 p.m.)

PANEL III INTRODUCTION BY VICE CHAIRMAN CLEVELAND

VICE CHAIRMAN CLEVELAND: Welcome to our third panel which is focused on new energy, particularly energy storage and nuclear power. This panel will explore China's rapid development of its energy storage industry and its efforts to cultivate export markets from nuclear reactors and reactor components, as well as the commercial and strategic implications for the U.S.

We will hear first from Dr. Joanna Lewis who is an associate professor at Georgetown's Walsh School of Foreign Service and a faculty affiliate in the China Energy Group at Lawrence Berkeley National Lab.

Professor Lewis leads Georgetown's U.S.-China climate research dialog and U.S.-China Energy and Climate Working Group as well as the National-Science-Foundation-funded project, International Partnerships and Technological Leapfrogging in China's Clean Energy Sector.

Her recent book, Green Innovation in China, was awarded the 2014 Harold and Margaret Sprout Award by the International Studies Association.

Next we have Jessica Lovering. Ms. Lovering is Director of Energy at the Breakthrough Institute, where her research focuses on how innovation in nuclear energy can bring down costs and accelerate deployment. She's author of the paper, Historical Construction Costs of Global Nuclear Power Reactors, and co-author of the report, Atoms for Africa: Is there a Future for Civil Nuclear Energy in Sub-Saharan Africa?

Ms. Lovering is currently completing a Ph.D. in engineering and public policy at Carnegie Mellon for which her dissertation focuses on the impact of reduced U.S. trade in nuclear technologies to U.S. influence in international nuclear governance.

Finally, we have James Greenberger, the Executive Director and Co-founder of NAATBatt International, a not-for-profit trade association of advanced battery manufacturers and their supply chain partners.

Prior to founding NAATBatt in 2008, Mr. Greenberger was a lawyer in private practice, most recently at Reed Smith in Chicago where he led the clean tech practice group.

Currently, he sits on the board of two companies in advanced battery industries and two academic advisory committees.

We'd appreciate it if you would keep your remarks to seven minutes because we all always have a lot of questions. So, welcome. Dr. Lewis, if you'll start?

OPENING STATEMENT OF JOANNA LEWIS, PH.D., ASSOCIATE PROFESSOR OF SCIENCE, TECHNOLOGY AND INTERNATIONAL AFFAIRS, GEORGETOWN UNIVERSITY

MS. LEWIS: Members of the Commission, thank you for the opportunity to testify this afternoon. My remarks will focus on China's capabilities and ambitions in clean energy technologies.

Growing global energy demand will require significant investments in new energy infrastructure and most of this investment will be in renewable energy.

Around $7.8 trillion is projected to be invested in renewable power worldwide through 2040 in technologies including onshore and offshore wind, utility-scale rooftop and distributed solar and hydropower.

BP projects two-thirds of new power generation will come from renewables over the next two decades.

China is now the world leader in the development of wind and solar technologies and it is poised to lead in energy storage technologies in the coming years.

Renewable energy has long been identified as a strategic technology sector for China and it has become even more critical given recent initiatives to reduce the country's reliance on coal due to concerns about climate change and air pollution.

China's green innovation strategy has propelled its clean energy sector to be among the largest in the world.

China is a latecomer to the clean energy field, therefore, cooperation with many of the countries that have expertise in specific technologies has been a very important way for Chinese firms to enter this sector.

These technologies transfers to China from overseas firms have led, in many cases, to fruitful cooperation and occasionally to tense relationships over intellectual property.

This rise has also launched international trade battles with its biggest green technology competitors.

China's ability to leapfrog to clean energy technologies will be determined in part by its ability to become an innovator and global leader in the development of these technologies it so critically needs.

Its entry into these sectors also has important implications for the ability of these technologies to diffuse globally.

For example, China's entry into the manufacturing of wind and solar technologies has led to significant cost reductions and increased learning around the world.

China's policies to support renewable energy have always included mandates and incentives to support the development of domestic technologies and industries.

While some elements of these policies, like requirements for using locally manufactured materials, are unduly protectionist, the policies aimed at promoting deployment are less controversial and in many cases modeled after similar policies that have been used in other countries.

Of the non-hydro-renewables, wind and solar have been particularly successful in China over the last decade.

By the end of 2018, China constructed over 200 gigawatts of wind power, more than all the European Union countries combined, and almost twice the amount of the second-largest installer of wind in the United States.

China's also becoming the largest market for offshore wind power development with $11.4 billion in investment and 13 new projects being constructed in 2018 alone.

China's now by far the leading country in installed solar capacity with about 170 gigawatts, or 35 percent of total global capacity. In 2017, China invested $126 billion in clean energy, its highest amount ever and almost half the global total.

In 2018, this number declined due to a decrease in solar investment but China still led the world with $100 billion of clean energy investments last year.

China's experimenting with large-scale deployment of renewable energy as no other country has before it.

As a result, it's becoming a de facto global laboratory, experimenting with the challenges that will benefit the rest of the world should they follow China's path.

Today, one of the biggest challenges facing China's renewable energy sector is integration or making sure that the wind and solar power being produced by China is absorbed by the grid and consumed.

Curtailment rates for 2018 were around 7.7 percent for wind and 2.9 percent for solar, which is a notable improvement on recent years, where over a fifth of wind power, for example, that was produced was wasted.

Curtailment, of course, leads to major losses for wind farm operators, and from an environmental perspective it leads to wasted pollution-free electricity.

Most recently, there's pressure in China to remove the wind and solar industry's reliance on subsidization.

The feed-in tariffs for wind and solar have recently been reduced and the National Energy Administration has released a development plan for subsidy-free wind and solar projects, with the first batch of projects, about 20 gigawatts spanning 16 provinces, announced this year.

So, if China's first major clean energy technology successes are wind and solar, their next big success is poised to be in energy storage.

Energy storage technologies represent a $620 billion investment opportunity over the next two decades, and while China is still in the early stages of energy storage deployment and utilization, its companies are already among the world's top energy storage technology manufacturers.

At the end of 2017, the Government released a ten-year strategy for developing a domestic energy storage industry with two key purposes.

One, to support battery manufacturing for its already massive electric vehicle manufacturing enterprise, and two, to help with the serious grid challenges related to integrating renewables into the grid.

China's energy technology goals reach beyond its borders as well. China has emerged as the largest single provider of overseas infrastructure investment in the world and particularly in Asia.

Many of these investments are motivated by China's Belt and Road Initiative.

And while China actually exports far more solar panels around the world than any other country, this deployment is not evenly distributed.

Furthermore, China's development banks and state-owned enterprises, which make up the bulk of its overseas investment, are primarily supporting fossil fuel development abroad. And this is despite Chinese SOEs expanding their involvement in renewable energy industries.

As a result, China's been dominating the sales of coal plants abroad for a couple decades now.

The transition to a low-carbon economy is already underway and the United States is currently a leader in the development of the next generation of renewable energy industries.

These industries are creating domestic jobs and are generating new innovation with spillover effects across the economy.

I believe that now is the time to double-down on programs that are already accelerating the clean energy transition, ensuring we do not fall behind on innovating the core technologies of the future.

Therefore, I have three primary recommendations. First, that the U.S. Government launch new bilateral cooperation in emerging Asia.

Existing collaborations with China, for example, have revealed characteristics of effective bilateral cooperation including an intellectual property framework, joint work planning, and integration of public and private capital institutions.

Second, the Government should partner with the private sector to design and pilot a finance facility for clean energy technology projects in emerging markets.

These efforts can help to counter Chinese-dominated investment, particularly in Asia's energy infrastructure.

And third, the U.S. Government should engage in expanded dialog with China on how the two countries can work together to ensure that development finance institutions do not undermine global de-carbonization efforts.

Commonly agreed safeguards should be developed to promote green over brown investments, particularly in emerging and developed countries.

These recommendations are elaborated further in my written statement and I'm happy to discuss any of this during the question and answer. Thank you.

PREPARED STATEMENT OF JOANNA LEWIS, PH.D., ASSOCIATE PROFESSOR OF SCIENCE, TECHNOLOGY AND INTERNATIONAL AFFAIRS, GEORGETOWN UNIVERSITY

Joanna I. Lewis
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Testimony before the U.S.-China Economic and Security Review Commission
Hearing on "Technology, Trade, and Military-Civil Fusion:
China's Pursuit of Artificial Intelligence, New Materials, and New Energy"

June 7, 2019

China's Capabilities and Ambitions in Clean Energy Technologies

China is the world leader in the development of wind and solar technologies, and is poised to lead in energy storage technologies in the coming years. My testimony will review the evolution of China's wind and solar industries, and how experience in these industries shapes China's emerging policy strategy for promoting energy storage industries. I will also discuss China's energy technology export ambitions, and recommendations for US policy to strengthen the United States' competitiveness in energy storage and renewables.

The Evolution of China's Wind and Solar Industries

Renewable energy has long been identified as a strategic technology sector for China, and it has become even more critical given recent initiatives to reduce the country's reliance on coal due to concerns about climate change and air pollution. China's green innovation strategy has propelled its clean energy sector to be among the largest in the world. China is a latecomer to the clean energy innovation field, therefore cooperation with many of the countries that have expertise in specific clean energy technologies has been a very important way for Chinese firms to enter this sector. These technology transfers to China from overseas firms have led in many cases to fruitful cooperation, and occasionally to tense relationships over intellectual property. This rise has also launched international trade battles with its biggest green technology competitors.[1]

China's ability to leapfrog to cleaner energy technologies will be determined in part by its ability to become an innovator and global leader in the development of these technologies that it so critically needs. Its entry into these sectors also has important implications for the ability of these technologies to diffuse globally. For example, China's entry into the manufacturing of wind and solar technologies has led to significant cost reductions and increased learning globally.

China's policies to promote renewable energy have always included mandates and incentives to support the development of domestic technologies and industries. While some elements of these industrial policies—like requirements for using locally manufactured materials—are unduly protectionist, the policies aimed at promoting domestic renewable energy deployment are less controversial and, in many cases, modeled after similar policies first used in other countries.

China's promotion of renewable energy was kick-started with the passage of the *Renewable Energy Law of the People's Republic of China* that became effective on January 1, 2006.[2] The

Renewable Energy Law created a framework for regulating renewable energy and was hailed at the time as a breakthrough in the development of renewable energy in China. Since the passage of the Renewable Energy Law, numerous policies and regulations have followed to support key renewable energy technology industries. While framework policies set the national stage for the promotion of renewable energy and pricing policies promoted its deployment, another set of policies aimed to promote the technology transfer and then the localization of renewable energy technology.

Of the "non-hydro" renewables, wind and solar have been particularly successful in China in the last decade. By the end of 2018, China had constructed 206 GW of wind power, more than all the EU countries combined, and almost twice as many as the second largest installer of wind power capacity, the United States.[3] China is also becoming the largest market for offshore wind power development, with $11.4 billion in investment and 13 new projects being constructed in 2018.[4] In 2017, China accounted for a record 45% of global investment in renewables investing $126.6 billion that year—its highest amount ever and almost half the global total. [5] In 2018, this number declined due to a decrease in solar project investment, but China still led the world with $100.1 billion of clean energy investments.[6]

A core national innovation strategy in China has been one that targets domestic development of technologies even if they were initially based on foreign-innovated designs. Given this priority, the Chinese state opted to support the development of wind power technology with a strategy similar to what it used in other industries. China has pursued the development of a domestic wind turbine industry almost from the very beginning of its development of wind power.[7] China's development of indigenous wind technology capabilities was aligned with its broader domestic innovation strategy to move away from reliance on foreign technologies and build up local manufacturing capacity in strategic sectors. China's wind power industry has benefited from various forms of government policy support; some policies have specifically targeted industrial development for the wind power industry, while others have indirectly supported industrial development by establishing a local market for wind power. Trade policies have also been used in a variety of ways over time to try to encourage different modes of local manufacturing and industry development.[8]

China is experimenting with the large-scale deployment of renewable energy as no other country has before it. As a result, it is a de facto global laboratory, experimenting with the challenges to large scale renewables deployment that will benefit the rest of the world should they follow China's path. Today, one of the biggest challenges facing China's wind sector is integration: making sure the wind power being produced by China's wind farms is absorbed by the grid and consumed. Curtailment rates for 2018 were around 7.7% for wind and 2.9% for solar, which is a notable improvement on recent years where a fifth of total wind power produced was wasted.[9] Curtailment leads to major losses for wind farm operators, and from an environmental perspective leads to wasted pollution-free electricity.[10] The location of China's wind resources leads to difficulties in transmitting China's wind power to population centers, and many completed wind farms sit idle while they wait for the construction of long-distance transmission capacity.

China's solar technology sector was developed almost entirely for export, while China's wind power sector was developed almost entirely for domestic use. As a result China's global dominance in solar power utilization is recent, while its dominance in manufacturing is not. Most of the past decade saw China increase its solar panel manufacturing primarily for export to wealthier countries, and very low levels of solar power utilization domestically. The global financial crisis was a turning point in China's solar industry, leading the government to introduce many domestic stimulus policies that benefited China's struggling solar industry. As a result, China is now by far the leading country in installed solar capacity, installing 53 GW of solar in 2017 and 43 GW in 2018, bringing the total national capacity to about 170 GW or about 35% of total global solar capacity.[11]

China's innovation model in the solar technology sector has been somewhat similar to the wind sector, in that most Chinese companies have purchased some form of production technology from companies located in countries that were earlier innovators in the solar industry. As the production lines moved to China, PV manufacturers gradually adapted them to local conditions, for example if less expensive inputs were available. Since a major part of the PV manufacturing process includes "know-how" as opposed to just technology hardware, access to skilled employees has been a major asset to Chinese companies.[12] One study estimates that over 60 percent of the leadership (CEOs and board members) of Chinese solar companies studied or worked abroad.[13] By 2016, domestic competition has become steep, and as a result many Chinese PV companies are expanding into emerging markets, building manufacturing plants overseas and even acquiring foreign companies to aid with this expansion.[14]

Chinese government policy support for solar PV goes back to the sixth five-year plan, and has appeared in every plan since. While the majority of China's solar policies in recent years have targeted support for large-scale solar manufacturing deployment, this is actually starting to change as a result of recent integration challenges, seeing China return to its original solar strategy of promoting decentralized applications. As with wind, a challenge for China's solar industry is integration. But unlike with wind, solar can work very well as a distributed source of power. As a result, recent Chinese government policies have targeted increasing the use of distributed solar and building-integrated PV so that the electricity is consumed at the point of generation and not transmitted over long distances.

Most recently, there is pressure to remove the wind and solar industry's reliance on subsidization. The feed-in tariffs for wind and solar have recently been reduced, and the National Energy Administration has released a development plan for "subsidy-free" wind and PV projects, with the first batch of projects (20.76 GW total) spanning 16 provinces.[15]

Evaluating the innovation coming out of China's wind and solar industries is challenging, as traditional metrics for measuring innovation, such as patents, are often not easily comparable across different national contexts. Looking at specific technologies, the crystalline silicon-based solar technology produced by the leading Chinese firms is of comparable performance and quality to that of their foreign competitors. Products along the PV supply chain are generally more standardized than in wind turbines, for example, therefore competitiveness is primarily based on quality and cost. Likewise, in wind, Chinese turbine manufacturers are quickly catching up to the most advanced global turbine designs which are for multi-megawatt offshore turbines.

Perhaps a more important metric than current technology is whether Chinese firms have the ability to innovate to produce the next generation of renewable energy technologies, especially solar. China is arguably still behind the United States in fundamental solar technology research being done at universities and national laboratories, as well as in second generation technologies such as thin film solar cells.[16] NEA's 12th Five-year plan for solar attributed challenges in the industry to inferiority in core technologies and research and import dependence on key machinery.[17] Few Chinese companies have been willing to take the risk needed to move into alternative solar technologies including thin film, and instead focus on incremental innovations targeting process improvements and cost reduction. One exception is Chinese firm Hanergy from Beijing, a large thin film manufacturer that has bought several US startups. As China has consolidated the entire upstream solar supply chain, some have argued that this vertical integration can stifle disruptive innovation making it less likely that we will see the emergence of new, innovative solar technologies from China.[18]

The Rise of China's Energy Storage Industry

If China's first major clean energy technology successes were in wind and solar, their next big success is poised to be in energy storage. Energy storage technologies represent a $620 billion investment opportunity over the next two decades.[19] While China is still in the early stages of energy storage deployment and utilization, its companies are already among the world's top energy storage technology manufacturers.[20] At the end of 2017, the Chinese government released a 10-year plan for developing a domestic energy storage industry for two key purposes: (1) to support battery manufacturing for its already massive electric vehicle manufacturing enterprise; and 2) to help with the serious grid challenges related to integrating substantial amounts of wind and solar power into the grid.[21]

China is a relative latecomer in the development of energy storage technologies, but it has been ramping up its capabilities very quickly over the past few years. As a result, it is already on track to surpass current global leaders in the industry. In 2017 over 40GWh of batteries were installed in electric vehicles, and 121MW/502.3MWh of other electrochemical energy storage projects were installed. With the continued proliferation of EV batteries, prices for energy storage are also expected to continue to decline rapidly. According to the China Energy Storage Alliance, China had 28.9 GW of energy storage capacity projects in operation at the end of 2017, up 19% from the previous year, or 16 percent of the global market.[22] About 99% of this capacity is pumped hydro storage, followed by electrochemical energy storage (389.8MW), which while a small share of total storage was up 45% from the previous year. Li-ion batteries made up the largest portion of electrochemical energy storage capacity at 58%.[23]

The energy storage market in China began to take off in 2015, primarily in response to challenges facing the grid companies. A few earlier guidance documents, including the 2014 Energy Development Strategy Action Plan (2014-2020), mentioned energy storage technologies in the list of technologies being targeted for innovation prioritization, but it was the 2015 push to begin the reform and marketization of the electric power sector that brought energy storage into the national spotlight.[24]

China's 13th Five-Year Planning Period (2016-2020) includes multiple policy efforts targeting the reform of China's energy systems. This includes innovation in new energy technologies, smart grid development, and the increased deployment of renewable and non-fossil energy sources. In particular, 2016 saw a surge of policies promulgated that targeted the development of the energy internet, ancillary service and microgrids, all of which declared the need for increased use of energy storage technologies. The 2016 Guidance for Promoting Internet and Smart Energy Development [25] mentioned promoting the development of distributed ES technologies, and the 13th Five Year Plan mentioned a focus on promoting innovation in new energy technologies that included energy storage.[26] The October 2017 *Guiding Opinions on Promoting Energy Storage Technology and Industry Development* further describes the development goals for China's energy storage industry over the next ten years.[27]

The March 2016 Energy Technology Revolution Innovation Plan (2016-2030) provides detail about Chinese government priorities for innovation in energy storage technologies.[28] This includes a supercritical compressed air energy storage system (goal of 10MW / 100MWh), flywheel energy storage array unit (goal of 1MW / 1000MJ), vanadium flow battery energy storage system (100MW), sodium sulfur battery energy storage system (10MW) and lithium ion battery energy storage system (100MW). Innovation goals for 2030 include having a better grasp of different energy storage technology options, and having achieved demonstration as well as the standardization and verification of ES technologies. Other goals include the development of an industry value chain for ES technology manufacturing, as well as a goal of technological catch-up equivalent to the most advanced international level.[29]

Storage is also increasing in northwestern China in response to increasingly severe wind and solar power curtailment, though it is underutilized in China compared with other countries to aid in renewable energy integration. Most ES targeting renewable energy integration in China focuses on wind power, which has been experiencing the most severe curtailment rates as previously discussed.[30]

Energy storage has only recently emerged as a policy priority for the Chinese government. As a result, the policy support system for energy storage technology development and deployment is still rather immature. While energy storage is frequently mentioned in China's national energy policy documents and plans, but there are yet to be any explicit subsidies for energy storage deployment. Most of the policy focus to date has been on encouraging continued technological innovation. In addition to the central government plans and policies supporting energy storage technology development, several local and regional governments have implemented their own support schemes. If energy storage follows a similar path to that of wind and solar, we can expect to see the increased use of industrial policies targeting the energy storage industry, as well as the emergence of deployment policies to attract large scale project development, including perhaps a feed-in tariff.

While China is still in the early stages of ES deployment and utilization, its companies are already among the world's top ES technology manufacturers.[31]

China's Energy Technology Export Ambitions

Developing countries are the engine for growth in energy demand in the 21st century. India, China and Southeast Asia together account for 60% of the projected future energy demand globally through 2040.[32] While China has been the driver of global growth of the past two decades, due to the rapid economic and population growth expected across Southeast Asia, its projected growth in energy demand will be twice as large as China's over the next two decades, representing one-tenth of the rise in global demand.[33]

Growing global energy demand will require significant investments in new energy infrastructure, and most of this investment will be in renewable energy. Around $7.8 trillion is projected to be invested in renewable power worldwide through 2040 in technologies including onshore and offshore wind; utility-scale, rooftop and distributed solar; and hydropower. Renewable energy in fact comprises the bulk of the investment that is projected to be spent across the entire power sector, compared with $2.1 trillion to be invested in fossil fuels, mainly in emerging economies.[34] BP projects that two-thirds of new power generation will come from renewables over the next two decades.[35] Developing economies committed $177 billion to renewables last year, up 20% from the prior year; this is even larger than the $103 billion in developed countries, where investment was actually down 19%.[36] Last year marked the largest shift towards renewable energy investment in developing countries that we have seen yet. In the Indo-Pacific alone, investment totaled $168.9 billion. [37]

China has emerged as the largest single provider of overseas infrastructure investment in the world, and particularly in Asia. Many of these investments are motivated by China's Belt and Road Initiative (BRI). China does not provide official numbers for outbound energy infrastructure investments, but estimates suggest that, since 2000, China's two state-run policy banks (the China Development Bank and the China Export-Import Bank) may have provided between $150-250 billion in global energy infrastructure financing, of which approximately half stayed within Asia.[38] An increasing amount of that funding is being directed toward Southeast Asia to meet the region's growing infrastructure needs, including energy infrastructure.

China has been dominating the sales of coal plants abroad since the early 2000s. Developing countries tend to want coal plants, not just because they are being sold inexpensively, but because they represent a tried and true model of development that they want to replicate. The vision for technology leapfrogging is like the model we saw in cell phones, where many developing countries leapfrogged over the use of landlines and straight towards mobile phones, allowing access to the internet and financial services even in remote locations. In clean energy this is not always being achieved, because the countries that industrialized first and are already transitioning to clean energy technologies still want to export their polluting technologies elsewhere. For example, we see that even China, still the largest coal user in the world, has put in place very stringent environmental regulations to reduce domestic air pollution, and has established the world's largest carbon market. As a result, there are reports that they are shutting down some of their dirtier, less efficient coal plants before end of their useful life, and exporting these dismantled plants to countries in Southeast Asia.

China is not alone in financing coal-fired power plants overseas. Japanese, Korean, French, and German banks are currently the major sources of finance for coal-fired power plants around the world, but China is beginning to catch up with and will potentially surpass Japan as the region's largest foreign direct investor and component provider.[39] One study estimates that Chinese firms are involved in the construction, ownership, or financing of at least 16% of all coal-fired power stations under development outside China.[40] Chinese energy companies have strong national support and domestic policies that favor them and their overseas investments; they can outbid competitors and provide power plant projects at a lower cost. This access to cheaper labor, materials, and financing has helped China become a leading investor in overseas coal plant development. Of all the power capacity additions in Asia involving Chinese corporations, 68 percent of operating capacity and 77 percent of under-construction capacity is in coal.[41] Most of this coal power finance is concentrated in South Asia and Southeast Asia, with the largest markets in India, Indonesia, and Vietnam.[42]

This goes against the vision for a clean energy future that many governments are putting forward. For example, many emerging Asian countries have pledged aggressive renewable energy targets as part of their Paris Agreement commitments that if met could lead to many gigawatts of renewable power being built in these countries.[43] In addition, there are significant risks to an extensive reliance on coal given the rising environmental and social costs. Around the world, coal plants are increasingly at risk of becoming stranded assets and a frequent target of public protests.[44] Despite the risks, Chinese coal plant development is on a growth trajectory due to the pull from poorer nations that seek the cheapest options for energy finance, as well as the desire for Chinese companies to expand their markets overseas.

In contrast, almost all of the multilateral development banks have been restricting coal plant investments due to environmental concerns. The World Bank pledged in 2010 to stop investments in coal, and more recently in oil and gas as well. The Asian Development Bank (ADB) has not funded any coal plants since 2013. Even the China-led Asia Infrastructure Investment Bank (AIIB) has an aggressive energy sector strategy guiding its investments with very restrictive language about supporting coal and oil investments.

While China actually exports far more solar panels around the world than any other country, this deployment is not evenly distributed across the world.[45] While China's development banks and state-owned enterprises are primarily supporting fossil fuel development abroad, the majority of international investment coming from privately owned Chinese enterprises is in renewable energy. One study estimates that between 2014-2017 Chinese banks and companies invested $190 billion in fossil fuels abroad, and only $12.9 billion in renewable energy.[46]

There does seem to be growing awareness among Chinese SOEs in expanding their involvement in renewable energy industries. For example, Shenhua, the largest coal company in the world, has been partnering with wind and solar companies. In 2016 Shenhua announced a partnership to build 1 GW of solar thermal projects in China with US company SolarReserve.[47] Its 2017 merger with Guodian Corporation also helped to diversify Shenhua's portfolio in renewables.[48] Shenhua also acquired a stake in Greek wind projects in 2017 with plans to build additional wind projects.[49]

Recommendations for US Policy

The transition to a low carbon economy is already underway, and the United States is currently a leader in the development of the next generation of energy technology industries. American companies are leading the world in making solar photovoltaics cheaper with more efficient materials as well as flexible solar cells; in developing advanced biochemical and renewable fuels; in developing solar thermal technologies to operate conventional steam turbines; and in developing smart grid technologies to allow for intelligent energy systems that can shift and reduce demand.[50] We are leading in developing efficient building materials, lighting, and energy management software. We are also leading in the soft, technical skills needed to plan for and design low carbon energy systems. These industries are creating domestic jobs, and are generating new innovation with spillover effects across the economy.[51]

For all countries, the transition to cleaner sources of energy is not just about climate change; this transition will lead to the creation of new, globally competitive industries. For all countries, the low carbon transition is an economic issue, a competitiveness issue, and a public health issue—not "just" an environmental issue. And this transition does not have to come at the expense of economic growth. As global carbon emissions growth slows, economic growth has increased. In the United States, air quality has improved dramatically over the past two decades, even as the economy has expanded. [52]

Now is the time to double down on programs that are accelerating the clean energy transition, ensuring we do not fall behind in innovating the core technologies of the future. The U.S. government has established several sophisticated programs that are directly supporting U.S. energy entrepreneurs. Programs like the Advanced Research Projects Agency (ARPA–E) and Cyclotron Road target early-stage, high-impact energy technologies with the potential to radically improve economic prosperity, national security, and environmental well-being.[53] These innovative programs are being emulated by many other countries around the world. At the subnational level, many U.S. states have been promoting aggressive clean energy policies and developing smarter, more efficient ways to manage power systems. These incentives are creating new job opportunities ranging from installation and manufacturing jobs to high tech jobs. In California, employment in advanced energy technologies grew six times faster than overall employment growth last year.[54]

The United States has been engaging with numerous Indo-Pacific nations on clean energy, natural resources, and climate change; engagement with some countries including China and India spans several decades. In many cases, this engagement has directly benefited U.S. companies, and led to fruitful technology partnerships with researchers at U.S. universities and national laboratories.[55] This cooperation has also played a crucial role in expanding global action on energy and climate change.

In addition, global linkages can spur innovation. The United States benefits from collaboration with other countries, including China: the largest clean energy market in the world. Should the United States decrease its involvement in such efforts, it risks its own technology industries and research community becoming more isolated. The United States is innovative because of its global linkages and partnerships, not in spite of them.

We should launch new bilateral collaboration in emerging Asia. Existing collaborations with China (CERC) and India (PACE-R) have revealed characteristics of effective bilateral collaboration, including an *a priori* intellectual property framework, joint work-planning, and integration of public and private capital and institutions. Now the United States has an opportunity to launch new collaborations that build on and improve upon existing initiatives. For example, in addition to R&D, international technology collaborations should also target industrial-scale demonstration projects that consolidate individual research projects and provide more scope for joint patent filings. Moreover, the funding and prioritization schemes should be even more flexible to adapt to changing needs.

Given the scale of investment that will be directed at the energy sector in Asia in the coming decades, the U.S. Government should partner with the private sector to design and pilot a finance facility for clean energy technology projects in emerging markets. The goal of the facility would be to develop a self-sustaining, replicable and scalable fund that requires decreasing amounts of concessionary capital over time as the risks associated with investment in this space are better understood and quantified. In addition, conventional energy infrastructure has traditionally consisted of large, centralized fixed assets developed using well established project financing structures and instruments, while many of the most promising sources of clean energy are harnessed using smaller scale, distributed facilities. Therefore, the government should look to lay a key role in establishing and incentivizing means of capital aggregation for next generation distributed renewables and low carbon technologies. Such efforts can help to counter Chinese dominated investment in Asia's energy infrastructure.

As existing multilateral agencies like the World Bank are moving away from financing polluting energy sources such as coal, China has emerged as an important alternative source of finance that has yet to enact strict lending guidelines on the environment, particularly in the context of its expansive Belt and Road Initiative. The U.S. should directly, bilaterally engage in expanded dialogue with China on how the two countries can work together to ensure that development finance institutions do not undermine global decarbonization efforts. Commonly agreed safeguards should be developed to promote green over brown investments, particularly in emerging and developing economies in the Indo-Pacific.

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OPENING STATEMENT OF JESSICA LOVERING, DIRECTOR OF ENERGY AT THE BREAKTHROUGH INSTITUTE, PH.D. STUDENT AT CARNEGIE MELLON UNIVERSITY

VICE CHAIRMAN CLEVELAND: 12 seconds to spare. Ms. Lovering, can you beat that record?

MS. LOVERING: Good afternoon, Commissioner Cleveland and Commissioner Lee, and other Members of the Committee.

I wanted to thank you, or thank the Commission, for the opportunity to testify regarding China's ambitions for exporting nuclear energy technologies.

My remarks today will focus on the decline of the U.S. in global nuclear power markets and the rising ambitions of China, and finally, the opportunities for the U.S. to regain its market share with advanced nuclear technologies.

As I will explain, competition between the U.S. and China for nuclear projects has important implications not only for export revenue but also for geostrategic objectives.

Global demand for nuclear energy is rising. Over 30 countries are pursuing their first nuclear power projects and the IEA predicts that global capacity will need to double by 2050 to meet climate targets.

Historically, the U.S. has been the largest producer of nuclear energy and the dominant exporter of nuclear technology and fuel.

But in the last two decades, China has been rapidly growing its domestic fleet of reactors and is predicted to surpass the U.S. as the world's largest producer of nuclear energy by 2030.

Now, most of the commercial nuclear power-plants operating global are light-water reactors with the majority of the designs actually derived from U.S. technology.

Even in China, the nuclear power sector initially relied on upon a suite of imported designs from France, Canada, Russia, and the U.S.

But there has been a major effort to localize the supply chain and develop indigenous reactor technology. By 2014, 80 percent of components and equipment for Chinese nuclear reactors was produced in China.

Because of that, the capital costs of nuclear power-plants in China are about half of what they are in the U.S. and Europe.

While low labor costs and cheap financing from the state help to bring those costs down for Chinese projects, the most important factor is reduced component costs through economies of scale across the industry and design standardization.

China is now hoping to capitalize on this domestic success to export their technology globally.

As part of their Belt and Road Initiative, they are pursuing a broad strategy of influence through nuclear projects consisting of three components: marketing their indigenous reactor designs for export, investing in existing nuclear projects abroad like the Hinkley C Project in the U.K., and partnering with Canada and the U.S. to develop advanced reactor concepts.

Meanwhile, the market for traditional light-water reactors in the U.S. is pretty stagnant and nuclear companies have struggled to secure new contracts for exports when competing against Russia, China, and now South Korea.

When newcomer countries take bids for their first commercial nuclear power projects, they look for vendors that have a recent track record of building reactors on time and on budget.

With only two light-water reactors under construction in the U.S. and the bankruptcy of

Westinghouse, the future of American exports for traditional large-scale light-water reactors is in doubt.

The rise of China and the decline of large U.S. firms in global light-water reactor nuclear markets has important geostrategic implications.

Historically, the U.S. has used trade and commercial nuclear technologies to require stricter safety and security standards in host countries.

For example, they put limitations on enrichment and reprocessing in exchange for U.S. technology, or required adherence to the additional protocols of the nuclear non-proliferation treaty.

There has been growing concern among American policymakers that the stagnation of the U.S. nuclear industry could reduce our ability to influence these countries in nuclear governance.

However, a suite of new nuclear technologies, known collectively as advanced nuclear, have the potential to reverse this trend and help the U.S. regain its market share in nuclear energy.

Advanced nuclear technology includes things like small modular reactors which are scaled-down and factory-produced versions of the large light-water reactors that we're building today.

The term also includes a suite of alternative designs that rely on different fuels, different coolants, different business models. And they all have the potential to be significantly cheaper and safer than traditional light-water reactors.

The U.S. is actually a leader in nuclear entrepreneurship with over 50 companies developing advanced reactor technologies. Many have received significant private funding and are hoping to demonstrate their technology in the 2020s.

However, China is also pursuing advanced reactor technologies.

They have two state-owned enterprises working on small modular reactors, they've just about completed construction on a pair of high-temperature gas-cooled reactors, and they're also pursuing molten salt technology at some of their national labs.

But these efforts are primarily aimed at the domestic market for now and that means that the U.S. has the opportunity to take the lead in the global market for advanced nuclear.

To understand the implications of this declining market power of the U.S. and the potential for advanced nuclear to reshape the global market, my doctoral advisors and I convened a workshop last fall.

The workshop brought together high-level experts from both the national security field and the nuclear energy industry to discuss the role of commercial trade in international governance, and to evaluate potential strategies to strengthen U.S. influence going forward.

Contrary to the common arguments we hear from some industry representatives, our workshop participants did not see overly restrictive export control policies as a major obstacle.

And while the higher cost of U.S. technology is a challenge, the main reason the U.S. is not competitive as an exporter is a lack of a successful market at home.

The U.S. only has 2 reactors under construction, whereas China has over 30. For these reasons, many see the U.S. as unable to compete with state-owned and state-supported nuclear vendors abroad.

However, I believe that with smart policies and investments, American nuclear companies can commercialize advanced reactor technologies that are actually more competitive globally.

The reason for this is that more and more countries are moving towards deregulated and liberalized power markets, where nuclear will receive less state support and will need to compete on equal terms with other sources like renewables.

If advanced nuclear developers can prove their designs in deregulated markets in the U.S., they will be very attractive to emerging deregulated markets abroad.

Policies that could help accelerate commercialization of advanced reactors in the U.S. include investments in the innovation infrastructure, like testing facilities, federal and state-level clean energy mandates, and progress on nuclear waste management.

We've seen movement in the right direction with the NECA and NEMA bills that were passed last year and signed into law, as well as the Nuclear Energy Leadership Act which was introduced in the Senate just last month.

These bills contain important support for nuclear innovation but more focused and coordinated efforts are needed to push export projects globally.

While China appears to be on a path to surpass the U.S. in the global nuclear market, their success in exports is far from guaranteed.

Federal policies in the U.S. should recognize the environmental, economic, and national security benefits of commercial nuclear power.

With more targeted government investment, private companies can commercialize advanced nuclear technologies that could be more competitive both in domestic markets and globally, strengthening U.S. influence in emerging nuclear nations.

Thank you.

PREPARED STATEMENT OF JESSICA LOVERING, DIRECTOR OF ENERGY AT THE BREAKTHROUGH INSTITUTE, PH.D. STUDENT AT CARNEGIE MELLON UNIVERSITY

Testimony before the U.S.-China Economic and Security Review Commission

Hearing on Technology, Trade, and Military-Civil Fusion:
China's Pursuit of Artificial Intelligence, New Materials, and New Energy

Jessica Lovering

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PhD Student, Engineering & Public Policy,
Carnegie Mellon University

June 7th, 2019

Good afternoon Vice Chairman Cleveland and Commissioner Lee, and other esteemed members of the Commission. I would like to thank the Commission for the opportunity to testify about China's export ambitions in advanced nuclear energy. It is an honor to participate in this hearing.

My remarks today will cover the decline of the US in global nuclear power markets and the rising ambitions of China, particularly with respect to new and advanced nuclear technologies. China has the largest number of nuclear reactors under construction today, and will soon surpass France to have the second largest operating reactor fleet. Beyond their short-term plans for large-scale light-water reactors, China is also investing significant resources in small modular reactors (SMRs), offshore nuclear, molten salt reactors, and high-temperature gas-cooled reactors.

This comes at a time when the US nuclear industry has stagnated domestically and struggles to win new export projects. The risk from a decline of U.S. dominance in the global nuclear market is about much more than economics. Historically, the US has used trade in commercial nuclear technologies to require stricter safety and security standards in host countries. There has been growing concern among US policymakers that with the decline of nuclear exports, the US is losing a strong tool of influence in regions of strategic importance like the Middle East, sub-Saharan Africa, and southeast asia.

While the lack of strong state support for nuclear power in the US is often seen as a competitive disadvantage on the global market, I will argue that this weakness is actually a strength. The US maintains a robust nuclear power industry with dozens of companies, both small and large, working on commercializing advanced nuclear designs. With smarter federal policies, US companies can develop nuclear technologies that are actually better suited for deployment in competitive markets abroad and at home.

While my remarks today are focused on China, many of these arguments apply to competition with Russian nuclear exports as well.

China's Role in Advanced Nuclear Development

Around the world today, most of the 450 commercial nuclear power reactors are light-water technology, burning uranium oxide fuel and using regular water as both a coolant and neutron moderator. There are also about 50 heavy-water reactors, particularly in Canada and India, and 15 gas-cooled reactors, mostly in the UK.

There is a broad group of technologies that we refer to as "advanced nuclear" that are under development by national governments and companies around the world. The US and China both have devoted significant funding to advanced nuclear designs. At the most basic level, advanced nuclear is anything other than the large-scale water-cooled reactors that we operate today. The term can also include light-water small modular reactors (SMRs), which are essentially scaled down models of traditional reactors, but with the ability to be factory produced and with enhanced safety and performance features.

Beyond light-water SMRs, there are several broad categories of advanced nuclear reactors that are in development. These include molten salt reactors, gas-cooled reactors, and fast breeder reactors. Their attributes differ, but most advanced reactors are pursuing passive safety features, smaller sizes and modular fabrication, with the goals of reduced capital costs and improved performance.[1]

Most of these designs were originally developed and tested in the U.S. starting in the 1960s, but struggled to find commercial success. Factors including improved materials, manufacturing techniques, and computer modeling capabilities have led to a renewed push to commercialize these technologies. In addition, growing concerns around climate change have spurred a new generation of engineers to work on improving the economics and performance of nuclear power.

Over 50 companies in the US are developing advanced reactor technologies, and several hope to construct their first commercial demonstration in the 2020s.[2] While some of these companies were spun out of university and national laboratory programs, many have been successful at raising private funding.

As federal funding for nuclear development has declined over the last few decades, China has scaled-up investment across the board in both traditional and advanced nuclear. China has two state-owned enterprises developing SMRs. Construction of their first commercial demonstration of a 125MW SMR will begin in late 2019 with completion expected in 2025. They also have plans to demonstrate a floating barge-based version of this reactor, for deployment in the South China Sea. China has a pair of 200MW high-temperature gas-cooled

[1] Nordhaus, T., Lovering, J. & Shellenberger, M. *How to Make Nuclear Cheap*. The Breakthrough Institute (2013). https://www.thebreakthrough.org/articles/how-to-make-nuclear-cheap
[2] Third Way. "The Advanced Nuclear Industry: 2016 Update" December 12, 2016 https://www.thirdway.org/infographic/the-advanced-nuclear-industry-2016-update

reactors under construction in Shidaowan, originally based on a German technology, with expected grid-connection in 2019. China has also invested over $300 million in molten salt technology over the last few years, with plans to build small-scale demonstrations of both a solid-fueled and liquid-fueled design in the 2020s, with commercial demonstration in the 2030s. The most prominent international collaboration was a Chinese partnership with the Bill Gates-funded company Terrapower to demonstrate a metal-cooled fast breeder reactor near Beijing. Due to increased nuclear trade restrictions, Gates announced this project would be cancelled in early 2019. However, Terrapower is still moving forward with a molten salt design in the US.

China's Transition to Indigenous Reactor Technology and Domestic Supply Chain

China currently has the world's third largest fleet (46) of operating commercial nuclear reactors, and the largest number of reactors under construction (11). After a pause in approvals for new construction following Fukushima, China looks likely to fall short of their target for 58 gigawatts (GW) of installed nuclear capacity by 2020. But as they've begun approving the first new construction projects in three years, they are re-committing to strong growth, predicting 120-150 GW of installed capacity by 2030, which would mean they surpass the US as the world's largest producer of nuclear power.[3]

While China's nuclear power sector initially succeeded with a suite of imported designs from France, Canada, Russia, and the US, there has been a major effort to localize the supply chain and develop indigenous reactor technology. When the first reactor was supplied by France in 1987, only 1% of the components and equipment were manufactured in China. In 2006, the Chinese government set a goal to localize 75% of the supply chain, and by 2014 they had surpassed that goal with a reported 80% of components and equipment manufactured in China. Now the government is pushing manufacturers to export these components to nuclear projects abroad.[4]

Over the last decade, the Chinese government asked its two main nuclear developers to coordinate on a 1000 MW indigenous reactor design that could be exported starting in the 2020s. The result was the Hualong-1, which is a derivative of a French design.[5] Pakistan is planning to build five Hualong-1 reactors at two power plant sites. In 2017, the UK began Generic Design Review of the reactor for a potential project there, and there are also plans for export to Argentina.

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[3] Reuters. "China likely to more than triple nuclear power capacity by 2030 - official." November 8th, 2018. https://www.reuters.com/article/china-nuclearpower/china-likely-to-more-than-triple-nuclear-power-capacity-by-2030-official-idUSL4N1XJ3AR

[4] Nuclear Business Platform. "China's Nuclear Supply Chain Movement: From Localization To Globalization" http://www.nuclearbusiness-platform.com/nuclear-industry/chinas-nuclear-supply-chain-movement-from-localization-to-globalization/

[5] Hibbs, M. *The Future of Nuclear Power in China*. (Carnegie Endowment for International Peace, 2018). pg. 56

China pursuing nuclear exports for political influence in addition to economics

Nuclear vendors recognize that there is a large and growing potential export market for commercial reactors. Over thirty countries are pursuing their first nuclear power plants, according to the IAEA.[6] And the IEA predicts that global nuclear capacity will need to double by 2050 to meet aggressive decarbonization targets.

China is not alone in recognizing the size of the future nuclear power market, but they also recognize the important geostrategic goals that nuclear exports facilitate. Building a nuclear power plant in a foreign country establishes a 60-100 year business and political relationship that goes beyond supplying fuel and components for the physical plant. Nuclear supplier countries have in the past used nuclear exports as a gateway product to facilitate other trade deals,[7] and also to establish influence in the fuel cycle, regulation, and power sector of the foreign country.

China is pursuing a diverse campaign of influence through its Belt and Road initiative. For nuclear power in particular, China's overseas ambitions fall broadly into three categories: 1) marketing its domestic Hualong reactor for export, 2) investing in existing nuclear projects, such as Hinkley C in the UK, and 3) partnering with Canada and the U.S. to develop advanced reactor concepts. Additionally, China has invested heavily in nuclear innovation, including developing small modular reactors (SMR), molten salt reactors, and high-temperature gas reactors.[8]

From 2000-2015, China signed over 50 nuclear cooperation agreements with 20 countries including: Egypt, Jordan, Saudi Arabia, Algeria, and Turkey in the Middle East and North Africa; Pakistan, Thailand, Taiwan, Japan, and Korea in Asia; the UK, France, Russia, Belarus, and Romania in Europe; along with Australia, Argentina, and the U.S. In about half of these agreements, China acted as the supplier, providing concrete technological support for things like nuclear power plants, reactors, or fuel cycle facilities or services.[9]

In sub-Saharan Africa, China has recently signed nuclear agreements with Kenya, Sudan, and Uganda, and appears keen on increasing its scope of nuclear influence on the African continent more broadly. In 2014, partnerships were signed between the Nuclear Energy Corporation of South Africa (Necsa) and both the China Nuclear Engineering Group and China's State Nuclear Power Technology Corporation. Both agreements were focused on training for nuclear power plant construction and NPP project management. China General Nuclear owns and operates the world's second largest uranium mine in Namibia, as well as submitting a proposal for a small nuclear power plant there. China has also built research reactors in Ghana and Nigeria.

[6] World Nuclear Association. Emerging Nuclear Energy Countries. Updated March 2019. http://www.world-nuclear.org/information-library/country-profiles/others/emerging-nuclear-energy-countries.aspx

[7] Bratt, D. *The Politics of CANDU Exports*. (University of Toronto Press, 2006).

[8] Ichord, R. F. *US Nuclear-Power Leadership and the Chinese and Russian Challenge*. (2018).

[9] Data from: Jewell, J., Vetier, M. & Garcia-Cabrera, D. The international technological nuclear cooperation landscape: A new dataset and network analysis. *Energy Policy* 128, 838–852 (2019).

Chinese reactors half the cost of western designs
It has been difficult to get accurate costs of nuclear power plants from China, but limited evidence suggests they are roughly half the cost of reactors in the US or Europe. A 2015 study from the OECD estimated that average overnight capital costs for new nuclear in China were $2,200/kW, compared with $4,100/kW in the US.[10] Financing costs add about 100% to the overnight capital costs, which brings the total cost to $5,000/kW for China, compared with $9,300/kW for the US. For context, this implies that a typical 1,000 MW reactor under construction today would cost $9.3 billion in the US but only $5 billion in China.

One can also compare levelized costs, which puts all lifetime costs into present day value per unit of energy produced. According to the same OECD report, the levelized cost of electricity for a new nuclear plant built in China today is about $42/MWh, whereas it's estimated at $78/MWh in the US. More importantly, the levelized cost of electricity from nuclear in China is cheaper than from coal, gas, wind, or solar. Only hydroelectric produces cheaper electricity in the long run. By contrast, in the US the levelized cost of electricity from nuclear is more expensive than natural gas and onshore wind. This can help to explain why China continues to invest heavily in new nuclear power plants whereas the US has built relatively few in the last thirty years.

Cheap financing from the state helps bring the costs down for these projects, and lower labor costs also help, but the most important factor is reduced component cost through economies of scale and series. There are a number of key components involved in a nuclear project that are both expensive and nuclear specific. China has worked to localize manufacturing of these key components, while also sourcing the raw materials nearby, allowing them to reduce the cost up to 80%. Investing in the manufacturing facilities, which are often imported, to produce these key components would not be economical unless China was building a lot of nuclear power. Similar factors are at play in South Korea, which is why an American advanced nuclear firm, NuScale, recently partnered with a Korean manufacturing firm, Doosan, to produce their pressure vessels.

The biggest limitations of China's domestic nuclear industry and future exports are project management and quality control. For China's ongoing international builds, like the EPR and AP1000, they have chosen to partner with US and French architect-engineering firms for overall project management. It is unclear how well this skill can be localized, and may represent an ongoing opportunity for US firms to stay competitive in China. Similarly, despite strong government pressure to localize production, China's state-owned nuclear firms often prefer to source components from foreign firms when they worry a domestic contractor will outsource production to a low-quality supplier who is unfamiliar with nuclear facilities.[11]

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[10] IEA. Projected Costs of Generating Electricity (2015 Edition). (2015).
[11] Metzler, F. & Steinfeld, E. S. *Sustaining Global Competitiveness in the Provision of Complex Products and Systems: The Case of Civilian Nuclear Power Technology*. MIT Political Science Department (2013).

U.S. Risks Losing Influence in Global Nuclear Governance

In the last ten years, there have been several prominent reports arguing that the U.S. is at risk of losing its significant influence in international nuclear governance regimes if the domestic industry continues to struggle to build and export commercial nuclear technology. In reports from 2013 and 2018, the Center for Strategic and International Studies made the case that success of the Non-Proliferation Treaty has been dependent on the dominance of U.S. nuclear technology in the global market.[12,13] Specifically, the US has leveraged the attractiveness of US nuclear technology to require countries to sign bilateral trade agreements that included much stricter proliferation controls than other countries required. Indeed, even countries like France, West Germany, and Canada tended to be much looser on such controls to secure nuclear export deals.

Motivated by these concerns, my doctoral advisors - Granger Morgan at Carnegie Mellon University and Ahmed Abdulla at UC San Diego - convened a workshop in September 2018 that was titled "Evaluating Strategies to Restore US Leadership in the International Nuclear Market and Control Regimes." We brought together experts from both national security and the nuclear energy industry to discuss the role of commercial trade in international governance and to evaluate potential strategies to strengthen US influence.

Most experts in our workshop thought the US still maintained strong influence through its legacy dominance of nuclear trade and technologies, but that this influence would certainly wane going forward, particularly as more countries build designs not originating in the US. Another concern was that the International Atomic Energy Agency, the international safety and security regulator, depends on expertise from the US, and the US has gained that expertise from decades of working with LWR technology.

Enduring Challenges for U.S. Nuclear Exports

While the higher costs of US technology is a challenge, the main reason the US is not competitive as an exporter is the lack of a successful domestic market. When newcomer nuclear countries take bids for their first commercial nuclear plants, they look for vendors with a recent track record of building reactors on-time and on-budget. This is how South Korea won the bid for the first four 1400 MW reactors under construction now in the United Arab Emirates.

By almost any metric, the U.S. civilian nuclear industry is on the decline. Of the 54 reactors under construction worldwide, only two are in the U.S. Research and Development funding for nuclear has also been on the decline since the 1970s, although has seen increases in the last few years. Likely as a result of reduced R&D spending, nuclear patents from the U.S. have also

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[12] Wallace, M. et al. Restoring U.S. Leadership in Nuclear Energy: A National Security Imperative. CSIS (2013).
[13] Wallace, M., Roma, A. & Desai, S. Back from the Brink. CSIS (2018).

been on the decline, averaging over 100 nuclear patents per year from 1960-2000, but falling to less than 20 per year in the last decade. In contrast, China has grown from almost zero patenting in the 1990s, to over 200 per year in the last decade.[14]

The US still retains strong influence from its legacy of LWR exports and former dominance of the global market. For example, a study of nuclear cooperation agreements by Jewell et al. (2019) found that the US still dominates these agreements for supportive technological cooperation, including areas such as knowledge exchange and training, safety and security, planning, regulation, and supportive infrastructure. But these agreements likely rest on past US experience building and exporting LWR technology.[15]

Therefore, the future market for advanced reactors provides a dual opportunity for the US to regain market power and influence in the next wave of nuclear governance. Luckily, there are over 50 companies working on advanced nuclear technologies in the US,[16] many with significant private investment and funding from the Department of Energy. Several are beginning pre-licensing activities with the Nuclear Regulatory Commission. Those that are farthest along are aiming for commercial demonstration in the 2020s.

While many express frustration that private US nuclear companies have to compete with state-owned enterprises in China, this can actually be to the U.S. advantage. In the 1960s and 70s, the U.S. spent significantly more money on advanced reactor research and development, even funding prototypes and commercial demonstrations. What was lacking was a market for such technologies. To have government agencies pick and choose technologies and then push them onto the market is a recipe for failure. A better role for federal investment is creating market demand and supporting the innovation infrastructure, such as testing facilities at national labs. This is exactly what NASA did starting in 2005 for commercial spaceflight. Rather than invest $25 billion to develop a new space shuttle to deliver cargo and crew to the International Space Station, NASA decided to stimulate the emerging commercial industry, accelerating technical readiness of launch vehicles that NASA could later contract with for launch services. This model proved cheaper and faster, but also encouraged more companies to compete with a variety of designs on the international market, making the U.S. a leader in global launch services in the space of 10 years.[17]

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[14] Lovering, J., King, L. & Nordhaus, T. *How To Make Nuclear Innovative: Lessons From Other Advanced Industries*. (2017).

[15] Jewell, J., Vetier, M. & Garcia-Cabrera, D. The international technological nuclear cooperation landscape: A new dataset and network analysis. Energy Policy 128, 838–852 (2019).

[16] Third Way. "The Advanced Nuclear Industry: 2016 Update" December 12, 2016 https://www.thirdway.org/infographic/the-advanced-nuclear-industry-2016-update

[17] Lovering, J., King, L. & Nordhaus, T. "Commercial Spaceflight: Case Study No. 1 in How to Make Nuclear Innovative." The Breakthrough Institute (2017) https://www.thebreakthrough.org/issues/energy/commercial-spaceflight

Policy Recommendations

At our 2018 workshop, experts evaluated potential strategies for both regaining U.S. market competitiveness as well as strengthening direct U.S. influence in international nuclear governance. The results from our expert evaluation concluded that three policies look promising from both an efficacy and feasibility perspective. The first is partnering with South Korea to build nuclear power plants in third countries. This would take advantage of Korea's manufacturing strengths and success at recent nuclear builds, paired with U.S. diplomatic strength and reputation in nuclear safety. The next policy is what we called the "NASA model", which is to move commercial development of advanced nuclear into the private sector, and use federal investment to build out a supportive infrastructure and create demand.[18] Lastly, the participants thought that the U.S. moving forward on a solution to nuclear waste could actually improve our ability to compete with nuclear vendors like Russia that offer fuel take-back.

These are not as improbable as they might seem at first. Recently passed legislation like the Nuclear Energy Innovation Capabilities Act and the Nuclear Energy Innovation Modernization Act,[19] are helping to accelerate commercialization of advanced reactors, but we need significantly more policy changes. The Nuclear Energy Leadership Act, introduced in the Senate in April 2019, goes much further in investing in innovation infrastructure and supporting commercial demonstrations. Mandates for procurement of nuclear electricity, similar to federal and state mandates for renewables procurement, could also stimulate demand for nuclear and revitalize the domestic market.[20]

Domestic success could help the U.S. be more competitive in the export market, but financing remains a major obstacle. Policies to expand funding for nuclear projects through the Export-Import Bank could help, but having a fully functioning EXIM board of directors is a good first start.[21] Going further, the U.S. government could pressure international financial institutions like the World Bank to change their long-standing prohibitions on funding nuclear projects. Such restrictions on funding push newcomer nuclear countries toward state-owned nuclear vendors that offer generous financing packages.

Ultimately, federal policies should recognize both the environmental and national security benefits of commercial nuclear power. With more targeted government investment, private companies can commercialize advanced nuclear technologies that could be competitive both in domestic markets and globally, strengthening U.S. influence in emerging nuclear countries.

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[18] Lovering, J., King, L. & Nordhaus, T. *How To Make Nuclear Innovative: Lessons From Other Advanced Industries*. (2017).

[19] Nuclear Energy Innovation Capabilities Act of 2017. https://www.congress.gov/bill/115th-congress/senate-bill/97 Nuclear Energy Innovation and Modernization Act https://www.congress.gov/bill/115th-congress/senate-bill/512

[20] Clean Energy Standards: How More States Can Become Climate Leaders. The Breakthrough Institute and Third Way. https://www.thebreakthrough.org/articles/clean-energy-standards

[21] NEI. https://www.nei.org/advocacy/compete-globally/export-import-bank

OPENING STATEMENT OF JAMES GREENBERGER, CO-FOUNDER AND EXECUTIVE DIRECTOR OF NAATBATT INTERNATIONAL

VICE CHAIRMAN CLEVELAND: Thank you. Mr. Greenberger?

MR. GREENBERGER: Good morning, good afternoon, Chairman Lee and Members of the Commission. My name is James Greenberger and I'm the Executive Director of NAATBatt International. NAATBatt was founded in 2007 to promote the manufacture of lithium ion batteries for electric vehicles in the United States. Today, NAATBatt exists as a not-for-profit trade association dedicated to advancing the science of and markets for advanced battery technology in North America.

NAATBatt currently has 110 corporate members including major automotive manufacturers, electric utilities, equipment manufacturers, battery cell and pack manufacturers, chemical companies, and professional firms.

I would like to thank the Commission for its invitation to speak today about the threat that Chinese domination of the lithium ion battery market poses to long-term American prosperity and to high-paying American jobs. Advanced battery technology, or more precisely, the technology that can store and deliver energy to an electrical device in precise amounts and precise times and at precise locations is and will continue to be one of the most important technologies of the 21st century. Lithium ion battery chemistry, which was invented in the United States and first brought to market in 1991, represents the most powerful new battery technology widely used in commerce today.

Lithium ion batteries not only power but enable light-weight consumer electronic devices, electric automobiles, drones, the Internet of Things, high-energy weapons, and a variety of other electrical devices and power applications.

Several new technologies will shape human society and the wealth of nations in the 21st century. Advanced battery technology will be one of them.

But importantly, advanced battery technology will touch upon and enable and provide essential added value to the large majority of those other technologies.

For that and other reasons, any nation wanting to gain leadership in those other technologies and provide its population with related high-paying jobs will want to have a vibrant advanced battery industry within its borders and, if possible, hold the leadership position in advanced battery technology worldwide.

The reason we are here today is because about ten years ago China figured this all out. China has set out and is well on its way to dominating the manufacture of lithium ion batteries and lithium ion battery technology worldwide.

Much is made of Chinese theft of intellectual property, unfair trade practices, and forced technology transfers.

There is some truth in all those allegations, but none of those things, absolutely none of them, accounts for the fact that today, 75 percent of all lithium ion batteries in the world are made in China and less than 5 percent are made in the United States.

To suggest otherwise is misleading and bears the strong scent of sour grapes.

The reason why 75 percent of all lithium ion batteries are made in China and why the United States is fast becoming a minor player is because China has a plan to dominate lithium ion battery technology and the United States does not.

You can't win if you don't play, and it is time that the United States starts to play. I would respectfully suggest to this Commission that rather than looking at China as a threat in advanced battery technology, we look at it instead as a model.

Not a model to copy wholesale, in fact, China's success in and prospects for gaining domination of advanced battery technology are more mixed than many realize.

But the Chinese experience may be a valuable model to learn from and to apply to an American industrial policy that can successfully compete not just with China but with all other countries in advanced battery technology.

First, let's look at what China has done well. Although China subsidizes lithium ion batteries in a number of ways, China's primary emphasis has been to build a robust domestic market for advanced battery-powered devices such as electric vehicles.

It is this robust domestic market that effectively drives everything else, from the ability to manufacture at high volume to the ability to require technology transfer by foreign firms.

According to Forbes Magazine, China spent $7.7 billion on electric vehicle subsidies in 2017 alone, a figure that may rise to $20 billion a year by 2020. Today, there are more than 400,000 electric buses on the road in China procured by local and provincial governments.

It is important to remember that for the cost of those 400,000 electric buses China could have put about a million diesel powered buses on the road.

Had it chosen to do so, we would not be sitting here today. The fact that we are sitting here today is powerful testimony to the importance of China's choice.

By contrast, U.S. policy such as it is has focused on investments in manufacturing capacity for a market that does not yet exist in any robust sense.

Almost all of the $2 billion of investment in advanced battery manufacturing made under the ARRA have failed commercially.

The simple lesson to be drawn from the Chinese experience is that demand-pull policies are more effective than supply-push policies, certainly when done at scale.

The Chinese have also been very disciplined in requiring local content in battery-powered products sold in their domestic market that are eligible for subsidy.

These local content requirements help provide Chinese manufacturers throughout the extensive advanced battery supply chain with business opportunities that they would not otherwise have.

But even more importantly, it provides Chinese workers with the opportunity to learn by doing on the shop floor. The importance of learning by doing on the shop floor cannot be overemphasized.

The shop floor is where most technology innovations occur. In my written remarks I point out that this phenomenon has been particularly evident in advanced battery manufacturing over the last ten years.

By contrast, there is no requirement in the United States that tax incentives provided for purchasing an electric vehicle apply only to U.S.-made batteries.

Likewise, the battery manufacturing funding provided by the ARRA in 2009 did not require that automotive manufacturers use batteries that were made by manufacturers who received that funding. Again, another lesson to learn.

Now, where have the Chinese not been so successful?

While the Chinese have been extremely successful in capturing the market for assembly of lithium ion battery cells and packs, they have been less successful, at least internationally, in capturing the higher ends of the smiling curve of lithium ion battery manufacturing.

The smiling curve, of course, is a theory originally proposed by Stan Shih in 1992 which says that the two ends of the value chain of any product, conception and marketing, command higher values added to the product than the middle part of the value chain, that being assembly and manufacturing.

This is true in the battery manufacturing as well, where R&D, product development, branding, sales and marketing command higher values than the mere act of assembling the battery.

Of course, the Chinese are well aware of this and undoubtedly hope to use their dominance of manufacturing technology to capture leadership and market recognition for their R&D, product design, and branding capabilities. But they are not yet there.

Holding onto those functions should be an important policy objective of U.S. battery and vehicle manufacturers.

Finally, the Chinese have not been successful in cornering the market on advanced battery talent and probably never will be. This may sound trite but freedom matters.

We think of political freedom and individual liberty as a moral issue, it certainly is, but it is a moral issue with real economic consequence.

In my trips to China and in my discussions with colleagues from China, I often hear the same story: to get ahead in Chinese industry or academia you have to have connections.

Political loyalty matters as much as talent and ambition. That is true in all countries with authoritarian regimes. Power corrupts and absolutely power corrupts absolutely.

Corruption properly understood is a tax and it is a tax that falls most heavily on the talented and the ambitious. In closing, I want to tell you a story about the man who was supposed to be here today instead of me, my good friend and NAATBatt Chief Technology Officer, Bob Galyen.

Bob is one of the leading lights of advanced battery technology in the United States. About seven years ago Bob was recruited to move to China in something called the Chinese Friendship Program.

He was given a job at a fledgling battery company called CATL, which Bob and his colleagues have since built into the largest advanced battery manufacturing company in the world.

What Bob found when he got to China is that the Chinese Friendship Program recruits to come and work in China top experts from all around the world in the 10 to 14 technologies being targeted by Chinese industrial policy. According to Bob, program participants are treated like royalty. He tells me it is a little bit like winning the Chinese version of the Nobel Prize. The Chinese Friendship Program is, of course, ingenious.

The value of intellectual property is often overblown. A patent is something that describes an invention that has already been made.

If you want yesterday's innovation, steal a patent. If you want to tomorrow's innovation, steal the talent. That's what the Chinese have figured out.

So, why don't we have a Friendship Program here in the United States? In fact, we do. If you go down to Battery Park in Manhattan and look out over New York Harbor, you will see a monument to that Friendship Program holding a torch in one hand over her head.

In fact, the U.S. Friendship Program is the most successful corporate HR program in the history of mankind.

It is not an accident that a high percentage of the battery scientists and entrepreneurs in the United States today are Americans of first or second generation Chinese heritage.

Today, the U.S. Friendship Program is under serious strain. We hear almost non-stop about the crisis along our Southern border and the dysfunction of current immigration policy.

It is beyond the scope of what I was asked to talk about today to comment on that, but I want to leave you with is this thought.

The race for domination of the advanced battery technology is as much about the competition for talent as it is about anything else.

Talented and ambitious advanced battery experts from around the world must be convinced that they are welcome in the United States and their opportunities in the United States will be better than anywhere else.

The crisis in U.S. immigration policy is undermining that message.

Although the debate and publicity in the United States concentrates on our Southern border, it is sending a message to the talented and ambitious around the world that undermines this country's greatest asset and its greatest advantage over China in the advanced battery race.

That policy, and even more important, the messaging around immigration in the United States must get fixed and must get fixed quickly as part of any plan to protect American prosperity and high-paying American jobs in the 21st century.

I respectfully refer the Commission to the other five policy recommendations contained in my written remarks.

Thank you for your time and attention.

PREPARED STATEMENT OF JAMES GREENBERGER, CO-FOUNDER AND EXECUTIVE DIRECTOR OF NAATBATT INTERNATIONAL

June 7, 2019

James J. Greenberger
Executive Director, NAATBatt International
"Testimony before the U.S. China Economic and Security Review Commission"
Hearing on "Technology, Trade and Military-Civil Fusion: China's Pursuit of Artificial Intelligence, New Materials, and New Energy"
Panel III: China's Capabilities and Export Ambitions in New Energy, Nuclear Power, and Energy Storage

Introduction

My name is James Greenberger and I am the Executive Director of NAATBatt International. NAATBatt is a trade association of advanced battery manufacturers and their supply chain partners doing business in North America. Today, NAATBatt has 110 corporate members, including major automobile manufacturers, electric utilities, equipment manufacturers, battery cell and pack manufacturers, chemical companies, energy materials suppliers and professional service firms. Our organizational mission is to support developments in the science of and markets for advanced electrochemical energy storage technology in North America consistent with the goals of enhancing energy efficiency, reducing petroleum dependence and enabling carbon-free electricity generation.

I apologize for the rough nature of these comments. I am a last minute substitute for NAATBatt's Chairman Emeritus and Chief Technology Officer, Robert Galyen, who had originally been scheduled to testify today. Mr. Galyen, who also serves as the Chief Technology Officer of CATL, the largest lithium-ion battery manufacturer in the world based in Ningde, Fujian Province, China, has a unique perspective on Chinese capabilities and ambitions in advanced battery manufacturing. Mr. Galyen asked me to express his deep regret at being unable to be here today.

Of necessity, my remarks will focus a little less than Mr. Galyen's would have on what is going on in China and a little more on the prospects for the U.S. advanced battery industry in light of the large and growing investment that China is making in lithium-ion battery technology. The views I express are my own and are not the official position of NAATBatt International.

The Importance of Battery Technology

Advanced battery technology, or more precisely the technology that stores and delivers energy to an electrical device in precise amounts, at precise times, and at precise locations, is and will continue to be one of the most important technologies of the 21st Century. If the United States wants to remain a leading economic power, it is essential that U.S.-based companies master this technology and maintain leadership in its innovation, manufacture and deployment.

Advanced battery technology is a strategic technology in that it touches upon and provides spin-out opportunities into most of the other technologies that will shape human society in the 21st Century. Vehicle technology, stationary energy storage on the grid, consumer devices, implanted medical devices, drones, the Internet of Things, high energy weapons, electrified aircraft, ships and submersibles will all depend upon the ability to access electric energy at precise times and places that the traditional electricity grid cannot accommodate. In fact, battery technology sets the pace at which many of these other technologies can evolve and come to market. For example, Apple already knows what the iPhone XIV is going to do. It is just waiting for a battery light enough, powerful enough, durable enough and safe enough to power it. The same is true for other technologies such as rail guns, long duration drones and implanted medical devices. Because the battery is such a key factor in these technologies, the battery manufacturer will always have insight into them and the ability over time to enter into their markets.

An advanced battery also provides a substantial value-added component of the manufactured goods into which they are installed. In electric vehicles today, the battery pack accounts for roughly 40% of the vehicle cost. This percentage may fall as the cost of lithium-ion batteries decline. But it will remain a significant part of the overall vehicle bill of costs because the battery substantially simplifies and makes less expensive the balance of the vehicle. The ability to add substantial value to end products is an essential attribute of a manufacturing process that has the potential to provide high wages to its workers and high profits to its owners.

Battery manufacturing provides substantial backward linkages within its supply chain that help stimulate other industries. Manufacturing lithium-ion batteries requires base materials, such as lithium, nickel, copper, and cobalt, as well as the mixing, compounding and formation of those materials. It requires specialized manufacturing and testing machinery, monitoring devices, electrical control devices, software, adhesives, and metal working. Batteries lie at the end of a long and complex supply chain. Stimulate battery manufacturing and you stimulate a wide swath of advanced manufacturing in other industries.

Finally, the process of battery manufacturing involves a lot of "learning by doing". Over the past 10 years, the price of lithium-ion batteries have fallen by about 80%. Almost none of that reduction has come from improvements in the chemical composition of lithium-ion batteries. The vast majority of the reduction has come from hundreds of small improvements made in the design of batteries on the manufacturing shop floor. That is not surprising. Economists increasingly recognize that the vast majority of technology innovations take place, not in a laboratory or classroom, but on a shop floor. Lose the shop floor and you lose an important opportunity to innovate.

Chinese Efforts to Dominate Advanced Battery Technology

China figured out the importance of advanced battery technology to its economic development more than 10 years ago and has been heavily investing in the sector ever since. Unlike the United States, which has a longstanding ideological discomfort with industrial policy (i.e., picking winners in the private sector), China's innovation and investment in the lithium-ion battery industry has experienced strong support from Federal, Provincial and City governments through a variety of methods ranging from incentive programs, licensing programs, allocations in infrastructure development, to actively managing the battery industry.

In 2016 the Chinese National government issued what has come to be referred to as the "White List" of lithium-ion battery companies. This list is made up of entirely domestic cell manufacturers with more than 8GWh of installed capacity. No non-Chinese companies are included on this list.

All electric vehicles sold in China must use cells and packs made by companies on the list or they will not be eligible for any incentives. This has forced out all non-Chinese manufacturers from the Chinese market.

But the primary focus of the Chinese government in its effort to support the manufacture of advanced batteries has been its support of market demand for the vehicles which are powered by lithium-ion batteries. *Forbes* reported that incentives for the production of electric buses propelled electric bus sales in China from just over 1,000 in 2011 to 132,000 units in 2016. Today there are over 400,000 electric buses in the road in China and more than 30 e-Bus manufacturers.

Purchase incentives for light electric vehicles, including cars, have been at least as aggressive. *Forbes* reports that based on an average subsidy of about $10,000 per vehicle, China's central and local governments spent $7.7 billion on electric vehicle subsidies in 2017 alone. Assuming that current subsidies continue (though it is not clear that they will), *Forbes* estimates that subsidy payments would rise to approximately $20 billion in 2020 and $70 billion in 2025.

China's efforts to corner the market on lithium-ion battery manufacturing have been largely successful. Today, approximately 75% of all lithium-ion batteries made worldwide are manufactured in China.

China's success in capturing lithium-ion battery manufacturing stands in unfortunately contrast to the largely unsuccessful efforts of the Obama Administration to promote lithium-ion battery manufacturing for electric vehicles in the United States. Although the American Recovery and Reinvestment Act of 2009 invested more than $2 billion in domestic battery manufacturing, few if any of the funded projects were commercially successful. With the exception of the Tesla/Panasonic Gigafactory in Nevada, no large scale manufacturing of automotive lithium-ion batteries takes place in the United States today. China's demand-pull approach has proven more successful than the limited supply-push initiatives in the United States.

Policy Recommendations

China and its success in lithium-ion battery manufacturing should not be viewed as a threat. The United States should endeavor to learn from the Chinese experience and to employ some of the same tools that China has used successfully to build its own advanced battery industry. Some possible policies would be the following:

1. *Procurement of Public Electric Vehicles for Mass Transit*. The United States should establish a substantial and well-financed "Procure for Innovation" policy. First priority should be the purchase of electric buses for public transport and of light, medium and heavy vehicles for use by public bodies. Today, almost all procurement decisions in the public sector are driven by price, which generally drives purchasers to non-electric vehicles. This makes sense from the standpoint of the locality or agency doing the purchasing. But it is counter-productive on a national level. A robust investment in public electric vehicles, coupled with strict local content requirements that support the development of lithium-ion battery production in the United States, would return to the public treasury in the long run many times the additional expense of acquiring electric buses and other public vehicles today.

2. *Continue and Expand EV Purchaser Incentives*. The United States should double-down on its investment in tax subsidies and other purchaser incentives for private electric vehicles. Any such subsidies should be conditioned on strict domestic content requirements for the battery technology contained in the vehicle. The local content requirement must be carefully specified. It is not just a matter of mandating U.S.-made steel. The battery technology and battery components should be largely of domestic origin. Also, Congress should consider enacting a special funding mechanism to expand existing purchaser incentive programs. A small user fee charged to purchasers of electric vehicles starting in 2028 could be sold to raise funds for the near-term payment of additional purchaser incentives. The fee would end up paying for itself if an increased market for electric vehicles in the short term helps improve battery technology and lowers the cost of electric vehicles during the period in which the fee is charged. Public investments in vehicle electrification are really investments in infrastructure. They can be financed through user fees, in much the same way that toll roads are financed.

3. *Use Public Subsidies to Push the Envelope on Battery Technology*. Any "Procure for Innovation" policy and EV purchaser incentives should be structured to encourage battery manufacturers to push the envelope of battery technology. The availability of public procurements and private purchasing subsidies should depend on the vehicle battery being "state of the art" and addressing specific areas of concern in battery technology, such as energy density, safety, ease of second use and recyclability. These requirements can be staged over time to push manufacturers to innovate, just as is done with fuel economy standards in ICE vehicles today.

4. *Learn from Foreign Battery Manufacturers*. Foreign-based battery manufacturers should be encouraged to locate in the United States and have access to the U.S. market, provided that American workers have the opportunity to learn from the battery manufacturing technology they bring. Foreign-based companies building battery plants in the United States should be required to use some minimum percentage of local suppliers, engineers and manufacturing technology in their factories and products. The opportunity for American workers to "learn by doing" must be jealously protected as a matter of public policy.

5. *Focus Long-Term Research on Disruptive Battery Technologies*. China's decision to make a massive investment in lithium-ion technology was motivated in part by its desire to compete with more established Western vehicle manufacturers by disrupting the internal combustion engine technology that those Western manufacturers dominate. Having made that investment, however, China is now itself vulnerable to a competitor that can disrupt lithium-ion technology with a better energy storage or energy generation technology. Lithium-ion chemistry is unlikely to be the last word in battery technology. New and better technologies will replace it in time. The United States should focus its public research dollars on finding and commercializing that next generation energy storage/generation technology.

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ADDENDUM

Questions Posed by the Commission:

1. *Describe China's current capabilities in battery production. How have they progressed in the last five years, and what has driven this progress?*

a. The stated reason for battery production is a social need for electrified vehicles which help to reduce air pollution. The government has openly stated that the fast-industrial growth in China has contributed significantly to air pollution, which has in turn created unsafe air to breath in many of the large cities. Cost of health care for people in these large cities are sky rocketing putting a large load on medical costs for society. Therefore, the need for energy storage systems, such as batteries are needed. This is creating social instability in the major cities, forcing people to leave the cities moving back to the countryside or other countries.

b. China has aspired to create manufacturing systems to produce cost effective batteries for use in electrified vehicles through new process innovation, better understanding of the chemistries involved and improved internal process flow, inventory management, supplier development and significantly improved quality systems. China has passed Japan and Korea in battery production in the past 5 years. USA runs a distant 4th place in overall global battery production, and this is with foreign domestic manufacturing capacities from Japan and Korea already in place in USA.

c. China manufacturers have must create their own new process and tooling to increase production speed without sacrificing quality. Much of this has to do with designing and building their own equipment as other equipment manufacturers do not have the experience of making such machines to exacting standards.

d. China's premium cell manufacturers are making high quality batteries for these type applications. Individual cell quality must be in the low parts per million failure rates. Multiple industries needs are fueling other developments which can be utilized into other market segments, such as bus cells used in grid energy storage systems.

e. The biggest manufactures like CATL and others are highest tier quality but there are second tier manufacturers and offshore (Korea, Japan) which drive a culture of fast, aggressive technology development, cost reduction and quality improvements.

f. China has been more customer friendly to work with in terms of customizing designs and even chemistries for faster product development.

2. *To what extent is China's innovation in batteries driven by spillover from its manufacturing capabilities in electronics, as well as government support for developing advanced manufacturing facilities?*

a. There is no "spill over" from electronics in terms of helping the manufacturing processes of batteries. Actually, the battery industry is driving the electronics industry. However, there are two significant factors in how the electronics industry plays a key role in manufacturing of batteries. First, sophisticated electronics for controlling these complex electrochemical cells during charge and discharge is required. Due to the complexity of the chemical reactions these cells must be "balanced" by highly accurate electronic measurements and control. Secondly, the consumer electronics industry started the revolution of using advanced battery technologies due to size and weight requirements for handheld devices. This same approach in technology was adopted into the transportation sector. Although electronics play a significant role in these battery systems for all applications, the electronics industry did not drive the battery production, it was the battery technology which drove the electronics industry by enabling dispatch-able energy.

b. The battery industry did not have the right equipment for high precision battery technology manufacturing. The battery manufacturers had to design the equipment themselves, then farm it out to companies to make the equipment for them.

c. The Chinese governmental incentives packages drove the industry but not direct investment. The stated purpose of these incentives were to improve air quality in the large cities by utilization of electric vehicles. This was done in harmony with reducing coal burning plants or cleaning up the coal burning. This pushed and encouraged innovation in battery manufacturing technology. These incentives drove cooperation between vehicle manufacturers and battery manufacturers to achieve common goals of production and profitability. The incentives targeted the automotive and bus market segments directly, not batteries.

3. *How does production in the United States compare to production in China, both in the level of technological sophistication and overall manufacturing capabilities? How is it likely to evolve in the next five years?*

a. The manufacturing technology in most U.S. plants is old compared to that of China. Typically, technologies of domestic battery companies in the U.S. are more than 8 years old, the majority built during the Obama Administration from U.S. government funding.

b. China's level of manufacturing technological sophistication in the larger corporations is at or beyond MES (manufacturing execution system) 3-4 level. Human hands do not touch the product. Automation is nearly 100% in cell manufacturing, and most module manufacturing, and even prevalent in battery pack systems manufacturing. Traceability and quality systems are already in place for complete raw materials, process monitoring, process control and record retention for 15 years. Some of the most sophisticated gaging systems are in place for assuring precision and accuracy in process control measurements.

c. The likelihood of accelerated evolution in China is very high due to high market demand. This is expected to accelerate during the next five years as shown by many consulting forums predictions. In China many battery manufacturers are now consolidating into a few large battery manufacturers.

d. The growth of battery manufacturing sophistication in the United States over the next five years will be largely dependent upon governmental policy and market demand for electric vehicles. The China governmental policy is called "Double Credit Policy" which requires car manufacturers to "balance" the ICE vs EV cars with increasing the balance towards EV's over the next several years.

e. The level of technical sophistication in lithium-ion cell manufacturing in the United States is generally low and the installed capacity within the U.S. is now only about 2% of the total global capacity.

f. The manufacturing capacity that was installed as part of the 2009 ARRA Act was entirely based on Japanese and Korean equipment manufacturers and has not progressed much since then. Significantly, the U.S. government did not require that auto manufacturers in the United States use cells from any of the facilities funded by ARRA grants. So almost the entire manufacturing capacity funded by the ARRA sits idle today with the exception of the LG Chem plant in Holland, Michigan.

4. *Outside of the United States and China, who are the major global players in battery production, and how do their production capabilities compare? How dependent is the United States on imports from these countries, as well as from China? How dependent is China's battery industry on other countries?*

a. Outside of USA and China there are only three major global players, which are located in Japan and Korea. Those players are LG Chem and Samsung of Korea, and Panasonic of Japan. It hard to compare the manufacturing technology due to the stringent security of these manufacturers' plants, just like the Chinese plants. This industry is rich in manufacturing trade secrets.

b. It is true that the U.S. consumer electronics industry is highly dependent upon batteries from offshore. But a significant piece of the consumer electronics business is also offshore, meaning the batteries are already installed before hitting U.S. soil. On the EV front, nearly all batteries are manufactured by foreign own domestics or imported from offshore to service the automotive OEM's in the United States.

c. China is not dependent on other countries for battery supply. There has been a significant effort in the past decade to become independent from outside country sourcing due to the multiple industry needs within China's society. Raw materials sourcing, manufacturing equipment, research and development are all well self-contained within China. Only a few raw materials need to be imported into China to complete the battery bill of materials.

d. In the lithium-ion battery space the major players are CATL (China), LG Chem (Korea), Samsung SDI (Korea), Panasonic (Japan), and BYD (China). The U.S. is entirely dependent on China, Japan and Korea for our lithium-ion cells. With very few exceptions, even battery packs that are assembled in the U.S. are made with cells that are sourced from somewhere in Asia. Today, China accounts for about 75% of all lithium-ion cells manufactured in the world. Korea and Japan combined account for about 25% of all lithium-ion cells manufactured in the world with the EU and the U.S. accounting for 1-2% each. However, recent plans and announcements in the EU will increase the lithium-ion cell manufacturing there. In his latest book, "Lithium-ion Battery Chemistries: A Primer" (2019) Dr John Warner estimates that there is about 265GWh of globally installed capacity, and of that only about 25-28GWh are installed in the U.S., and about 22GWh of that is the Tesla/Panasonic Gigafactory. Dr Warner goes on to write:

China has been very actively working to grow and manage the lithium-ion battery manufacturing industry within its borders. The 13th Five Year Plan that was issued in 2015 for the period of 2016–2020 with areas of lithium-ion battery focus including "Use of new energy vehicles to be promoted and the industrialization of electric cars improved" as well as "Clean production to be promote and green and low-carbon industry systems set up. Green finance to be promoted and green development fund established" (Xinhuanet, 2015). In 2016 China's Ministry of Industry and Information Technology (MIIT) created a "White-List" of approved lithium-ion manufacturers for xEV (transportation) applications. In order for a lithium-ion battery manufacturer to be included on the list and be eligible to be used in a xEV application, it requires that 100% of the manufacturing is done in China and was updated in 2017 to include a requirement to have at least 5GWh of installed capacity to be eligible to be on the list. This rule has effectively closed the lithium-ion market for all non-Chinese manufacturers.

The European market has also been moving quickly to install lithium-ion battery capacity. Initially, it was mostly the Asian manufacturers such as Samsung SDI, CATL, and LG who were installing new capacity. However, today there are several new domestic EU lithium-ion battery plants in the works. One is the Swedish firm Northvolt, who broke ground in mid-2018 for a 32GWh plant in northern Sweden. Another was Terra-E, which was a consortium of German manufacturers who had planned to build a 34GWh facility in Germany.

e. France has been putting together a new consortium to support Saft, their domestic lithium-ion cell manufacturer.

5. *Aside from new energy vehicles, what emerging industries are highly dependent on batteries or poised to develop rapidly with improved (e.g., lighter or with greater storage capacity) battery technology? Is the United States competitive in those industries? How is the United States faring vis-à-vis China (including in third country markets)?*

a. Several markets are emerging which can and will utilize advanced battery technology. Those include: marine, rail, drone, mining, agriculture, sensors, micro-mobility, aerospace and many others. ESS, or Energy Storage Systems, is an expression used for grid electric energy storage which is becoming prevalent in the USA due to the increase of renewable energy. All of these are becoming reality as the energy density of the batteries increase and battery prices decrease.

b. Ancillary technologies supporting battery technology cannot be overlooked. Several US based affiliates in China create value in battery technology with their specialty products as suppliers to the big battery manufacturers, whose revenues flow back to the U.S. corporations.

c. Lithium-ion and other advanced battery technologies are now powering a wide range of technologies and markets that have historically used other technologies, including agriculture, mining, and forestry equipment; marine and maritime vessels; buses, ranging from small six person buses up to transit buses; light, medium and heavy duty trucking and delivery vehicles are all experiencing a rapid growth of electrified options; the emerging autonomous vehicles (AV) market will be powered by lithium-ion based technologies. In the aviation space, autonomous and unmanned drones; aircraft; and satellites all use lithium-ion or advanced technology batteries.

e. In addition to these many new and emerging markets, virtually all consumer electronics use a lithium-ion battery technology. Robotics ranging from warehouse stocking robots to military grade explosive detection robots all use lithium-ion batteries. In the medical field more and more new technologies are being enabled by lithium-ion batteries. With the introduction of battery power equipment is now becoming mobile, where it can be brought to the patient rather than bringing the patient to the equipment. This has also enabled telecommunications solutions that allow medical experts to be able to evaluate patients from great distances through wireless, mobile technology. The markets for smart phones, smart devices, the IoT, telecommunication backup centers are all powered by lithium-ion batteries. And increasingly, power companies are installing lithium-ion based energy storage on the grid, with about 95-98% of all new grid energy storage being based on lithium-ion batteries.

f. With new battery developments occurring almost daily and technologies such as solid-state batteries, lithium-sulfur, and others rapidly coming to fruition many of these industries are set for rapid growth, once the energy storage technologies have evolved to a point where power is no longer the limiting factor. And while the U.S. may be competitive in these markets, the batteries for all of these are coming from non-Domestic, and almost entirely Asian, sources.

6. *Where is China putting the most effort into developing new battery technology? What are the advantages and possible applications of these new technologies? What is the state of development in these industries in the United States?*

a. China has a multi-front effort in developing advanced battery technology.

i. First is the chemistry technology of the battery. Chemistry is the heart and soul of battery technology in its ability to store energy in a chemical form and release it upon demand. China, like the rest of the world, could not wait on academicians to spawn new chemistry technology, so most major battery companies have their own internal Research Institutes.

ii. Second is packaging technology which is a critical aspect of battery technology as you must be able to contain the stored chemical energy safely. The higher the voltage the more difficult packaging becomes. All of this is safety related yet influences energy density and charging infrastructure. This involves other aspects such as thermal management, serviceability, recyclability and first responder’s accessibility.

iii. Third is measurement and control technologies of these sophisticated battery cells are critical for safety, performance and life of the battery. Since no two cells are ever exactly the same, these minor differences are compensated by electronics.

b. The advantages and possible applications are already emerging. Here are a few examples:

i. In the aerospace industry nearly 100 companies have sprouted in the past couple of years to develop short range aircraft utilizing advanced aerodynamic electric prop aircraft with passenger loads of 6-12 passengers for short commuter flights of less than 500 kilometers.

ii. In the material handling equipment industry, there is a fast change-over of fork trucks to lithium batteries. Dock cranes are now being equipped with batteries to take advantage of "what goes up must come down" concept. Even elevator technologies are investing wide spread use of batteries for energy recovery.

iii. Several agriculture and construction equipment companies have active projects to investigate electrification to reduce or eliminate in some cases the use of hydraulics. Many have found maintenance and serviceability improvements. It also enables autonomous equipment to do work and return for recharge automatically without operator intervention, such as farming.

c. In some cases of the aforementioned examples U.S. companies are on par, or ahead of other, other companies, but the battery technology in most cases are coming from offshore or foreign owned domestics.

d. The trends in China appear to be heading in several directions. First and foremost, Chinese companies are investing in ways to make their products lower cost as price has always been the main reason for non-adoption. This will allow Chinese companies to effectively "buy" the market and force out non-Chinese companies. Second, China is investing in an entire suite of "Beyond Lithium" chemistries with Solid-State Batteries at the forefront. The promise of low cost, high energy density solutions that can reach 500Wh/kg and 1,000Wh/L may require some form of solid-state battery technology. Third, there is significant interest in multi-valent ion technologies. These are elements such as Aluminum which can transport more than one electron (lithium can only transport a single valence electron). These hold much promise but require much additional work to bring them to fruition.

7. *The Commission is mandated to make policy recommendations in its Annual Report to Congress. What other recommendations do you have for policy that could strengthen the United States' competitiveness in battery production and innovation and reduce its dependency on China?*

Please reference the five policy recommendations made in the main body of my comments.

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PANEL III QUESTION AND ANSWER

COMMISSIONER LEE: Thank you. Commissioner Wessel?

COMMISSIONER WESSEL: Thank you all for great testimony. It has stimulated a lot of questions.

Mr. Greenberger, let me start with you and a lot of questions in part generated by your last comments about your colleague. Because you indicated that he went to China under I believe the Thousand Talents Program, the Friendship, but I think the underlying authorization is the program which pays up to $160,000 for individuals to go there and help China advance their industries.

I have a problem with that, where some of our best talent is going there and building up some of our greatest competitors. At the same time, I don't know whether BYD is a member of your organization --

MR. GREENBERGER: They are not.

COMMISSIONER WESSEL: Well, that helps for my question. BYD is importing, allegedly importing, battery modules here to the U.S., having them put in a case and then having that qualify under Buy America provisions.

Because you talked about demand-pull and I think Buy America is a demand- pull approach but if that approach is undermined by policy games, gimmicks, and lack of proper auditing procedures, we have significant problems.

I was going to use a different term. Please give me your thoughts on why some of our greatest entrepreneurs, et cetera, are going to China to help them create the competitive forces we're now facing as well as what you're aware of in terms of the flaws in our demand-pull system. I think the BYD situation was, in fact, audited in Arizona and found to be at a 53 percent content provision, which is far less than federal transit requirements.

MR. GREENBERGER: Yes. First, with regards to our talent going to China and Chinese talent coming here, it's a free market for talent in the world and we benefit from that.

Overall, I think we win on that trade, hard as it is to say. We've gotten amazing scientists throughout advanced battery technology and other technologies that really drive innovation and job creation in the United States. So, if that's how China wants to play, bring it on. I think it's a great thing to do and we're going to lose a few but I think we're going to win a lot more; we just have to concentrate on winning that talent game and an open competition.

China is paying our talent to go to China and paying talent from around the world because that's the only way they can get it there.

We have a lot of other mechanisms and we need to really double-down and play to our strengths.

With regards to the BYD audit and local content requirements, I'm really not familiar with that particular case, though, quite frankly, given other things I've heard, that doesn't really surprise me.

I think shame on us for not writing those content requirements a little bit more sharply in order to foreclose some of those gaming competitions.

Gaming the law, I can speak as an attorney by training, it sort of comes in with mother's milk and it's always a race between regulators drawing up those regulations and businesspeople trying to avoid them.

We just need to be better regulators, but I believe the opportunity exists to do that and I hope Congress will take advantage of this opportunity to do so.

COMMISSIONER WESSEL: Thank you. Ms. Lovering, you talked at length about the nuclear area.

We have almost no, as I understand it, N-class manufacturers here left in the U.S. since it's been so long since we've produced any new equipment.

And I guess most of the N-class is either in Japan primarily, some in Canada, and an increasing amount in China because of their operations.

What kind of threat do you think the lack of N-class production capabilities here in the U.S. poses to further development as well as national security?

MS. LOVERING: It's definitely a challenge, particularly on cost on the U.S. being able to produce or build new nuclear power-plants at a reasonable cost.

I think the direction that the industry is going is much more globalized and so it's not necessarily the worst situation to be in.

We've just seen news I think two weeks ago that NuScale Power, which is an American company, is partnering with Doosan Heavy Industries from South Korea to do the forgings for their reactor.

And it would be great if those manufacturers were in the U.S. but we simply don't have the market demand to uphold such a large amount of manufacturing.

Particularly for those really large forgings, you need to be doing a lot of nuclear new builds to make that economic, to invest in those facilities.

So, I think the industry is going to succeed or fail based on how well they can do collaboration with manufacturers in other countries. And I think there are good partners and bad partners and South Korea is probably going to be one of the good partners.

Japan we partnered with a lot in the past to do those sorts of forgings. So, that's the direction I see, that's the positive direction we could go in, is better international collaboration.

COMMISSIONER WESSEL: I've heard of concerns on the containment facility issue.

Less concern, of course, sourcing from Japan but if the containment facilities were sourced from China because of production techniques, oversight, et cetera, concern.

Do you share that concern?

MS. LOVERING: Not so much.

From what we've seen with regards to safety standards, China actually tends to follow the safety requirements and standards of the country where they got the technology from.

So, what they tend to do is import the manufacturing facilities from, say, France or Japan and produce them to the standards of those countries.

COMMISSIONER WESSEL: So, for the AP1000 or anything else they're producing, it's the specs of the original?

MS. LOVERING: Yes.

COMMISSIONER WESSEL: Okay, thank you.

VICE CHAIRMAN CLEVELAND: Commissioner Fiedler?

COMMISSIONER FIEDLER: As I recall, the history of Westinghouse, wasn't there a major theft of Westinghouse's technology by the Chinese cybertheft?

MS. LOVERING: I am not familiar with that. That might be before my time.

COMMISSIONER FIEDLER: I may be misremembering.

Of the 50 U.S. companies that you mentioned, anecdotally anyway, because we don't know or at least I don't know, how many of those have been attacked?

Or successfully attacked?

MS. LOVERING: I haven't heard of any cases of IP theft or cyberattack at any of these companies. They're all pretty in the early stages of development and licensing.

COMMISSIONER FIEDLER: You, Mr. Greenberger, sort of diminished the role of cybertheft in lithium batteries.

MR. GREENBERGER: I'm familiar with infringements on intellectual property by the Chinese.

I think the most notorious cases I've heard of have to do with non-payment of royalties due actually to Hydro-Quebec for lithium ion phosphate batteries, which are used almost ubiquitously in China.

But I've been told by folks at Hydro-Quebec they've never seen a dollar of royalty payments. That certainly --

COMMISSIONER FIEDLER: Theft but not cybertheft, right?

MR. GREENBERGER: Not cybertheft, I'm not familiar with cybertheft.

COMMISSIONER FIEDLER: Is the lithium industry on the verge of any technological breakthroughs in the United States? Lithium batteries?

MR. GREENBERGER: No, in a word.

No, we're not because we've for the last ten years, as I had stated in my written remarks, the remarkable thing about the lithium ion battery industry is that we've seen almost an 80 percent reduction in costs and yet, we're still using roughly the same technology that was invented ten years or so ago.

There are certain step changes that are coming, solid-state batteries for example. So, the next stage may be a lithium sulfur battery system, which will get higher energy density and lower cost.

Those are still a few years out.

But the real advances that have been made in batteries have not been because of earthshaking changes in technology manufacturing, but rather by these 100 small changes, these learning by doing on the shop floor that has really advanced the art and moved that technology forward.

There's a lesson in that to be learned about the importance of manufacturing that shouldn't be ignored. But that's where we are in battery tech now.

COMMISSIONER FIEDLER: A number of us know that --

MR. GREENBERGER: I'm sure.

COMMISSIONER FIEDLER: Without any further lesson. What are the proliferation problems with Chinese nuclear exports, if any?

MS. LOVERING: So, there is an ongoing concern because of how China sort of mixes civilian and military technology and science in nuclear.

The concern for exports is more about what they limit and what they constrain in their nuclear cooperation agreement.

So, when the U.S. signs, for example, a 123 Agreement with another country on nuclear cooperation, we tend to require much stricter standards, prohibitions on enrichment and reprocessing as I mentioned.

And the concern is that China is signing these agreements left and right with countries all around the world and that they won't have such strict requirements in place.

COMMISSIONER FIEDLER: Are any of those countries particularly worrisome to us?

MS. LOVERING: There's a lot of countries in Sub-Saharan Africa that are signing agreements with China.

They're very far from importing their first reactors and we don't know if they're actually going to pursue enrichment and reprocessing but that would definitely be a concern if they did.

The other area that's very hot right now is the Middle East and China definitely has ambitions there. So, those would be a concern.

COMMISSIONER FIEDLER: Thank you.

VICE CHAIRMAN CLEVELAND: Commissioner Lee?

COMMISSIONER LEE: Thank you. Thanks to all the panelists for being here today and for your testimony.

Mr. Greenberger, I wanted to ask you a question about one of your policy recommendations around procurement of electric vehicles for mass transit.

And you talk about strict local content requirements that would be required to ensure at least the development of lithium ion battery production. But what about the rest of the vehicles?

Is it realistic to talk about those being here? And then just one further question, up above that you talk about an average subsidy of about $10,000 per vehicle in China.

Can the U.S. Government match that? Is that something that we need to match, or do you think we can be successful in bringing some of that production to the United States in the absence of those big subsidies?

MR. GREENBERGER: First, with regards to local content requirement in buses, I know that there are local requirement regulations for buses.

I think they were referred to by one of your colleagues and I really don't have expertise in that particular area so I can't address it specifically.

But to the point I had earlier made, defining what local content means in an electric vehicle and defining it very specifically is an important thing to do and it's something that we'll probably have to refine over time.

In fact, it can be a tool to help advance the technology itself, as I point out in one of my other recommendations. So, that's something we really need to look at in the United States.

Your second question was whether or not we can be successful in the United States in battery manufacturing without public subsidy of the market.

My opinion is no, we cannot be successful in the United States without a robust domestic market for the products that we want to domestically manufacture.

Japan and Korea have a different model, I think they're going to find themselves very vulnerable in the battery area as China's industry grows.

But the one lesson I pull away from China, the one thing they should have taught us or we should have learned, is the importance of making sure we have a domestic market for the products we're concerned about manufacturing, whether those products are electric vehicles or whether those products are nuclear power-plants. You really can't develop manufacturing domestically, you have no right to expect it, if your local market, your domestic market itself, isn't going to support it.

COMMISSIONER LEE: And the local market in this case would be public procurement, so government procurement dollars being dedicated?

MR. GREENBERGER: Correct, it's an easy way to a lot of batteries on the road and manufactured.

It's probably the lowest-hanging fruit, lower I believe, actually, than private electric vehicles. The economic case for mass transit buses is better than the economic case for private light vehicles.

VICE CHAIRMAN CLEVELAND: Commissioner Lewis?

COMMISSIONER LEWIS: Ms. Lovering, I'd like to ask you a question about the nuclear energy.

Does China have a problem with the waste from nuclear energy and what are they doing about the waste in the countries where they're building nuclear plants?

Is that the main reason that the domestic market has slowed down?

MS. LOVERING: No, it's not a factor for the U.S. market in terms of -- well, it's not a major factor. There are definitely states in the U.S. that have restrictions on new nuclear until the waste problem is solved.

I believe China is in a similar position to the U.S. in that they are developing a long-term strategy to deal with their waste but it hasn't really been implemented yet.

And the reason is very similar to the U.S. in that there's actually not that much waste, it's pretty small in volume so it's a problem that you can sort of put off for a while. And China has not exported any nuclear power projects except to Pakistan so they haven't come up against this problem yet in terms of returning the waste.

The counterexample that I think is really important to keep in mind is that this is how Russia has been very successful in exporting nuclear power, is that they take the fuel back at the end of its life.

So, they deal with the waste for countries and that makes them very attractive, particularly for developing countries that want to start nuclear power programs.

Now, whether China will be able to follow a similar model will determine how successful they are in export projects.

COMMISSIONER LEWIS: I'm surprised to learn that waste is not the major problem. What is the major problem of why the domestic market has collapsed?

MS. LOVERING: Cost I would say and construction duration but the thing really is demand.

So we stopped building new nuclear power-plants around 30 years ago and high cost was one reason but also demand for electricity flat-lined in that period.

And so we just didn't build a lot of new power-plants of any kind, coal, natural gas. And then now that a lot of coal plants are retiring, we need to build new generation and the cost is just too high and natural gas is very cheap.

And this is something that you do see comparing the U.S. and China. It's not just that the cost of nuclear is about half in China, it's also cheaper than coal and renewables in China.

Whereas, in the U.S., the cost of nuclear is more than natural gas and more than wind.

COMMISSIONER LEWIS: Could you tell me the military implications of what's going on with nuclear?

MS. LOVERING: What specifically do you mean by military implications?

COMMISSIONER LEWIS: What are the military implications of the fact that our construction of nuclear plants has diminished and China's is building up?

MS. LOVERING: I don't know if it has specific military effects.

The nuclear navy in the U.S. is very separate from the commercial nuclear side, whereas, in China they are much more merged in terms of science and technology.

But I think the broader concern is that the U.S. will start to lose influence in nuclear governance globally and that's where the concerns really lies.

COMMISSIONER LEWIS: Thank you. Mr. Greenberger, I have a question for you about the batteries in Tesla.

I understand the Tesla Gigafactory in Nevada is maybe the largest in the world but China's building ones equally large, and Tesla's building automobiles now in China because the battery is coming from there.

Do you expect that a lot of the automobile companies in the world will move to China because of the battery production there?

MR. GREENBERGER: Well, first of all, my understanding is that there are several battery manufacturing plants around the world, almost all of them in China, that are much larger than the Gigafactory currently in Nevada.

The Gigafactory was big when it was built but technology and the size of the market have moved beyond it since.

COMMISSIONER LEWIS: Where are the other locations?

MR. GREENBERGER: Mostly all in China I think. I don't recall the statistics but I know Bob Galyen always scoffs at the size of the --

COMMISSIONER LEWIS: I'm sorry, I thought you said around the world. Mainly in China?

MR. GREENBERGER: Mainly in China, almost exclusively I believe in China.

COMMISSIONER LEWIS: Okay.

MR. GREENBERGER: With regards to whether auto manufacturing is going to move to China, I've always believed that he who makes the batteries will one day make the cars.

And I do think that is part of the Chinese strategy to go up those other ends of that smile curve and to use the manufacturing of batteries to capture a higher value of products including automobile manufacturing.

I haven't seen that really happen internationally yet but I'm sure that's part of the plan.

COMMISSIONER LEWIS: Are there military implications to what has taken place with the batteries?

MR. GREENBERGER: Absolutely. The first railgun was deployed on a naval vessel just in the last 18 months. The railgun that will one day, they say, replace gun powder in navies.

That's a great step forward technologically, there's just one problem: that ship wasn't ours. You can go on YouTube and see a picture of it, docked in Dalian, in China. It's a Chinese vessel.

Again, we don't know its capabilities but we're cutting our railgun program or cutting back on it is my understanding.

China is moving forward on it largely, I suspect, because they've got so much capability and are getting so much knowledge in managing the types of large electrical charges and storage of energy to produce the large electrical charges that are coming out of their energy systems.

COMMISSIONER LEWIS: When you say railguns you mean what we've seen in the movies?

MR. GREENBERGER: Well, they're lasers, which is kind of what you see in the movies.

But the railgun is actually a projectile that will be shot at hyper speeds out of what looks to be essentially a gun barrel that is expected, really, to replace both conventional military artillery as well as certain missiles. Very cost-effective, it costs you about $10,000 a shot versus hundreds of thousands a shot for a cruise missile.

COMMISSIONER LEWIS: Thank you very much.

VICE CHAIRMAN CLEVELAND: Commissioner Kamphausen?

COMMISSIONER KAMPHAUSEN: Thank you to the panel for appearing today and for your testimony. Dr. Lewis, it's nice to see you again after a number of years.

I actually have a couple questions for you with regards to your testimony. I know your target was to talk about renewables, but could you speak about the broader context of China's both goals for its renewables within its broader energy mix? So that's one.

And then two, you introduced in the latter part of your testimony discussion about export ambitions.

And here I think you talked more broadly about China's energy export ambitions rather than just renewables, especially with regards to Belt and Road.

And so I'd ask maybe if you could make a little add-on to your comments there and maybe even talk to us about some of the downside risks with this broad array of energy infrastructure projects that China is exporting with its Belt and Road initiative?

MS. LEWIS: Thank you for the questions. On your question about broader goals for renewable energy, I think it's important when we're talking about energy storage, this is a relatively new industry, right?

And it's a very exciting place to look at what China's doing there but I think we can actually learn a lot from where China didn't necessarily succeed in these other industries like wind and solar.

Because you actually see a very similar model now being deployed in the energy storage industry focusing on batteries, as you saw, and wind 20 years ago.

And so I would agree with a lot of what was said but I think it's important to be a little bit cautious about the merits of industrial policy and local content requirements in particular.

I think that there's certainly a time and a place for protecting early markets, and that can be a very important part of getting an industry off the ground.

And this is something China has done very effectively across different renewable energy industries, but it actually has I think hurt China in the long run in its ultimate competitiveness and its ability to compete globally in, for example, wind and solar technology.

So I would have some concerns with us sort of copying the Chinese model in the storage industry domestically.

If you're protecting a market, you're also cutting off access to global knowledge and information and we saw in the early days of China's wind power industry, they benefitted greatly before they put in place local content requirements from having side-by-side companies from Denmark, the United States, Japan demonstrating technologies.

And that was actually how they were able to get the early start in this industry. The protectionism came later once they were trying to keep the GEs out of the market.

So, I think we need to look a little bit holistically at the whole picture and where industrial policy can and can't really help these industries be successful.

And China's entry into the clean energy space, it very much is a technology -- it's in the innovation policy, it's about strategic focus on industries.

It's also about climate change, it's also about air pollution, right, but it's the synergies that is what leads to this focus. And I think that's why it's been so successful.

And just briefly on Belt and Road, and this is obviously a huge enterprise in clean energy, it's one piece of what China's doing in its broader export ambitions.

But I think the real key here is that China is looking for markets abroad because it actually has overcapacity in wind, solar, and maybe even soon in batteries.

Because it needs new markets, its own markets are essentially saturated and dealing with challenging grid integration problems. And so these demand-pull policies only go so far.

There's a lot of pushback against subsidization in China so they're looking for new markets to sell these technologies.

COMMISSIONER KAMPHAUSEN: Can I follow up? Can you remind us of state planning goals with regards to how much wind and solar renewable China wants to have as part of its mix, so overall energy mix at some out year?

MS. LEWIS: So, as part of China's agreement to the Paris Agreement, China has, in addition to a carbon-peaking goal, a renewable energy goal to get to 20 percent of total energy mix by 2030.

And they're probably on track to meet that.

COMMISSIONER KAMPHAUSEN: They are on track?

MS. LEWIS: They will probably exceed that at the moment.

VICE CHAIRMAN CLEVELAND: I think we're going to go to a second round of questions, but I have two.

Ms. Lovering, in your testimony you say despite strong government pressure to localize production, China's state-owned nuclear firms often prefer to source components from foreign firms when they worry a domestic contractor will outsource to a low-quality supplier who is unfamiliar with nuclear facilities.

I have to say that sentence alarms me, that there would be a supplier who is unfamiliar with nuclear facilities. Could you talk a little bit about that concern?

MS. LOVERING: Yes, so part of this, as I mentioned in my spoken testimony, is that China succeeded initially by importing most of their designs from all over the place.

And it sounds like similar to renewables, they partnered with a lot of the leading companies and then worked to indigenize the technology.

But one area where they are struggling and where they still actually rely on foreign companies is in architecture and engineering, the actual construction, and project management.

That's a harder thing to import and a harder thing to copy, whereas, it's easier to buy a manufacturing facility and then start cranking out your own components.

But they're not necessarily -- while they do have very specific targets for localization of components and equipment, they don't seem to have such opposition to relying on foreign companies for project management.

And so I think it's a decision they have made in terms of trade-offs of what works for them and it is concerning that they don't trust their own suppliers. And particularly when they're outsourcing to subcontractors.

But the fact that they recognize that and they trust their regulator for quality control, they want to make sure that they actually meet those standards.

So that is a positive.

VICE CHAIRMAN CLEVELAND: For now.

MS. LOVERING: Yes.

VICE CHAIRMAN CLEVELAND: Dr. Lewis, could you talk about -- I was interested in your testimony that China's development banks and state-owned enterprises are still supporting fossil fuel development while AIIB, the World Bank and others are not.

It seems to be a have-your-cake-and-eat-it-too proposition in terms of China supporting a renewables policy and approach and, yet, their state enterprises and banks continue to be primarily fossil-fuel-focused.

Can you just talk about that blend? And I'm particularly interested in the international lending piece of it.

MS. LEWIS: Yes, I think it's an interesting dynamic because China, of course, has an increasingly important role in the multilateral space as well.

So, AIIB is actually taking on many of the same environmental safeguards that now the World Bank and the Asian Development Bank and others have been essentially pressured to through international conversations.

Whereas, these more commercially driven Chinese banks have a little more latitude in where they want to lend.

And they tend to back the SOEs because that's where their relationships are and the SOEs tend to be dominant in fossil-fuel technology. We see some divergence there.

Shenhua, which is the largest coal company in the world, you see them strategically partnering with acquiring solar and wind companies from around the world. So I think that's a really interesting sign.

It's going to be some time since the move off of coal but I've spoken with many of their executives and I think they realize that coal's days are numbered, not just in China but around the world.

And when you look at these numbers that I've presented for new investment opportunities in the energy sector, what we're building internationally is essentially non-fossil.

The lock-in, the current infrastructure, is primarily fossil but in terms of new investment, far more is actually going into non-fossil. So, they want to be part of that opportunity.

VICE CHAIRMAN CLEVELAND: What would you say percentage-wise was the division between what the state enterprises and state banks have invested in fossil versus what new partnerships or AIIB may be investing in renewables?

Is it 50/50, is it 80/20? What does it look like?

MS. LEWIS: It's closer to I believe 90/10 and I can give you a report that was recently released by the World Resources Institute that tries to lay that out quite carefully.

It's very difficult to get these numbers because they're coming from many places but they did a nice job and I'd be happy to share that with you.

VICE CHAIRMAN CLEVELAND: So, still 90 percent fossil --

MS. LEWIS: Coming from the investment out of China, yes. But within the private companies, if you look just within private investment, a much higher share is going to non-fossil.

VICE CHAIRMAN CLEVELAND: Okay. Commissioner Wessel?

COMMISSIONER WESSEL: Thank you. Dr. Lewis, the second half of this, I guess, is going to be more on you. And thank you again for your testimony.

I want to challenge some of your comments regarding China's policies and their success or failure. You've pointed out that they've built up overcapacity.

Well, they're starting to shove that into the Belt and Road countries. They shoved a lot of it into the U.S.

As I'm sure you probably recall, the -- what is it? -- 3-plus gigawatt wind turbine has 300-plus tons of steel in it, not to mention copper, et cetera, et cetera.

And China was exporting blades and was exporting towers here to the U.S. for a number of years. Whereas, GE, which wanted to export towers and turbine blades and collars and everything else, gear boxes, was told if you want to sell in China you have to produce there.

So, I don't see that China has suffered dramatically. They built up a huge solar sector that we had to do a major trade case, and as you know, it's decimated domestic solar cell, not panel, but solar cell production here in the United States.

So, I want to challenge your comments, your earlier comments also, about the success of bilateral cooperation. We've looked here various times over the duration of the Commission at who benefits from our cooperative research programs. And when one looks at commercialization as a metric, the commercialization production jobs metrics I think are somewhat skewed in China's favor.

So, if you could take that bucket of issues and let me know your thoughts I'd appreciate it.

MS. LEWIS: I'd love to, thank you. I'm going to maybe just start with the last one actually and go backwards because I think I was here in 2014 talking about U.S.-China cooperation on some of these issues, back when we had a more robust program ongoing.

And I think part of the issue is when we look at these questions, we have to think about what is our goal? I think the U.S. goal in this is to be competitive and innovative in these sets of technologies.

And then we have a global goal to deploy these technologies at the lowest cost as possible to deal with climate change and other environmental challenges, right?

And so we have to think globally about the supply chain, where our place is in it and how we can achieve I think both of those goals simultaneously.

COMMISSIONER WESSEL: Agreed, I agree with that, I'm one who believes there's a climate change challenge and it's a global need.

But each ton of steel produced in China, for example, emits three times as much carbon as a ton of steel produced here.

So when you look also at the network, the lifecycle, however you want to do the accounting, it's somewhat specious at times when one does the accounting as to what the overall benefit is of China's approach to commercialization.

MS. LEWIS: So, two points, one is if we are worried about the carbon emissions embodied in steel, there's a variety of domestic policies we could have in place, including carbon pricing and order adjustments which deal with that immediately.

Second, again, if we want to be exporting wind turbine towers around the world then, yes, protectionism works against us but I think we also want to be innovating in the more high-tech components of those technologies.

And that's actually where we still are leading and where China still is reliant on foreign companies. The tower essentially is the lowest-tech piece of the turbine.

COMMISSIONER WESSEL: Agreed.

MS. LEWIS: So, that would be just be my point on that.

And I think just on your last point, on the cooperation, to come back to that, I appreciate the work the Commission has done on trying to look at the effectiveness of cooperation programs.

I think that's very important, I'm writing a book on that as well right now.

And we look at a lot of U.S. companies who do the demonstration piece in China and so when you start to measure who benefits from the commercialization, it's a little bit of a grey area because you actually end up having to force these U.S. firms to do a lot of their deployment there because it's much cheaper to demonstrate these technologies.

Ms. Lovering mentioned it takes half of the cost to build a nuclear plant in China and so why would you ever build it here?

And so we need to think about that because if that is where the manufacturing and the learning is taking place, which I completely agree with, then we're missing out on the important piece of the innovation chain and we're not capturing the learning that could be taking place here.

And that effects the future of these technologies and cost reductions globally.

COMMISSIONER WESSEL: Thank you.

VICE CHAIRMAN CLEVELAND: Commissioner Lee?

COMMISSIONER LEE: Thanks, I'm going to follow up on Commissioner Wessel's question too, and maybe for all of you a little bit because I think we've heard somewhat different things from the panel around demand-pull versus supply.

And in terms of industrial policy or protectionism, it doesn't seem like there's going to be one answer. It's not that industrial policy always works or it's always terrible, it's really a question of getting the timing right. And there are various tools that a government can use in terms of creating demand. Even, Dr. Lewis, in your paper you talk about accelerating the clean energy transition and I think most people would think that's a good idea. And accelerating the clean energy transition in the United States creates a certain amount of demand, and then the question is how do you satisfy the demand?

So, procurement policy is a tool that the government has, that any government has. How do you use the perks and power of the government to encourage or discourage or reward certain kinds of behavior?

And trade policy is the other piece of it and Commissioner Wessel mentioned that certainly in the early stages of some of this clean energy production, a lot of other governments, the Chinese Government, was illegally subsidizing production of many of these things.

And then that creates kind of a trajectory over time where the United States is kind of behind the game.

And so a question is do we need to be using trade policy more strategically, more nimbly, more quickly in order to address these kinds of competitive disadvantages that arise through violations of the rules of the international trade system?

And when we've fallen behind, is there anything that we can do to not be permanently behind in some of these important changing innovative industries?

So, I'd open the floor to any of you who want to speak on it.

MR. GREENBERGER: I'll take a first go at it if, ladies, you don't mind. The thing about industrial policy is that you can't have an industrial policy for everything.

What makes industrial policy so problematic from the standpoint of a country like the United States is that we actually have to ask the government to make choices about which sectors it's going to support in private industry and which sectors it's not going to support.

COMMISSIONER LEE: But if I could, we do that all the time with our tax policy and intellectual property policy. We have an industrial policy, we just don't call it that.

MR. GREENBERGER: Indeed, I would completely agree but I think we are hampered by that fact nevertheless, and that is the reason why we don't have industrial policy in quite the magnitude that they have it in China.

We disguise it a little bit better but, yes, I think most of the major technologies that have evolved over the last century have really been pushed in one form or another by some form of government subsidy, whether that's by defense purchasing, by the space program, whatever.

There are choices we need to make as a country and perhaps we need to be a little less bashful about making them.

And I guess that would be my principal message to this Committee, at least with regards to advanced battery technology. This one is worth the bet and if we want to play in this particular area, we need to make a much bigger bet on it than we have.

MS. LOVERING: I just wanted to add on I think one thing we all agree on is the importance of creating market demand through policies and that's sort of what drives cost down and also drives innovation.

And I think particularly that's something we focused on with nuclear, is what the U.S. is lacking and why we're not competitive. Wind and solar have benefitted greatly from decades of production tax credits but also mandates for renewable energy generation, both at the state level and the federal level.

And that's something that nuclear hasn't benefitted from, and you are starting to see this, though, in the Nuclear Energy Leadership Act, which was introduced last month in the Senate.

There's provisions for a pilot program for federal power purchase agreements for advanced nuclear.

And so that's a small step but that would be a very important step for advanced nuclear and actually getting things built, and eventually bringing the cost down.

And so anything that creates market or helps stimulate the market in the U.S. would eventually help us with exporting and competing in the global market.

MS. LEWIS: I would just briefly add I completely agree with your statements and I think that we need to look at a broad set of demand-pull and supply-push policies together holistically.

I heard the last panel talking about this as well so this is not unique to energy. And my point was just that something like a local content requirement or a federal procurement, this is one piece of a broader set of policies that we need to think about strategically.

And of course there's a place for calling out specific industries. Most of our wind and solar success has been through federal tax credits and a combination of state-led policies, standards or whatnot.

And the RPSs are relatively technology-neutral, the tax credits are pretty specific. On the supply side, important programs that have been moving technologies from lab to market but I think we do better on the kind of early-stage, supporting early-stage commercialization, the sort of ARPA-E and loan guarantee programs.

Despite their challenges, that model is something China is trying to emulate. Their broader innovation ecosystem, certainly, they would like to replicate more what we do.

But they're better I think at capturing the risks associated with demonstrating new technologies and that's something where our firms lose out.

VICE CHAIRMAN CLEVELAND: We've talked a lot about power but we haven't talked a lot about storage and I'm looking at something that you did, Dr. Lewis, for a presentation on ITIF.

Because particularly when it comes to Belt and Road storage, I would think when it comes to renewables it would be an important application or opportunity.

Can you talk about where China is when it comes to developing energy storage technologies?

MS. LEWIS: So, when we move beyond the discussion of looking at ion batteries, there's a million kinds of energy storage technologies and over 99 percent of China's energy storage technically would be what we call the hydropower or the pumped hydro.

Because China has the largest dams in the world and that's a type of energy storage. And they use that not just to generate electricity but they actually use that to balance the grid because it's dispatchable.

So that is a way they can actually use it somewhat for integration. They don't tend to just because of geographic disparities.

But to your point on Belt and Road and where they're going with that, there's a variety of battery and other storage technologies that can be used to make renewables work in a variety of settings where they wouldn't otherwise.

And you see Chinese solar companies, for example, moving into the battery area, the energy storage area, because they can sort of sell a package set of -- particularly in developing countries that are not very connected, you need both.

And so I think that's actually an area where they have a huge advantage and there's a lot of markets around the world where Chinese companies are taking advantage both of their solar technology and the overcapacity that was discussed, as well as their innovation in the battery storage area.

And so this is a huge market in developing countries.

VICE CHAIRMAN CLEVELAND: Can you give an example of how you could see it commercially applied?

I'm sort of trying to think through what it would look like in terms of a market opportunity.

MS. LEWIS: So, it would be different if you're looking at an on-grid or an off-grid application but we could think about an island for example.

Hawaii is our test bed for renewables where they're trying to look at how you integrate large amounts of renewables but you don't have the interconnections, right? And so you have to figure out how do you balance the grid?

And so storage is a piece of that so a lot of the Pacific Island nations that are completely diesel-powered are looking for that. That's a huge opportunity.

There's obviously huge resilience and security benefits to having things other than imported diesel that they're reliant on for their grids.

And we, of course, saw what happened in Puerto Rico, it was sort of the reliance on a single grid system. So, commercial opportunity would be deploying that in these sorts of environments.

It could be an off-grid rural environment or it could be something more like the Chinese model, where it's centralized large-scale renewables.

They do wind and solar primarily in a centralized model and distributed is increasing, meaning like rooftops. But they tend to build these huge plants out in the desert or whatnot.

And so it's actually just like you're building a nuclear plant or a coal plant and you have the same issues with transmission but the additional issue of integration because the wind's not always blowing and then you have to immediately have some kind of load following.

We see interesting market opportunities for the ability to use storage to supply what we call ancillary services, so backing up reliability on the grid, being able to guarantee different services at different times.

So, a lot of this is like innovation also happening in power systems in a lot of countries that are new to building out their grids. They're looking for these smart grid technologies.

Often we talk about storage sort of being in parallel with these smart grid innovations that allow us to do storage, renewables and a variety of new technologies in a way that we didn't necessarily build up our grid here.

VICE CHAIRMAN CLEVELAND: Are we seeing that kind of technology incorporated into their Smart City pilots?

MS. LEWIS: As I understand it, yes. I think there's a lot of different models of what China's doing.

But, yes, one of the areas that if you were either under the storage strategies, smart technologies, smart grid technologies is a really important piece of that.

And I was reading about how you used to have a problem even with electric vehicles where if everyone plugs in their car at the same time, this could cause disruption in the grid.

But if you have a smart technology incorporated in that vehicle that essentially can talk to the grid and say, is this a good time, essentially, to plug in, it can actually shift the load to the middle of the night or a time when there's not an issue.

And so just simply having these smart sensors allows you to think about really new models of deploying these technologies.

VICE CHAIRMAN CLEVELAND: Anybody else? Commissioner Lewis?

COMMISSIONER LEWIS: I'd like to ask Mr. Greenberger and Ms. Lovering about recommendations.

Did I hear you right before that you felt there was no significant military implications for the fact that our nuclear energy construction is down and China's is really high? Did I hear you right on that?

MS. LOVERING: I think there's international relations implications and nuclear governance implications but there's not necessarily implications for our military.

COMMISSIONER LEWIS: If the major reason is cost, what would be your recommendation of how we could compete in that industry?

MS. LOVERING: I think that's one of the main drivers of this focus on advanced nuclear.

So, because we're shifting to very different designs, not light-water reactor technology, the motivation for that is that there can be -- because of passive safety and inherent safety features, you can make the designs much simpler, much easier to construct, and much cheaper.

Now, that needs to be demonstrated and proven but that is where we see sort of if there is a future for nuclear power, it's going to be in these new reactor technologies because they could be both much safer and much cheaper in parallel.

COMMISSIONER LEWIS: Thank you.

Mr. Greenberger, since there are military implications to what you were talking about, what recommendations would you have for us to -- and given that some of our country's leaders don't believe in climate change and so on, what recommendations would you have to build up a larger battery construction industry in the United States?

MR. GREENBERGER: Well, obviously, batteries are used in many more things than in technologies that are designed at least in part to address climate change.

As you correctly point out, they're used in a lot of military applications. I regret I don't have the statistics in front of me but I remember reading about what the cost is to put a gallon of gasoline in a forward operating base in Afghanistan.

It's astronomical, and that's the cost in dollars. There's also another statistic about what it has cost in American lives to move that gallon of gasoline to a forward operating base.

To save American lives, to save American dollars, to permit our military greater flexibility of operation is a message that can well be driven home. One of the other interesting phenomena that's going on politically at least in the United States with regards to energy storage on the grid is it's quickly becoming a bit of a bipartisan issue.

A lot of the states in the central part of the United States where a lot of the renewable energy is being developed traditionally are red states and we're seeing increasing support for technologies that really make those renewable energy assets more valuable. And one of those things that makes renewable energy more valuable is, of course, energy storage.

COMMISSIONER LEWIS: So, what were your recommendations for how to rebuild or how to invigorate the battery storage industry in the United States?

MR. GREENBERGER: Simply to continue to demonstrate that it's about a lot more than climate change, though climate change is certainly part of it. But to sell it on climate change alone really gives --

COMMISSIONER LEWIS: Don't do it.

MR. GREENBERGER: -- short shrift to the technology. There's a lot more at issue.

In particular from my standpoint, the case for economic prosperity and the growth of high-wage jobs, that's the strongest argument there is for battery manufacturing in the United States.

The spin-off opportunities from battery manufacturing, the downside supply pull through the supply chain.

Really, if you had to pick an industry that really had a profound ability to impact economic activity in a society such as the United States, you'd be hard-pressed to find one that had more positive benefits than manufacturing advanced batteries.

COMMISSIONER LEWIS: So, you see economic considerations as well as national security implications?

MR. GREENBERGER: Absolutely.

COMMISSIONER LEWIS: Thank you very much.

MR. GREENBERGER: Thank you.

VICE CHAIRMAN CLEVELAND: Unless there are any other questions, I think we will adjourn for the day. I very much appreciate your contribution to our work.

It's complicated but really interesting and I appreciate you all coming today. We will stand adjourned until June 20th I think is when we're meeting next. Thank you, all.

(Whereupon, the above-entitled matter went off the record at 3:04 p.m.)

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