STEPS

SCIENCE, TECHNOLOGY, ENGINEERING, AND POLICY STUDIES

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Robert (Bob) Hummel, PhD
Editor-in-Chief

IN THIS ISSUE

Articles

US National Security in a New Era of Intense Global Competition
The Honorable Zachary J. Lemnios

Standing Tall: Maintaining US Economic and Military Competitive Posture During Turbulent Times
The Honorable Alan R. Shaffer

Microelectronics: Supply Chain Challenges with "The New Oil"
Michael Fritze, PhD

Counting Things that Count: Assessing the Fundamental Missions of Research and Development Organizations
James J. Richardson, PhD

Free of Charge: Escaping China's Lithium-Ion Battery Dominance
Moriah Locklear, PhD

The Hypersonic Conundrum
Robert (Bob) Hummel, PhD

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About *STEPS*

STEPS: Science, Technology, and Engineering Policy Studies magazine is the technical publication of the Potomac Institute for Policy Studies, where scholarly articles of broad interest are published for the policy community. We welcome original article submissions including, but not limited to the following:

- Discussions of policies that either promote or impede S&T research
- Articles that address implications and/or consequences of S&T advances on national or international policies and governance
- Articles that introduce or review a topic or topics in science, technology, or engineering, including considerations of potential societal impacts and influences
- Articles that cover historical developments in science, technology, and engineering, or related policies, and lessons learned or implications going forward
- Non-partisan opinion pieces concerning policies relevant to S&T, to include S&T research trends or research opportunities, and the role of national policies to promote or modify those trends and opportunities

STEPS promotes the mission of the Potomac Institute for Policy Studies, which fosters discussions on science and technology and the related policy issues. Policies are necessary to advance scientific research toward achieving a common good, the appropriate use of human and material resources, and significant and favorable impacts on societal needs. At the same time, the creation of effective policy depends on decision makers being well-informed on issues of science, technology, and engineering, including recent advances and current trends.

Societal changes arising from technological advances have often surprised mainstream thinkers—both within technical communities and the general public. *STEPS* encourages articles that introduce bold and innovative ideas in technology development or that discuss policy implications in response to technology developments.

We invite authors to submit original articles for consideration in our widely-distributed publication. Full articles should be between 2,000 and 5,000 words in length, and should include citations and/or references for further reading. Contributions will undergo in-house review and are subject to editorial review. Short articles of less than 2,000 words, such as notes, reviews, or letters are also welcome.

Please submit articles to steps@potomacinstitute.org or contact us if you wish to discuss a topic before completing an article. Please refer to the Instructions for Authors for complete information before submitting your final manuscript.

Impressum

Editorial and Production Staff

Editor-in-Chief
Robert (Bob) Hummel, PhD
Email: rhummel@potomacinstitute.org

Associate Editor
Timothy W. Bumpus, PhD
Email: tbumpus@potomacinstitute.org

Director, Potomac Institute Press
Website + Imaging
Alex Taliesen
Email: ataliesen@potomacinstitute.org

Editing + Design
Sherry Loveless
Email: sloveless@potomacinstitute.org

About the Potomac Institute for Policy Studies

The Potomac Institute for Policy Studies is an independent, 501(c)(3), not-for-profit public policy research institute. The Institute identifies and aggressively shepherds discussion on key science, technology, and national security issues facing our society. The Institute remains fiercely objective, owning no special allegiance to any single political party or private concern. With over nearly two decades of work on science and technology policy issues, the Potomac Institute has remained a leader in providing meaningful policy options for science and technology, national security, defense initiatives, and S&T forecasting. The Institute hosts centers to study related policy issues through research, discussions, and forums. From these discussions and forums, we develop meaningful policy options and ensure their implementation at the intersection of business and government. A core principle of the Institute is to be a "Think and Do Tank." Rather than just conduct studies that will sit on the shelf, the Institute is committed to implementing solutions.

STEPS
SCIENCE, TECHNOLOGY, ENGINEERING, AND POLICY STUDIES

CONTENTS

About the Potomac Institute for Policy Studies 4

From the CEO 6
Jennifer Buss, PhD

From the Editor. 7
Robert Hummel, PhD

US NATIONAL SECURITY IN A NEW ERA OF INTENSE GLOBAL COMPETITION. 8
The Honorable Zachary J. Lemnios

STANDING TALL: MAINTAINING US ECONOMIC AND MILITARY COMPETITIVE POSTURE DURING TURBULENT TIMES 20
The Honorable Alan R. Shaffer

MICROELECTRONICS: SUPPLY CHAIN CHALLENGES WITH "THE NEW OIL" 34
Michael Fritze, PhD

COUNTING THINGS THAT COUNT: ASSESSING THE FUNDAMENTAL MISSIONS OF RESEARCH AND DEVELOPMENT ORGANIZATIONS 42
James J. Richardson, PhD

FREE OF CHARGE: ESCAPING CHINA'S LITHIUM-ION BATTERY DOMINANCE 53
Moriah Locklear, PhD

THE HYPERSONIC CONUNDRUM 57
Robert (Bob) Hummel, PhD

Featured Authors. 61

From the CEO

Jennifer Buss, PhD

In recent months, the Potomac Institute focused on facilitating discussions to raise awareness on the importance of economics and industrial input (both products and ideas) in US national security. Industries in the US have a vital role to play in defining national security capabilities and the government should expand avenues for outside voices to enter the conversation.

In order to foster such interdisciplinary conversations, the Institute's Global Competition Project (GCP) seminar series explores all facets of what it means for the US to again face nation-state competition, combining insights from experts in diverse fields associated with societal level competitions. This issue's authors confront the many challenges brought on by the convergence of military, economic, and political transnational competition in today's interconnected and interdependent world, with several of the articles drawing directly on discussions at GCP events for context and ideas.

Today's world is one of possibilities and perils, with advancements coming in nearly every aspect of science and technology every day. The US must find ways to harness these advancements for the benefit of society to remain competitive. The challenges of today are not easy, but the US does have the ingenuity to tackle them—provided all aspects of society are able to contribute to our national endeavor. Societal competition requires a national strategy facilitating the flow of ideas and capabilities between the public and private sectors to extract "goodness" no matter the source.

At the Potomac Institute, we pride ourselves on innovative thinking—pushing ourselves and others to see all that is possible. Through *STEPS*, we call on bold, innovative thinkers to author articles that help us, and our readers, think in this way. Pushing the boundaries of the possible and challenging us all to go forth and implement change. We trust that readers of *STEPS* will continue to appreciate both the cogent analysis and intellectual rigor put forth by the authors. We hope that, after much reading and some discussing, they will also join us in taking inspiration from the challenges laid out by the authors and drive forward to innovate and create the change needed to address our national needs.

Dr. Jennifer Buss
Chief Executive Officer, Potomac Institute
jbuss@potomacinstitute.org

From the Editor

Robert (Bob) Hummel, PhD

Science and technology policies are the engines that propel us to a future of peace and security. In these turbulent times, many other themes tend to drown out that notion. But that is our strong belief, and the foundation of the Potomac Institute for Policy Studies.

In this issue, our featured article, by The Honorable Zachery Lemnios, reminds us that the vectors of nation-state competition include the economic and political domains, as well as the traditional military defense systems. Lemnios points to critical technologies, many already existing in the commercial sectors, that could assist government in confronting the multi-dimensional challenges posed by the interactions of the economic, political, and military global competition. Drawing parallels to the dual-axis great power competition at the start of the Cold War, he calls for the need for a Commission to redefine strategies for national security. The article has received notable acclaim from its advanced publication on the Potomac Institute website.

Two of the additional articles, authored by The Honorable Alan Shaffer and Senior Fellow Michael Fritze, arise from the Potomac Institute's ongoing Global Competition Project. Shaffer discusses how the current trajectories for the refresh of military systems will "break the bank." Fritze continues the Institute's focus on the importance of microelectronics to economic health as well as military affairs, and contributes to the current debate over government funding to assist the United States in becoming less dependent on foreign manufacturing in this vital technology area.

The Potomac Institute consults with many government agencies that are concerned with assessing the performance of Research and Development (R&D) organizations. Senior Fellow Jim Richardson draws on his decades of experience helping R&D organizations assess performance to improve their productivity, providing sage advice and a procedure to define "metrics" that may be used by the leadership of such organizations.

This issue also includes a pair of "short papers." No less important, these contributions are intended as entrées into areas of current debate and foreshadow larger discussions in the future.

We hope this collection of articles offers the chance to reflect on some of the causes and ramifications of the turbulent times the world is experiencing, while inspiring readers to take hold of the opportunities to implement change.

We welcome articles, short articles, and other contributions for future editions. Instructions can be found at: **www.potomacinstitute.org/steps.**

Dr. Robert (Bob) Hummel
Editor-in-Chief, *STEPS*
Chief Scientist, Potomac Institute
rhummel@potomacinstitute.org

FEATURED ARTICLE

US National Security in a New Era of Intense Global Competition

The Honorable Zachary J. Lemnios
Member Board of Regents,
Potomac Institute for Policy Studies

Article first published online as the white paper: US National Security in a New Era of Intense Global Competition.

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Elements of Great Power Competition

A New Era

The United States and China are in a great power competition that will have profound impact on the national security and economic security of both countries for decades.[1,2] This competition aligns across interdependent economic, military, and political vectors. At the core, this is a competition of ideals and governance. But unlike the 20th century Cold War competition with the Soviet Union, the competition with China involves new challenges. The resulting tension between the US and China has opened a new era requiring a new national security framework.[3,4]

In the past, the United States has confronted the need for a complete transformation in the national security environment. For example, after World War II and the proliferation of nuclear weapons capabilities, the nation undertook Project Solarium and the Project Charles Air Defense Study to define a new national security operating model to contain the Soviet Union.[5] The competition with China poses an equally significant challenge now.

Made in China 2025

LOCALIZE AND INDIGENIZE

Promotion of indigenous innovation to develop indigenous technologies, IP, and brands.

SUBSTITUTION

Substitution by domestic production as a strategic imperative once dependence on foreign technology has been reduced.

CAPTURE GLOBAL MARKET SHARE

Capture domestic and international market share across MIC2025 industries and technologies after developing or acquiring its own technology.

KEY SECTORS

- New information technology
- High-end numerically controlled machine tools and robots
- Aerospace equipment
- Ocean engineering equipment and high-end vessels
- High-end rail transportation equipment
- Energy-saving cars and new energy cars
- Electrical equipment
- Farming machines
- New materials, such as polymers
- Bio-medicine and high-end medical equipment

Source: The People's Republic of China State Council, "Made in China 2025 Plan," May 19, 2015.

Economic Competition

The United States and China are in a fierce rivalry spanning a broad range of global markets and complex global supply chains. In 2020, US goods imports of $435 billion and exports of $125 billion reflect a trade imbalance with China. Persistent trade imbalances of this magnitude are unsustainable. This is caused by a complex competition in which the playing field is skewed and can lead to global market instability. Our companies and supply chains are interrelated. We depend upon each other's markets and host each other's companies.

The "Made in China 2025" plan, published in 2015, is China's ten-year plan to reduce China's dependence on foreign technology and to promote China's technology position in the global marketplace.[6] China is focused on leading ten key high-tech industries (see the "Made in China 2025" figure above). Particular technology areas of competition with the US include information technology, robotics, new materials, and aerospace equipment. This plan is structured to raise the Chinese domestic content of core components and materials to 70% by 2025. The plan is the foundation of China's economic competition.

The initial salvo for strategic industry leadership began with 5G wireless-telecommunications, as part of the "new information technology" sector. This is the entry point to the global digital and cyber-physical infrastructure with the opportunity to control the network infrastructure. This is also the path to position China as a "first mover" in training artificial intelligence (AI) algorithms on massive global data, driving AI to the network edge and accelerating digital transformation across many industries.[7]

As a result, China is driving the development of technologies in the 5G telecommunications sector, led by its private sector companies Baidu, Alibaba, Tencent, Huawei, and ZTE (Zhongxing Telecommunications Company Ltd.). While there are over 200 Chinese companies listed on US stock exchanges with a total market capitalization in excess of $2.2 trillion, Huawei and ZTE have been the subject of special scrutiny.[8] In late 2019, the *Wall Street Journal* reported that Huawei had access to as much as $75 billion in support from the China state government.[9] In July 2020, the US government officially designated Huawei and ZTE as threats to US national security, because of their close ties to the Chinese Communist Party and China's military apparatus and their legal obligation to cooperate with China's intelligence services. More recently, White House Executive Order 13959 identified 59 Chinese entities for which US investments are banned by the Treasury Department.[10]

The "new information technology" sector of the "Made in China 2025" plan also depends on advanced semiconductor technology. State-of-the-art-microelectronics requires a complex supply chain with specialized technical talent and massive capital investments. Manufacturing facilities (fabs) are benchmarked by semiconductor wafer size (measured in millimeters in diameter), manufacturing volume (wafers/month) and smallest printed geometric feature (nanometers). Today's state-of-the-art products are manufactured on 300mm wafers at 5nm geometries. At the end of 2018 there were 112 production-class fabs globally utilizing 300mm wafers.[11] The global industry is projected to add at least 38 new 300mm fabs by 2024. Of these, Taiwan is expected to add 11 large-volume fabs, and China will add 8 to account for half of the global 300mm large-volume fabs by 2024. To support this, the China state government has established an investment fund of $150 billion to finance mergers and acquisitions for companies and technologies in the semiconductor industry.[12]

As a result, China is poised to successfully compete in the semiconductor sector. China is making significant investments and now has 13% of the global fabless market, up from 5% in 2010.[13] The Chinese semiconductor manufacturing sector has seen an average compound growth rate of nearly 25% since 2014.[14] Design of semiconductors is also making significant progress in China. In 2019, China's semiconductor design sector reached a level that surpassed Taiwan, making China the second-largest design industry cluster after the United States globally. China's share of semiconductor design grew from 3.6% in 2004 to nearly 43% in 2019.[15] Leadership in semiconductor design and manufacturing implies leadership in new information technology, which is but one sector of emphasis of the "Made in China 2025" plan for economic competition.

The US has begun to recognize the criticality of America's supply chains and the economic security and national security challenge posed by foreign disruption. The recent White House review on this topic launched a comprehensive whole-of-government effort to strengthen domestic competitiveness and supply chain resilience across four critical sectors: (1) semiconductor manufacturing and advanced packaging, (2) large capacity batteries, (3) critical minerals and materials, and (4) pharmaceuticals and active pharmaceutical ingredients.[16]

To answer the challenge of economic competition, the US will need to greatly improve its ability to understand the national security implications of foreign economic developments and to provide better security for its own developments. New technologies can assist in addressing the national security implications of economic competition. Pursuit and integration of these directions into a comprehensive national defense apparatus might require new agencies and resources. Technology concepts, adapted from the commercial sector, could open new approaches to respond to economic challenges. These include the following.

- *Development and utilization of real-time national financial models to provide early warning indicators of critical supply chain disruptions, on both sides, thereby playing long-term offense and defense.* Statistical models applied to open-source financial and industry data are being used today by companies to optimize global supply chain efficiencies and costs. With additional data, these could be used at a national level to preemptively forecast supply chain risks and economic impact and to make decisions to secure critical supplies for national needs.

- *Development and utilization of macroeconomic models to forecast foreign government involvements across global markets, and to provide early indicators of potential disruptive activities*. For example, modeling mainland China's potential economic futures with Taiwan would help to better understand and shape the region to thwart conflicts. Monte Carlo simulation techniques exist today to model thousands of scenarios and alert on early warnings and emerging scenarios, and to game threats and optimize responses. Analysts today monitor military threats; future analysts will use tools to analyze economic threats.

- *Utilization of blockchain, watermarking, design partitioning, and hardware obfuscation security approaches.* Such approaches, emerging for use in commercial venues, can mitigate risks of counterfeiting, intellectual property theft, and tampering. A national approach is needed to integrate in-line data from millions of sensors across complex global supply chains with comprehensive analysis of the data to model and deploy strategies to defend the economic homeland.

Military Competition

Military strength and resiliency comprise a second element of competition. China's strategy of "Military-Civil Fusion" poses significant challenges for the US and our allies. China's Military-Civil Fusion development strategy has leveraged a whole-of-government approach to achieving parity with the United States in several military areas, including air defense systems, land-based conventional ballistic and cruise missiles, and shipbuilding.[17] The prospect of China developing and fielding advanced military capabilities by integrating research across its commercial sector with its military and defense industrial sectors, is a key element of this great power competition.

The Communist Party of China (CPC) Central Committee has established the goal of building a "fully modern military" by 2027, with the capability to defend national sovereignty, safeguard against security threats in the western pacific region, and protect overseas development interests as China's global economic presence grows.[18] These plans include accelerating its integrated development in "mechanization," "informatization," and "intelligentization," comprehensively strengthening military training and preparation. A recent report outlines the pace and impact of China's military modernization, with a focus on the People's Liberation Army's (PLA's) strategy to use science and technology for military purposes.[19]

Over the past decade, China has made significant progress in key technical areas including radio frequency systems, electronic warfare, hypersonics, and more recently quantum computing. As an example, Chinese researchers recently published an approach to network hypersonic weapons into a smart swarm for coordinated attacks.[20] The concept opens the alarming prospect of a saturation attack that would be difficult to counter, even with future air defense systems. Particularly alarming are the references that the Beijing Institute of Technology authors cited, including the Raytheon Tomahawk Cruise Missile (RGM/UGM-109) Technical Manual and System Description.

In the field of quantum technologies, the Intelligent Perception Technology Laboratory of the 14th Institute of China Electronics Technology Group Corporation (CETC) announced China's first quantum radar system in 2016 and displayed a mockup at the Zhuhai Airshow in 2018.[21,22] More recently, China opened the world's largest quantum research center to push the frontier of quantum computing. The National Laboratory for Quantum Information Sciences, a $10 billion four-million square foot facility, has programs in quantum sensing, self-contained navigation, quantum computing, and quantum communications.

The United States has relied upon US technology leadership, unmatched engineering talent, and highly trained military personnel to build, deploy, and operate the world's most technologically advanced military. With the development and availability of key advanced technologies from the commercial sector, nation state competitors and non-state actors now have equivalent access, eroding the technology overmatch to which our nation has grown accustomed. To recover and maintain technology superiority for military systems, new emphasis needs to be placed on defense technologies, involving new research and development agencies and approaches. Some concepts that should be explored prior to establishing such centers include the following.

- *Faster movement toward reinvigorating US technology development demonstrating and fielding advanced technology in key areas.* The Department of Defense can do so by expanding its Federally Funded Research and Development Centers (FFRDCs) and Department Laboratories, or instituting new ones, in partnership with US industry. By using new partnership models to engage in a campaign of continuous development with field testing and integration, the US can match and exceed the efficiency of China's Military-Civil Fusion model for military systems development.

- *Tools and techniques for persistent Gray Zone operations in competition with China.* New approaches are needed to comprehend the long-term regional environment—economically, politically, and militarily. Long-duration campaign planning tools must employ tailorable and reversible effects at the most effective points in a regional campaign. Machine learning and dynamic planning could be adapted from the commercial sector and tailored with appropriate sensor data and modeling to preemptively plan for emerging scenarios. Emerging tools and techniques are beginning to provide military planners a "look ahead" into incipient scenarios and the opportunity to plan accordingly.[23]

- *A new deterrence strategy to address a combined Nuclear, Chemical, Biological, Cyber (NCBC) threat, expanding the range of highest priority threats requiring national capabilities.* New deterrence, detection, and countermeasure techniques are needed considering that any combination of NCBC employment could present an existential threat to the United States. Natural or man-made, the COVID-19 pandemic resulted in millions of deaths and crippled the world's economy for many months. Fielding a global NCBC early warning capability is essential as engineered pathogens could have a similar impact. Deploying such a capability globally with allies and partner nations requires US global leadership.

Political Competition

Political strength is the third, and perhaps most challenging, element of the great power competition between the United States and China. China has harnessed its political and military strength in the South China Sea on a Gray Zone strategy. This has become an operational domain characterized by a long campaign of low threshold actions to achieve long-term strategic objectives without crossing the threshold of military confrontation.[24] It includes elements of Hybrid Warfare[25] and Soft Power.[26]

China and Russia are increasingly using Gray Zone means to achieve their objectives without direct military engagement and below the level of war.[27] The Gray Zone is growing rapidly in the South China Sea, where China is using coercion, intimidation, propaganda, and manipulation to expand its position in the region.[28] China has built an artificial island chain, reclaimed disputed land, militarized islands, and is using legal arguments and diplomatic influence to expand its position.

In early 2020, China's State Council established two new districts in Sansha City, a prefecture-level city headquartered on Woody Island which governs the bulk of China's territorial claims in the South China Sea. This development will expand China's control over the region and further complicate political and diplomatic dynamics.

While military deterrence is essential, the United States and our allies need a set of new technical and operational capabilities to operate in a persistent and multidomain Gray Zone.[29,30]

Prevailing in a prolonged political competition with China requires the United States to develop and implement a whole-of-government approach to integrate economic, political, and military signatures, indications, and warnings. The following technical approaches should be explored and deployed.

- *Intelligence, advanced forecasting, and decision support capabilities to detect, tailor, and preemptively plan economic, political, and military actions*. Political actions can involve influence operations, marketing, competitive assistance, as well as tariffs and sanctions. Techniques can be adapted from the commercial sector to process live-stream data and alert on emergent behavior.

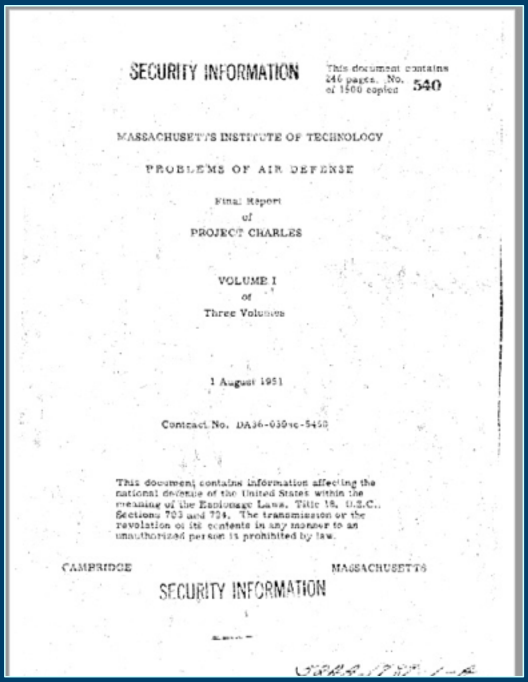
- *Whole-of-government synchronous strategic messaging and information operations using approaches from the commercial sector*. Social media has opened a new strategic communication channel for enabling red teaming against a range of simulated actions and responses from China. The development of multi-domain models could open the prospects of predictive risk assessment to extend our economic, political, and military options.

- *New technical approaches to detect and protect government, enterprise, and private information that are increasingly entangled and increasingly vulnerable***.** Developing an effective layered information defense system is a daunting challenge. In addition to protecting critical infrastructure, effective capabilities would position the United States as a leader in information security, countering China's cybersecurity laws that permit the government to obtain any information that they deem has an impact on Chinese security.

Peer-level Challenges of the Past

The US has faced peer-level national challenges in the past. Our peer-level competition with China on the economic, military, and political levels is no less daunting than the confrontation with the Soviet Union some 70 years ago.

Project Charles Early Warning Architecture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MASSACHUSETTS INSTITUTE OF TECHNOLOGY

PROBLEMS OF AIR DEFENSE

Final Report of PROJECT CHARLES

VOLUME I of Three Volumes

1 August 1951

Contract No. DA36-039sc-5450

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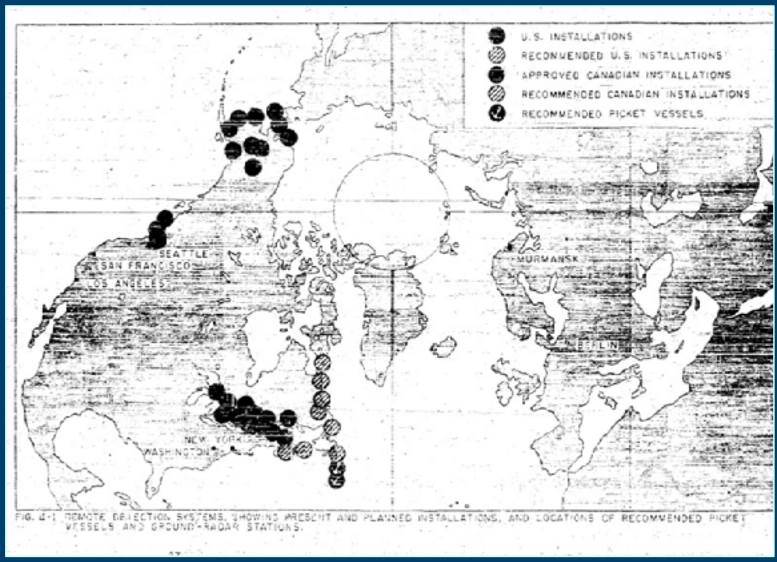


The Soviet Union detonated its first atomic bomb in September 1949, and by 1951, the Korean War had begun as a proxy war with the Soviet Union. With growing geopolitical tension between the United States and the Soviet Union, the US confronted the possibility of a devastating surprise attack.

In response, the US completely revamped the defense system in the 1950s and beyond. A strategy of containing the Soviet Union was devised, and more importantly, enacted. For example, the Project Charles Air Defense Study, begun in 1951, was more than a study, but a four-month effort to design short- and long-term development of an early warning system for attacks that might emanate from the Soviet Union.[31] It led to the formation of MIT Lincoln Laboratory,[32] and engaged scientists and engineers from across industry and academia, and military liaisons, to outline many of the principles of today's air defense systems. They focused on early warning target detection and discrimination, threat interception, and command and control. Project Charles working groups were briefed on Soviet strategic capabilities and visited military operational field sites. They evaluated approaches to detect a small number of threat aircraft buried in a large constellation of commercial aircraft, and the importance of field testing a prototype system comprised of a network of small radars connected to a central computer at a command center.

With urgency to quickly counter the Soviet threat, the Project Charles Study outlined a development program that included short-term extensions of current technologies and longer-term plans to leverage an "electronic high-speed digital computer…and the revolution that the transistor will bring about in electronics to open up quite new possibilities in aircraft and weapon control."[33] These options were available because the United States led the world in radar, electronic warfare, communications, electronics, display, and other key technologies needed to deploy an initial early warning system.[34]

Resulting contracts and development, called "Project Lincoln," led to the Semi-Automatic Ground Environment (SAGE) system and the Distant Early Warning system. Rand Corporation, another Federal Contract Research Center, was involved in developing the programming for the sophisticated mainframe computer, and MITRE was founded in 1958 to operate and expand the system.[35] SAGE protected the United States into the 1980s.[36,37]

The use of federally funded research and development centers (FFRDCs) was established for challenges that cannot be met solely through the commercial sector. As national security threats evolved from bombers to intercontinental ballistic missiles, FFRDCs focused their efforts on a major initiative in ballistic missile defense. This began in the late 1950s, expanded in the 1960s and grew significantly in the 1980s with President Reagan's establishment of the Strategic Defense Initiative.[38] This work was critical to US national security and led to software and hardware concepts which are in use today, including collection and analysis of test data, high fidelity simulations, critical discrimination techniques, and design of new radar and infrared sensors.

Lessons Learned from the Cold War Competition

We can learn from the competition between the United States and the Soviet Union in the second half of the 20th century. The Cold War was a competition between liberal democracies and communism, just as we now confront a competition with a different form of government. The Soviet Union's self-proclaimed world power centered on its massive number of ballistic missiles with nuclear munitions. Without its ballistic missiles, the Soviet Union could not project power very far beyond its regional boundaries.

In our current confrontation, the protagonists are, as before, very careful not to engage with each other in direct military confrontation. Just as the Cold War lasted about 40 years, the current competition is likely to last for multiple decades. The United States, with superior technology, won the Cold War. The US competed with the Soviet Union in a technology race to directly challenge their missile force with developments such as the Strategic Defense Initiative. The Soviet Union was in no position to engage and thus, conceded defeat when President Yeltsin dissolved the Soviet Union on December 8, 1991.[39]

Interdependent Elements of *this* Great Power Competition

While military, economic, and political interdependencies are not new, we are now in competition with a peer nation where military strength alone is not sufficient to succeed.

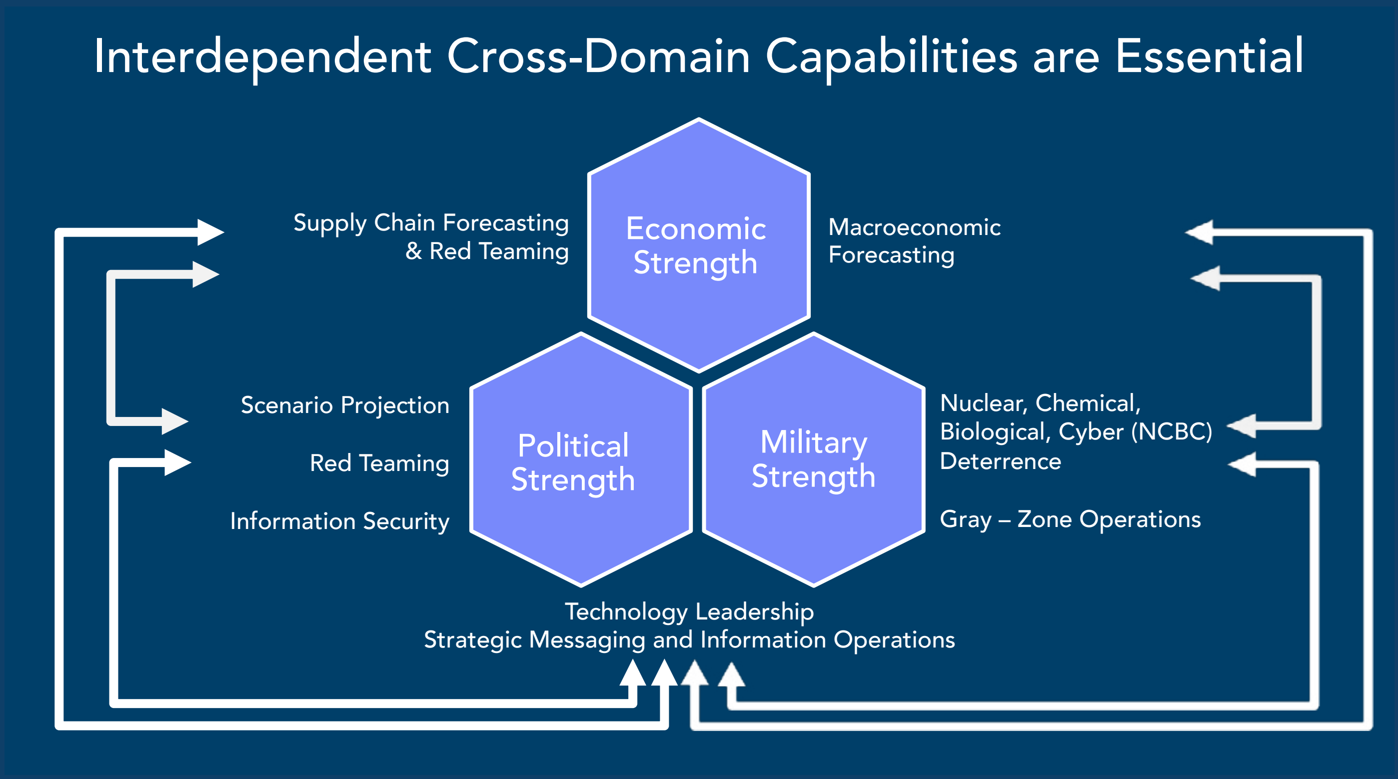
In a similar manner, new technical capabilities and operational concepts are needed to prevail in a long-term great power competition with China, which may also last for decades. In each element of great power competition, there are possible solutions, involving technology, policies, and investments in research and development.

But in developing solutions, we must recognize the interdependencies and interoperability of these capabilities. Responses in one area will affect other areas, and to prevail, we must respond in all areas. Each of these domains—economic, military and political—have unique signatures and can be competitively modeled. But it is the interplay between domains that is critical. The challenge is to decompose this into a cross-domain model, fed by live-stream data to provide insight for preemptive courses of action. This is a messy, loosely structured, data-rich environment with a host of potential threats and ambiguities. It is also the environment we must understand and in which we must prevail.

A Call to Action

The United States and China are in a protracted great power competition that will have profound impact on the national security and economic security of both countries for decades. The complex and interdependent economic, military, and diplomatic tension between the US and China has opened a new era of national security challenges. Just as superior technology allowed the United States to prevail against the Soviet Union, technology solutions will be the deciding factor in our current competition.

And yet, our current structures for acquiring and applying technologies are inadequate for the challenges posed by the new great power competition. The Defense Industrial Base designs and builds weapon systems with advanced technology. The commercial sector is remarkably effective at developing high technology commercial goods. Private industry, often with government help, invests in technologies for health care, transportation, energy, space, materials, and manufacturing. Basic research capabilities and advancements are strong. What is lacking, however, is an integrated approach to addressing the interlocking economic, military, and political competition with those who have developed their own capabilities and technological progress.



A focused executive commission is urgently needed to frame this multi-domain challenge, to include talent from across industry, academia, government, and the military. Like Project Solarium and Project Charles, the study needs to involve the most senior, trusted, and intellectual experts in the nation. The study's "Terms of Reference" should be succinct and blunt: How can the United Stated prevail in the great power competition with China? What new capabilities do we need? What are the operational models and how are these integrated across whole-of-government? Bold ideas merit exploration.

This will not be a study typically conducted by agencies today. This commission needs to have an impact. Both short-term and long-term recommendations must lead to action, both executive and legislative.

The results are certain to support a restructuring of our technology development enterprise. Near-term fixes will be proposed to leverage novel technologies. But long-term developments will also be needed. New long-term institutions are likely to be proposed, including new FFRDCs and new government laboratories. These might be carved from existing institutions, but they also might require new centers to support evolving needs. A pipeline of human capital and infrastructure resources will be necessary. Support to the military's combatant command at United States Indo-Pacific Command (USINDIOPACOM) will be critical to develop and validate cohesive econometric/military/political models that can be integrated through operations. Other combatant commands and collaboration with allies will be equally important. New weapon systems for deterrence will be but one aspect of fortifying a great power competition in the economic, military, and political domains.

The United States has risen to grand challenges in the past, but only by taking bold and decisive steps. Those actions served to prevail in the past, but only after commitments that lasted decades. Today's challenges require similar kinds of commitments. It is time to frame the problem, propose approaches, and make those commitments.

Endnotes

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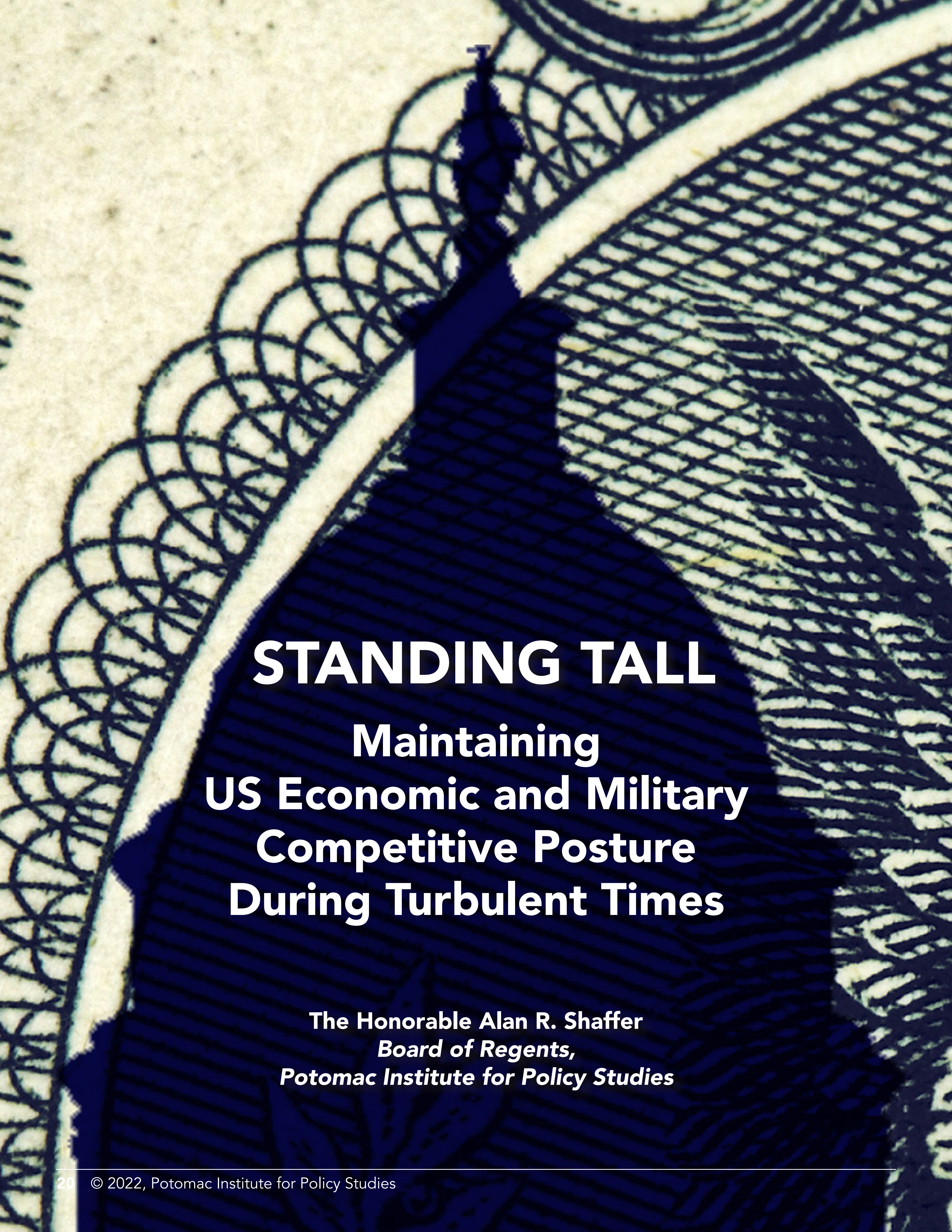
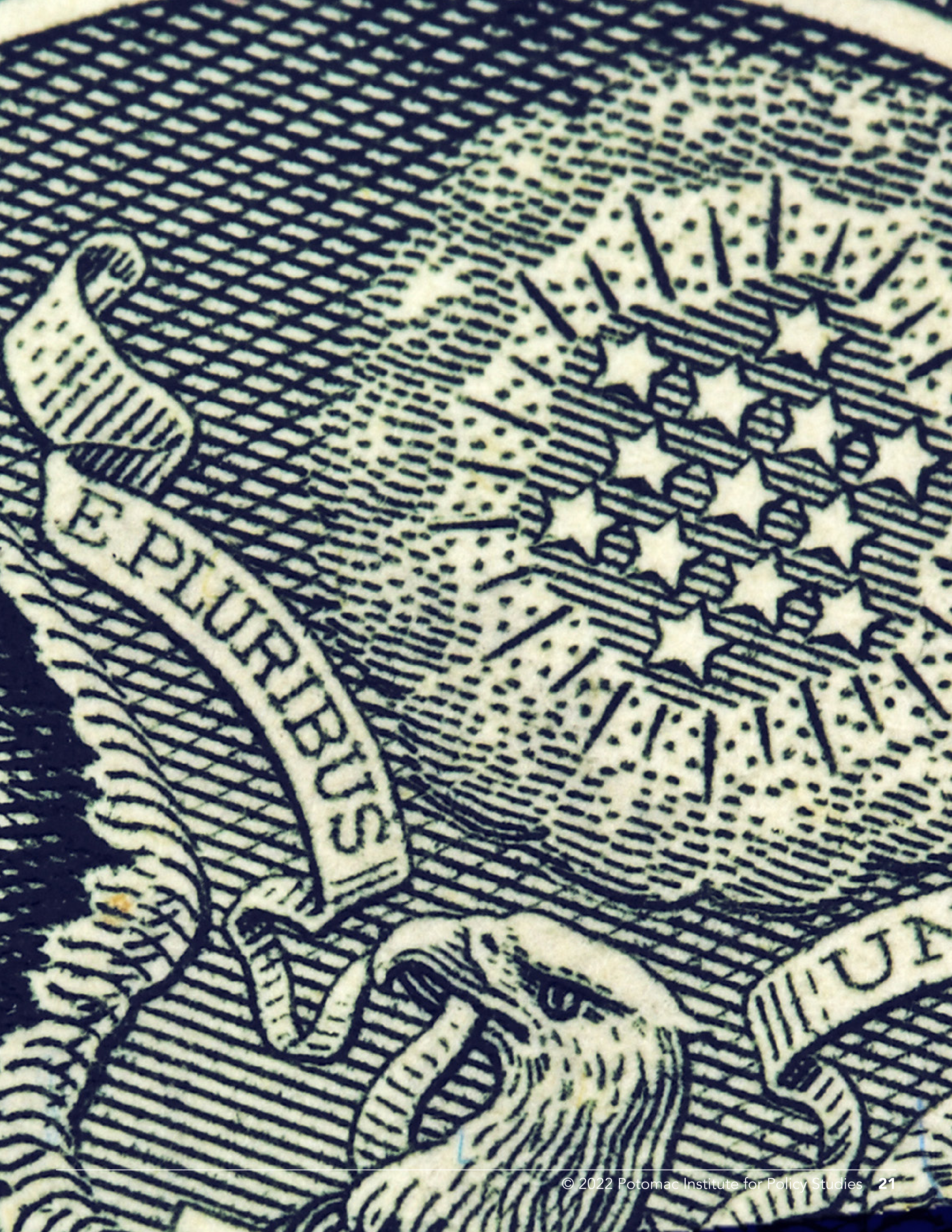


STANDING TALL

Maintaining US Economic and Military Competitive Posture During Turbulent Times

The Honorable Alan R. Shaffer
Board of Regents,
Potomac Institute for Policy Studies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Paul Kennedy's 1987 book, *The Rise and Fall of the Great Powers* demonstrated that throughout history, great powers fell into decline when their economic power failed to support their military and political ambitions. Ways, ends, and means fell out of balance. This paper contends that Paul Kennedy's basic premise applies to the United States in 2022.

The 2017 National Security Strategy used the phrase "Great Power Competition"— a phrase that has been used widely since. Recently, the terminology has been refined to "Strategic Competition with China and any other nation."[1] No matter the label, it is clear that America has reentered a period of competition. Thus, we should ask, "what *is* the current competitive posture of the United States?" This competition is becoming increasingly tense. As recently as the January 2022 Davos World Economic Forum, China's President Xi Jinping pointedly said that there would be grave consequences for any nation that attempted to shift the economic balance by interfering with China's global supply chains, their Belt and Road initiative, etc.

National power traditionally consists of three elements, as taught at the United States War Colleges: economic, military, and political power. This paper examines the current economic and military competitive posture of the United States. Our contention is that *America is living beyond its means* and that *both economic and military elements are in decline* from a competitive standpoint. We will not attempt to assess our standing in political competition with potential adversaries, but clearly challenges exist in that realm, as well.

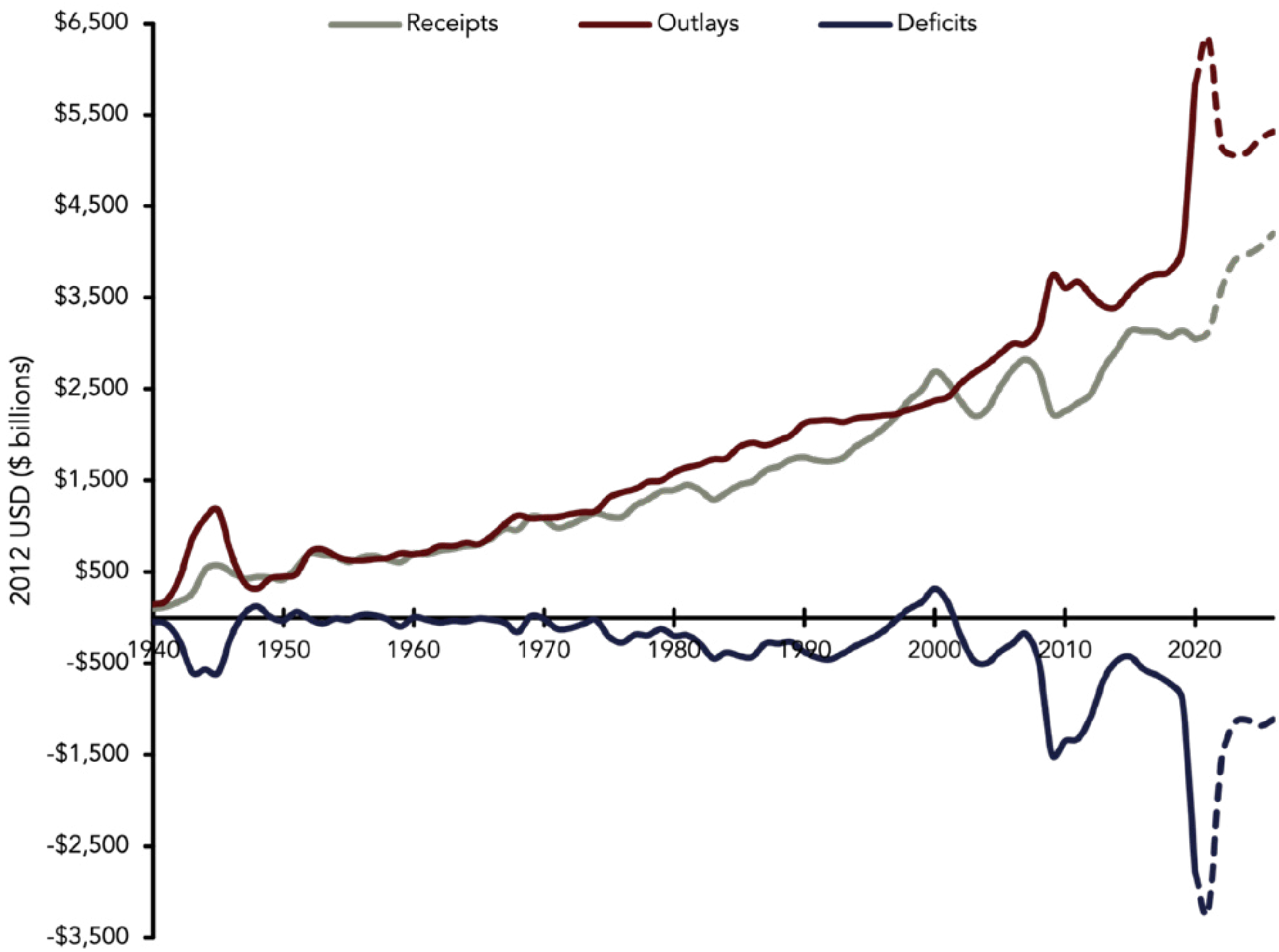

Figure 1. US Budget Snapshot Outlays, Receipts, and Deficit (1940-2025). Data Source: Office of Management and Budget Historical Tables (The White House). The latest OMB Data uses 2012 data for constant year dollars. To convert to 2021 dollars, figures would need to be multiplied by 1.19.

Addressing the economic and military competitive status of the United States will require some reprioritization—and concessions—by Americans. Fixes may occur through new technologies and better strategies, and our purpose here is to foster such discussions and developments.

Measuring national power is not exact. We investigate specific areas of concern for both economic and military competition, using available data. Although we examine them individually, they are strongly interrelated, and assessment of the overall competitive position is qualitative.

Economic

The United States' current competitive economic trajectory is going in the wrong direction as America becomes more deeply in debt, with a record high in both actual debt and debt as a percentage of Gross Domestic Product (GDP). Simultaneously, mandatory federal spending has surpassed discretionary spending. Finally, there is growing income inequality, which, left unchecked, can lead to increased social unrest.[2] Any of these items by themselves are cause for concern. But, if not addressed together, the United States will be challenged in its global competitiveness.

Figure 1 shows the federal outlays (spending), receipts (income from taxes and other sources), and deficits from 1940 to 2025, in constant year 2012 dollars.[3] Note that America has been in a severe deficit status since the early 2000s. The 2021 to 2025 figures are Office of Management and Budget estimates, which tend to be optimistic.

Figure 2. US Budget Snapshot Federal Spending per Person ($K). Data Sources: Office of Management and Budget Historical Tables (The White House) and Population of the United States (United States Census Bureau). The latest OMB Data uses 2012 data for constant year dollars. To convert to 2021 dollars, figures would need to be multiplied by 1.19.

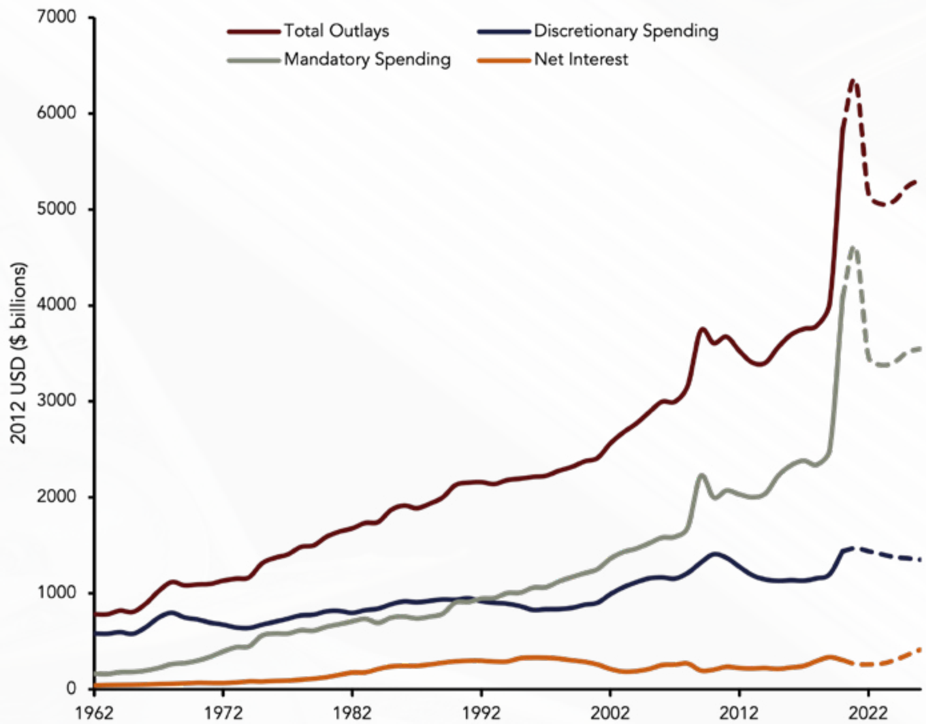

Figure 3. US Budget Snapshot Mandaory/Discretionary Spending (1962-2025). Data Sources: Office of Management and Budget Historical Tables (The White House) and Population of the United States (United States Census Bureau). The latest OMB Data uses 2012 data for constant year dollars. To convert to 2021 dollars, figures would need to be multiplied by 1.19.

Figure 4. US Budget Snapshot Mandaory Spending as a Percent of Federal Outlay. Data Sources: Office of Management and Budget Historical Tables (The White House and Population of the United States (United States Census Bureau).

Figure 5. United States National Debt to GDP. Sources: Congressional Budget Office and Federal Reserve Bank of St. Louis.

Since population growth could explain the growth in spending, Figure 2 is included to show federal spending per person from 1950 to 2021 in constant year dollars (2012). If federal spending aligned with population growth, the value would be constant. It is not. In fact, the federal government today spends three to four times what it spent per person in 1950.

Moreover, in constant year dollars, total federal spending is approximately six times greater than post World War II spending, while federal spending per person has increased four times. One reason for this change is the nature of government outlays over the past 50 years. Figure 3 shows the evolution of mandatory and discretionary programs over time. Figure 4 shows the continued growth of the mandatory portion of the budget as a percentage of total outlays. In 1962, about 25% of federal outlays were "mandatory" (Social Security, Medicare, Medicaid, interest on the debt, etc.). The best estimate is that by 2025, the mandatory spending will account for well over 70% of federal outlays.[4]

While the mandatory outlays have been growing, so has the national debt, both in constant year dollars and as a percentage of GDP. As of 22 January 2022, the United States debt is $29.8 trillion, which is the largest in American history.[5] Further, the ratio of debt to GDP is also the highest in American history, is at 127.55% [6, 7] This is even 10% greater than the end of World War II (see Figure 5). A September 2020 report by the Congressional Budget Office[8] projects that the debt will continue to grow for the next 30 years, reaching 200% of GDP by 2050. A recent report by the World Bank states that a country that has a debt to GDP ratio greater than 77% over an extended period of time will experience reduced economic growth.[9] The United States is well beyond 77%.

Methods to address the debt are limited because 70% of the federal outlays are mandatory. A change in mandatory spending will require a change in the law, which means the "easiest" lever is discretionary spending. Defense makes up half of the discretionary budget. Unfortunately, since 2008, there have only been three years (2008, 2014, and 2015) where the United States budget deficit for the year was smaller than the entire Defense budget. Said another way, Congress could zero out the Defense budget, and America would still have an increase in debt. Therefore, America will not be able to address this debt without changes to the mandatory spending programs, which is not a path that will be popular with most Americans.

Why does debt matter? There are several factors, but consider these two—servicing the US debt and loss of US ability to receive loans. The cost to "service" the debt continues to rise. In 2020, the cost was $522 billion—at minimal interest rates (2.4% in 2019 and 1.3% in 2020).[10] A 2019 study projected the cost to service the debt will be larger than the Defense budget by 2025.[11] This projection was based on estimates before the COVID-19 pandemic; since the start of 2020, the nation has added $6 trillion to the debt, which increases the cost to service the debt. With the size of the actual and relative debt, it is very possible there will be restrictions on the United States' ability to receive loans. Loan restrictions will limit the United States' capacity to participate freely in the global economy, thereby putting America at a competitive disadvantage.

Debt held by private citizens is also rising; it has more than tripled as a percent of GDP since the middle of the 1950s—from about 50% of GDP to over 150% of GDP.[12] There are multiple causes for this, but one contributor has been the cost of higher education. Long-term student loans contribute to economic trends affecting competitiveness of the United States, including income inequality. In short, Americans, like America, are living beyond its means.

In a healthy economy, the gap between the very rich and very poor tends to decrease—a solid economy raises all boats. As measured by the Gini index, an index that measures income inequality in a nation,[13] the US is going in the wrong direction. The 2020 Census Bureau reports that the Gini Index of the US has grown from 0.36 in the late 1960s to 0.46 today. Worldwide, the Gini coefficient is strongly correlated with community violence and social unrest.[14] The United States had the 27th highest Gini coefficient of 143 largest nations; and no NATO nation had a higher Gini coefficient.[15]

The United States income inequality now is more like a third world nation than an advanced liberal democracy. If this trend is not reversed, social unrest will likely grow. Simply, a nation at war with itself is not likely to stay competitive globally.

We have shown that the US national debt is growing rapidly, mandatory expenditures have taken over federal spending, and income inequality weakens our competitive posture. Economic deficiencies of this sort might not matter if we can produce what we need on our own. But when we are beholden to others, who might hold our debt, for essential goods and/or services, then national security can be jeopardized. We give two examples.

National Security Supply Chain Fragility

Microelectronic Supply Chain Vulnerability. Currently, the United States only produces 12% of the world supply of microelectronics, and very little at state-of-the-art (SOTA).[16] This is critical, because modern military systems depend upon a large set of microelectronics—they are the brains and eyes of modern systems. By 2030, the Semiconductor Industry Association predicts that the United States share of global production will decrease to 10%, while China and Taiwan will produce 50% of global microelectronics. Together with South Korea, over 70% of the world supply will be concentrated in one area of the world. Since the US consumes about 48% of the world semiconductor market, the United States is dependent on non-domestically produced chips. Potential adversaries could withhold access or insert "bugs" (e.g., Trojan horses, corrupted software, remote triggers, and so forth), that could conceivably allow an adversary to turn systems on or off remotely or alter the performance in some way. Even without inserted triggers, a monopolistic supplier base puts other nations at an economic disadvantage. This is especially true in an industry that requires expensive and lengthy investment periods before production capacity actually increases.[17] If the supply chain moves to a monopoly, competitive balance is eroded.

The recent shutdown of the Colonial Pipeline in the Eastern United States occurred when Russian hackers took control of the pipeline operating systems. Suppose that this were not a hacker group, but a group enabled by nondomestic chips with embedded backdoors. Similarly, the auto industry found itself at the mercy of a product monopoly foreign supply chain, as a shortage of chips caused a global automotive industry contraction in the amount of $210 billion.[18]

When national security is dependent upon a product, there is really no choice but to spend as needed to ensure economic and security self-sufficiency.

Rare Earth Elements: The American Geophysical Institute estimates that China currently controls 97% of the global supply of rare earth elements (REEs).[19] Many high-end defense systems use REEs and are essential for night vision, SONAR and RADAR systems, satellite communications, heads-up displays in fighter jets, laser systems such as guided weapons and laser targeting systems, and fiber optic cables. Even nuclear threat detection systems use REEs (lanthanum) to detect gamma radiation.[20] The automotive industry is also highly dependent on REEs. Currently, most systems relying on REEs do not have a suitable substitute. This is not an acceptable position for the United States, as REEs provide real capabilities needed by the Department of Defense (DoD), and society in general.

The challenges with a lack of REEs could be remedied by stockpiling (which could be expensive), restarting refinement or production domestically, or by finding a suitable substitute. Starting domestic processing has inherent risks because of the toxicity of processing the elements. It seems that the most logical approach would be a combination of stockpile coupled with a robust research program to find suitable substitutes. The nation does not have such a significant research effort at present.

Our nation is highly dependent on foreign sources for many other supplies and services. For example, pharmaceuticals are important to the health of the nation's population. The COVID pandemic highlighted the pharmaceutical supply chain vulnerability in the US (and the West). The key point is that in cases where the United States has critical dependencies that threaten national security, the nation must increase access from domestic or most favored nation sources.

Military

In August 2021, Admiral Chris Aqulino, Commander United States Indo-Pacific Command stated at the Aspen Security Conference that the United States still has the finest military in the world. The United States continues to spend more on defense than any other nation by a wide margin. Resulting capabilities of the military cover a wide range of mission sets.

The capabilities required for successful future warfighting, however, will be different than those of the past, yet the DoD is still largely focused on platforms that may not be relevant in that future fight. People talk of a 355 ship Navy, up from fewer than 300, now.[21] In 2019, the Center for Strategic and Budget Analysis presented a study indicating that the Air Force needed to grow to 386 squadrons—an increase by about 50 squadrons. Instead of talking in terms of numbers of platforms, the discussion should identify what the nation needs the DoD to accomplish and then, given that mission set, determine how the budget can be realigned to meet those needs.

The Strategic Air Command of the 1950 through the 1980s had the motto "Peace is our Profession." In fact, a primary role of the military in an era of great competition is to be strong enough to deter conflict. In any discussion of military competitive posture, it is an unstated goal to have the strength to deter major conflict. Unfortunately, the United States military is delinquent in modernization of capabilities in long-term competition with adversaries.

The bedrock of national security is the nuclear triad. Currently, the DoD is modernizing all three legs of the triad, with the "Ground Based Strategic Deterrent" replacing Minuteman-III; the Columbia class submarine replacing the Ohio class; and the B-21 Raider and Long-Range Strike Option replacing the B-2 and Air Launched Cruise Missile. The Air Force first fielded Minuteman-III in 1970 with an expected missile life of 10 years. Through several "Service Life Extension Programs," the missile has remained viable, but there is no more viable extension available, according to Admiral Chas Richard, the Commander of the United States Strategic Command.[22] The Ohio class submarine was first fielded in1981; the first will be replaced in 2031. A similar situation exists with the Air Launched Cruise Missile, which was commissioned in the early 1980s with a 10-year life expectancy.

In May 2021, the CBO estimated the cost of nuclear modernization over the period 2021 to 2030 will be $634 billion. Since the overall average total DoD RDT&E and Procurement Budget Request is about $250 billion per year, nuclear modernization will consume over 25% of the research and procurement budget for the next decade. This does not include the cost of modernizing nuclear command and control, another multi-hundred-billion-dollar bill over the coming decade. Subsequent costs after 2030 will be even greater.

Simultaneously, many other systems are entering the high-cost phase, to include full rate production of the F-35, the KC-46, and Next Generation Air Dominance Fighter, Virginia Class Submarines, Ford Class Aircraft carrier, and missile defense systems. We have multiple aging and expensive platforms that need to be replaced simultaneously. Much of this "bow wave" came about because of decisions that individually were logical, but in the aggregate, deferred a lot of modernization by 30 years. This started with the "Peace Dividend" following the fall of the Berlin Wall, to a post 9/11 focus on counterinsurgency, to the "Budget Control Act" of 2011. The cumulative effect places the United States competitive advantage at risk.

Assuming that these are the modernization platforms that align to future mission sets, the costs will nonetheless be staggering.[23] The sustainment costs alone will squeeze out any other research and modernization efforts. If these are not the platforms needed for future missions, then the issue is: How should the Department redirect funding, and what investments are required?

Figure 6 shows the historical trends of the DoD budget in constant year dollars, from an Oct 2021 Congressional Budget Office Study.[24] Figure 7 shows the historical DoD budget as a percentage of GDP.[25] The budget includes all aspects of Defense spending, from personnel costs, including (rising) health care, to acquisition and sustainment, operations, jet fuel, training, retiree pension payments, and when necessary, wartime operations. The DoD budget must address continued increases in "entitlements" (retiree pay, health costs for retirees, etc.). For instance, from 2020 to 2021, the cost of pay, housing and benefits grew by 5%, while force

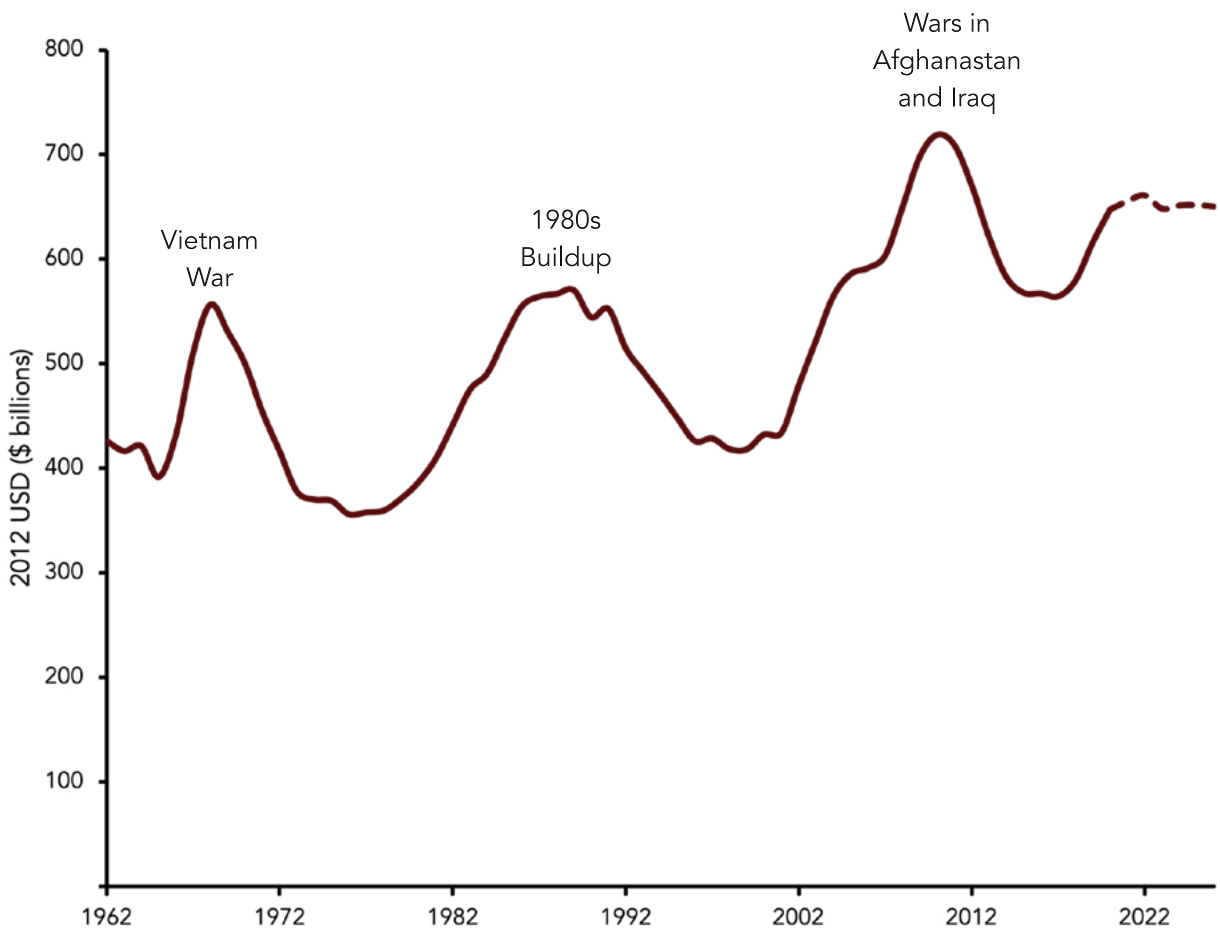

Figure 6. Annual Defense Budget of the United States DoD in Constant 2022 Dollars. Adapted from: Congressional Budget Office, *Illustrative Options for National Defense Under a Smaller Defense Budget.*

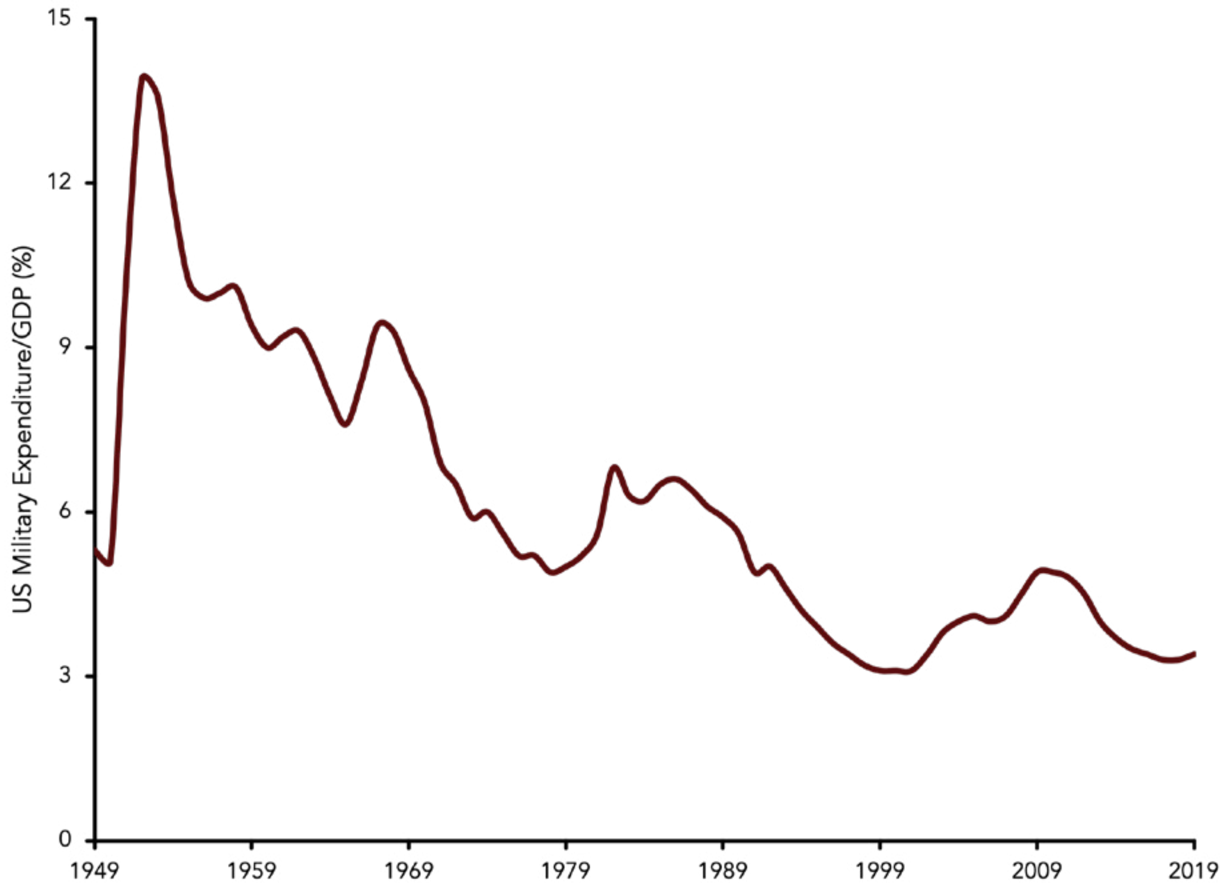

Figure 7. Military Expenditure as a Percentage of GDP. Data Source: Information from the Stockholm International Peace Research Institute (SIPRI), https://www.sipri.org/databases/milex.

size only grew 1%.[26] Major General Arnold Punaro (Ret) recently pointed out that the fully burdened cost of a mid-career person has ballooned from $80K to $400K per servicemember in the last twenty years.[27]

Others have stated the Defense budget will need a 3 to 5% real increase (above inflation) annually for the next decade to field systems in the pipeline.[28] Given other national priorities, this does not seem likely, and in October 2021, the Congressional Budget Office published an option for a $1 trillion reduction over a decade, resulting in a $600 billion budget in 2031.[29]

As seen from Figures 6 and 7, the United States is spending more on Defense in constant year dollars, but with a slowly decreasing percentage of GDP. It is time to readdress what the nation expects of the DoD. If the nation expects a defense against all potential threats, the nation will need to spend appropriately to achieve these goals. The goals must address the overall strategic balance of the defense of the homeland, defense of ideals, and defense of allies.

To compound the challenge, the Department does not have a coherent strategy for cyber, electronic warfare, maneuverable reentry missile defense, information operations defense, etc. The Joint Chiefs of Staff have issued a "Joint Warfighting Concept" for a vision of future combat, with four "strategic directives," which are: contested logistics, joint fires, joint all domain command and control, and information advantage.

Note that these are not platforms, but rather concepts. The DoD continues investing in platforms based on legacy systems and outdated concepts of warfare without prioritizing for future critical capabilities.

The nation has arrived at the position where the physical systems it is buying may not be affordable, let alone relevant to counter the threats we face. The Defense budget focuses on platforms, but not the "enablers" that will allow the force of the future to fight more effectively. The United States may be living beyond its means in what it spends on defense. Yet defense of the population is one of the primary functions of government.

There are two more fundamental changes that are needed to increase the competitive posture of the US military—both are needed to enhance agility and ability to respond more quickly and adapt systems. The first involves how the DoD buys systems—simply, all systems bought should conform to open systems architecture standards using digital engineering. The model that has served the United States well is being surpassed in commercial practices, which allows for easy upgradability. By adopting open systems, it will be possible to swap a microelectronic board, not a total subsystem. Use of digital engineering will likewise allow rapid adaptation. Both open systems and digital engineering will reduce sustainment costs and enhance downstream capabilities.

The other change is about how the DoD budgets. This change will require Congressional action. Currently, the Department must define how it will spend all its money to Congress, with a budget that is built 18 months or more before the money arrives. There has to be a way, working within the constrict that provides Congress the power of the purse, to allow the Department a sum of funds that can be allocated when needed, not when scheduled.

The Issues Going Forward

Integrating our assessments of the economic and military positions of the United States in today's competitive environment, we pose a sequence of salient questions:

- What does the nation expect from its defense enterprise?
- Given that defense spending is a proportion of GDP, and thus incurs opportunity costs that must be balanced against social spending and entitlement costs, what percentage of GDP should be devoted to defense?
- What capabilities and systems need to be procured and on what timetables, prioritized according to missions that answer threats of the future as determined by a strategic review?
- How can the nation efficiently procure those capabilities and systems with sufficient agility and responsiveness in a competitive environment?
- What proportion of defense spending should be devoted to R&D? What R&D is needed?
- How do we incentivize allies to assist in common aspects of defense?

The issues reflect certain structural problems in current practices. The last time the DoD executed a joint bottom-up review was in 1993.[30] In any given year, DoD completes 95% of its budget build for a fiscal year that does not start until 15 months later, thwarting agility and responsiveness. The requirements process of the acquisition system needs overhauling. The US should also expand mutual reliance on allies, such as in the NATO alliance.

Answers must happen at the national level. Taken individually, each of these issues is difficult. In the aggregate, they are daunting. However, other nations are also facing significant challenges, and if America begins to address these issues it is likely that the outcome will be one where America and American allies will not be disadvantaged. America has faced difficult positions in the past and has risen to the challenge.

What Needs to be Done

The DoD should conduct a complete bottom-up review of force structure and platforms and capabilities that are needed to meet a prioritized set of missions for a future defense of the nation. This could be done by a bipartisan panel of national security experts who are given a year or less to complete the review. The Marine Corps did this in their 2022 budget request, realigning their budget to the 2018 National Defense Strategy and Great Power Competition—and in so doing, retired several systems (to include all main battle tanks). A joint review, considering expectations of what national security of the future should include, should be convened.

To improve agility and responsiveness, the structure of the Defense budget, and the way the DoD buys systems needs to change. Current budgets are granular and relatively inflexible, overly prescriptive and not flexible enough for the fluid nature of the globally competitive environment. The DoD must be able to adjust funding as opportunities and necessities arise. In addition, the Defense Acquisition process has to adopt both open systems engineering and digital engineering as the foundation for future systems.

On-going reforms that add agility to the acquisitions system must be accelerated. Fixing acquisition starts with overhauling the requirements process, something the Joint Chiefs of Staff are trying to do. The DoD must step up efforts to prototype for production, not just prototype for technology. And finally, the DoD needs to implement both digital engineering and open systems architecture for all acquisitions. The Services are moving in these directions. They need to accelerate.

America must incentivize expansion of Defense spending by our allies and with those who we share similar values to assure our mutual competitive advantage in the future. NATO has been a successful alliance. While recent events have led to an increase in defense spending across NATO, in 2021, greater focus is needed on expanding mutual reliance, incentivizing fielding of capabilities that assure our mutual security and prosperity.

Implications

Some of the steps the nation may need to undertake will not be easy, or easily accepted by the American populace.

First, economically, America must begin to live within its means. Inevitably, this means incremental tax increases coupled with reduced spending. Reducing spending will require some reduction to mandatory spending.

At the same time, overall income inequality must be addressed. If America does not address the growing economic (and hence societal) gap in our nation, America will continue to bicker internally; a nation at war with itself will not be competitive on a global stage.

The nation must have a serious review of expectations regarding national security, and then allocate sufficient resources, both human and monetary. The review should provide a set of realistic options, and the nation will need to develop a consensus to commit to a long-term strategy. A serious bottom-up review of all platforms and capabilities in the acquisition pipeline will result in some systems being canceled.

Finally, the acquisition needs to be more agile, which will require legislative changes, including revising the planning, programming, budgeting, and execution (PPBE) process.

Summary

The recommendations are easy to write down, but difficult to implement. Addressing these problems in earnest will require balancing overall outlays with the goals and means of the nation. If we do not address these challenges, US economic and military posture will erode. The nation is in an economic situation where servicing the debt is exceeding the current budget for the defense, and the ability to borrow may become jeopardized. This supports Paul Kennedy's thesis that economically, the United States is having a hard time meeting both military and political aspirations, because it is living beyond its means.

Additionally, the nation risks an increased level of social unrest due, in part, to income inequality and an erosion of confidence in the political and economic systems to take care of the American people.

Thus, to remain competitive, America must define the expectations of common defense, and fund that expectation while rebalancing economic priorities, balancing mandatory and discretionary budgets, and addressing the growing inequality in America. Without doing so, the underlying premise of what America stands for will continue to erode, the United States will cease to be a world leader, and will lose its global competitive standing.

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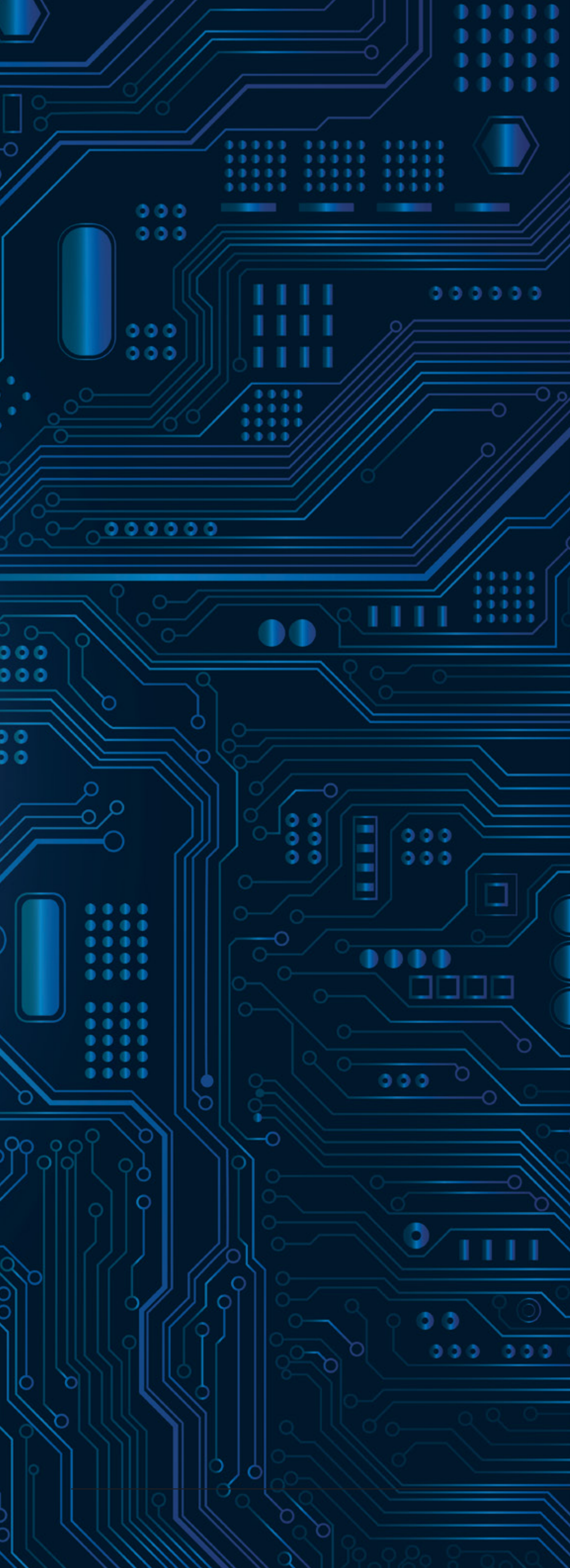
MICROELECTRONICS: Supply Chain Challenges with "The New Oil"

Michael Fritze, PhD
Senior Fellow, Potomac Institute for Policy Studies



A Shortage of Chips

The COVID-19 global pandemic has revealed the fragility of global supply chains. Business practices such as "just-in-time" supply chain strategies, so efficient during normal times, became serious liabilities in the face of supply disruptions, irrespective of their origins. Shortages of semiconductors ("chips") have been but one of the many disruptions to ripple through the US economy in the wake of COVID-19, but one that was both highly consequential and surprising.

The public quickly took note when in the summer of 2020 automobile inventory shrunk and prices rose sharply. Auto manufacturers, such as Ford, had to stop manufacturing new cars and trucks because they didn't have the chips on which the vehicles now depend.[1] Automotive chip shortages persist and the auto industry reportedly took a hit of $210 billion in 2021 alone as a result.[2] These shortages were due neither to delays at port facilities, nor to chip production interruptions at foundries. Rather, just as with shortages of Personal Protective Equipment (PPE) and other goods, a fundamental cause was a dependence on foreign supplies and a failure to maintain sufficient inventory with assured resupply lines in times of need.[3]

Early in the pandemic, the automobile industry made the mistake of canceling orders in anticipation of much lower demand. Other industries were impacted by the shortage of microelectronics and continue to experience disruptions.[4] The risks of relying on fragile supply chains reveals the potential of getting cut off from critically needed supplies in times of crisis. The pandemic highlighted the critical importance of securing US supply chains in the key industry of semiconductors.

National Security Implications

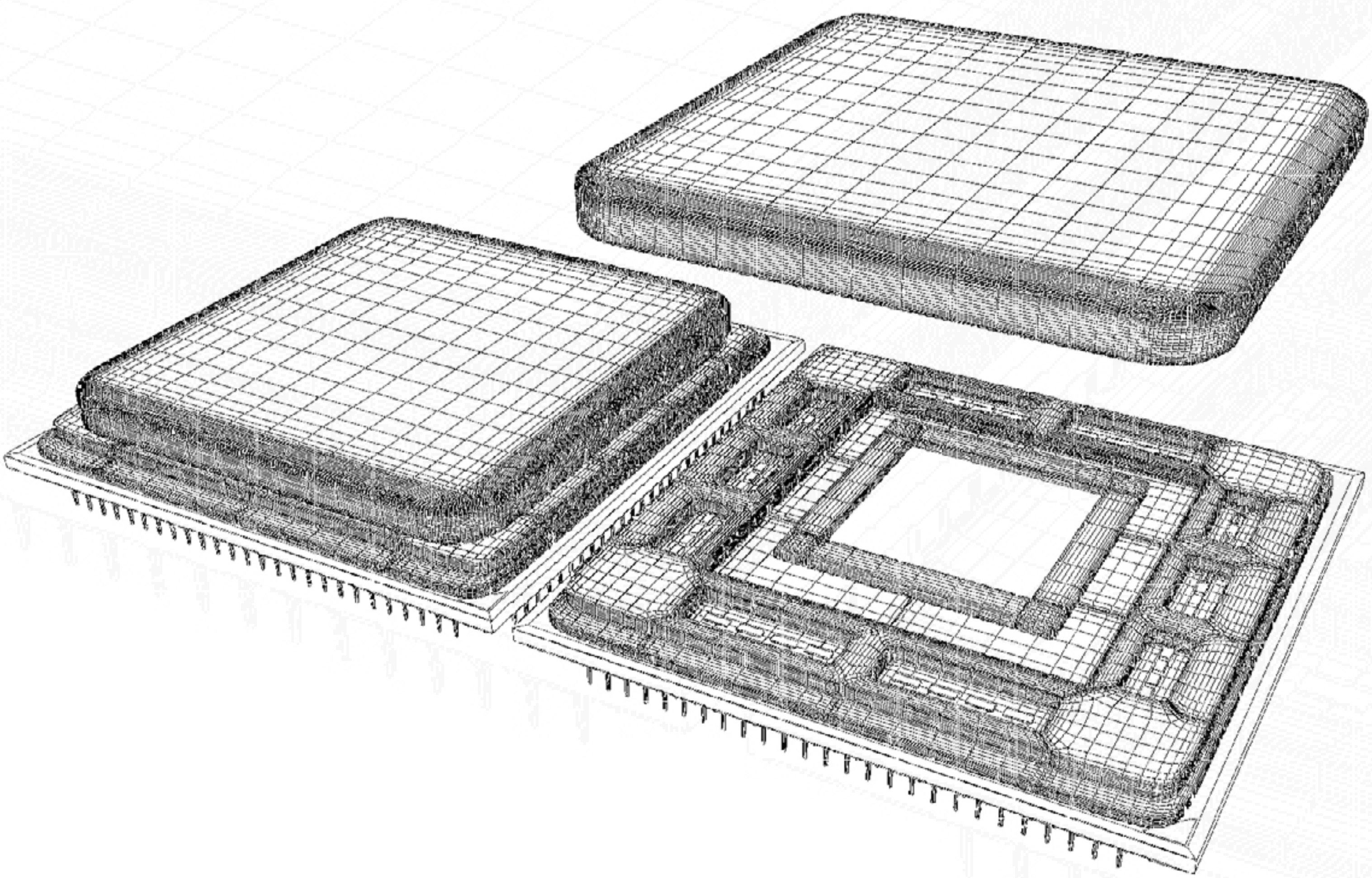
The ramifications resulting from chip shortages go beyond commercial inconveniences. Microelectronics are the foundation of the information economy, the underpinning of all information technology, and a prerequisite for advanced data science and telecommunications, which are all essential to a well-functioning society. But microelectronics is also at the heart of the US nuclear deterrent and conventional weapons systems, critical infrastructure and utility management, and all elements of national defense.

Current supply chain disruptions have shown potential adversaries how serious damage could be inflicted on the US, as described in Al Shafer's paper "The Canary in a Coal Mine."[5]

To be clear, in times of war—whether it is military, economic, or political vectors of combat[6] or whether it is a "gray zone" war or war of competition—dependence on foreign supplies can pose a major national security vulnerability. If supplies are cut off, as in the use of sanctions, manufacturers might be left using inferior parts. For weapon systems, inferior parts lead to inferior weapons. Adversaries might emplace kill switches into parts that are then incorporated into military equipment, giving attackers the power to defeat a system on command. Microelectronic parts, like software, are subject to cyber-attacks. Malicious insertions into microelectronics can enable foreign espionage, which can lead to information theft. Critical infrastructure might be disrupted in times of conflict: electric power or gas distribution might become unavailable. Communications might be disabled to hobble effective national responses.

The national security dependencies on microelectronics change our risk calculus. It is no longer just the losses of the automobile or consumer electronics industries. The security and surety of our microelectronics supply chain is an existential issue of national security, necessary for the protection of the nation from foreign influence, manipulation, and potential defeat.

However, the US Department of Defense (DoD) is no longer the driving force in research and market factors in the microelectronics field.[7] The needs of the commercial marketplace have overridden the national security interests of the US. The risk of supply disruptions is a shared concern across the civilian, military, economic, and commercial sectors.



Assured Access

Any solution must solve two issues with respect to the microelectronics supply:

- Provide a sufficient supply of state-of-the-art components upon demand, with guaranteed access even under adverse circumstances, such as a global pandemic or economic conflict; and
- Provide access to trusted parts free from counterfeits, defects, inferior parts, manipulations, or insertions.

The same issues apply to other sectors, but neither condition is currently satisfied for the microelectronics sector.

The US is highly dependent on overseas suppliers for key semiconductor manufacturing steps, particularly fabrication and packaging and test. The semiconductor industry is a highly globalized endeavor, wherein key supply chain elements are located around the world (see Figure 1). There are multiple steps required in the production and delivery of chips (Figure 2), with the "chip build" as the crucial step for the fabrication of the actual product. As a result of consolidation within the fabrication sector, Asian companies have dominated chip manufacturing (Figure 3). In particular, TSMC (based in Taiwan) holds a commanding 58% market share in the "pure play" foundry market,[8] where the company manufactures semiconductors primarily for outside customers and not internal consumption. Today, the US still dominates in design and verification, and possesses some foundries, but the state-of-the-art components with the most recent developments are only manufactured in Asia.

Access to *trusted* microelectronics is even more challenging. Substitutions, insertions, or other tampering can occur at any point in the supply chain, and the fabrication step is

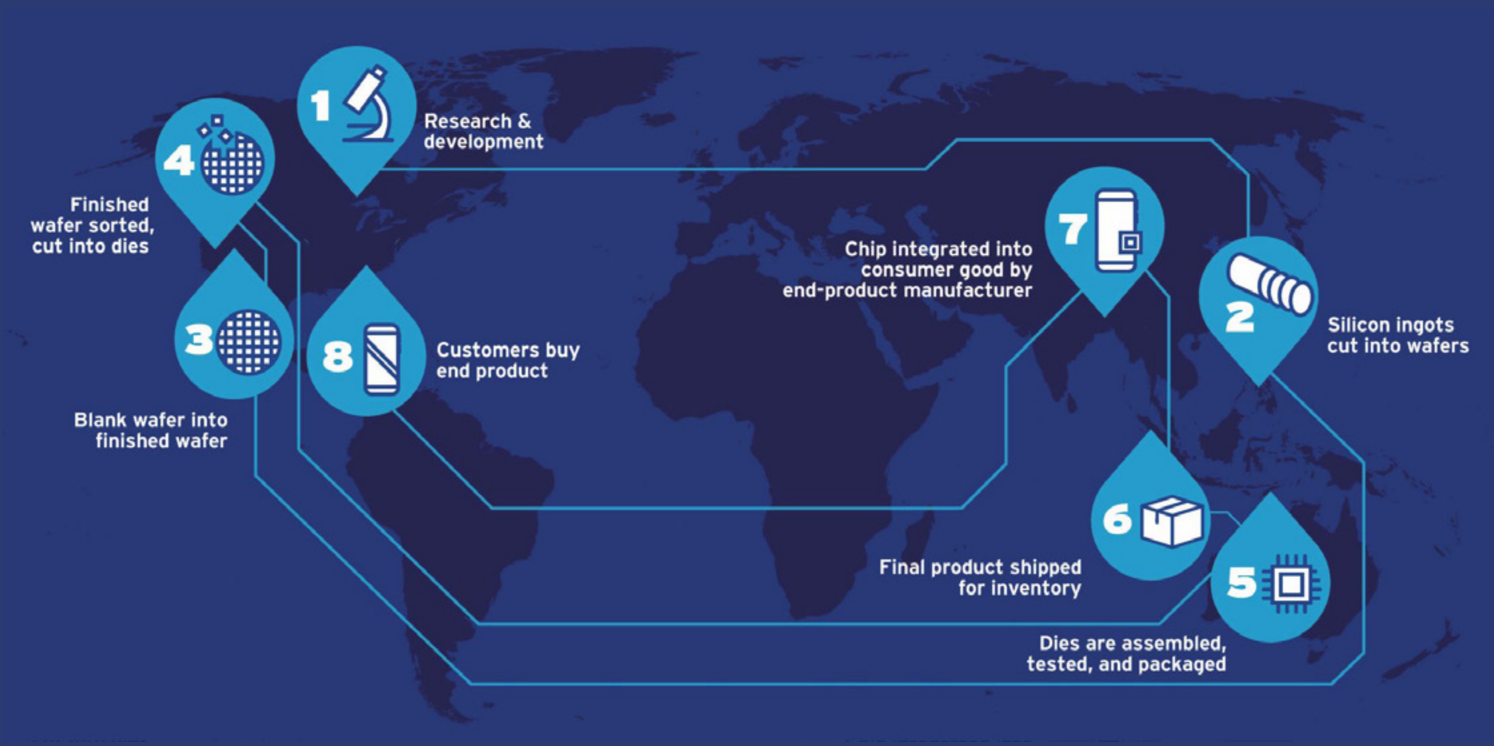


Figure 1. Complex Global Semiconductor Value Chain Map. Source: Semiconductor Industry Association. Used with permission.

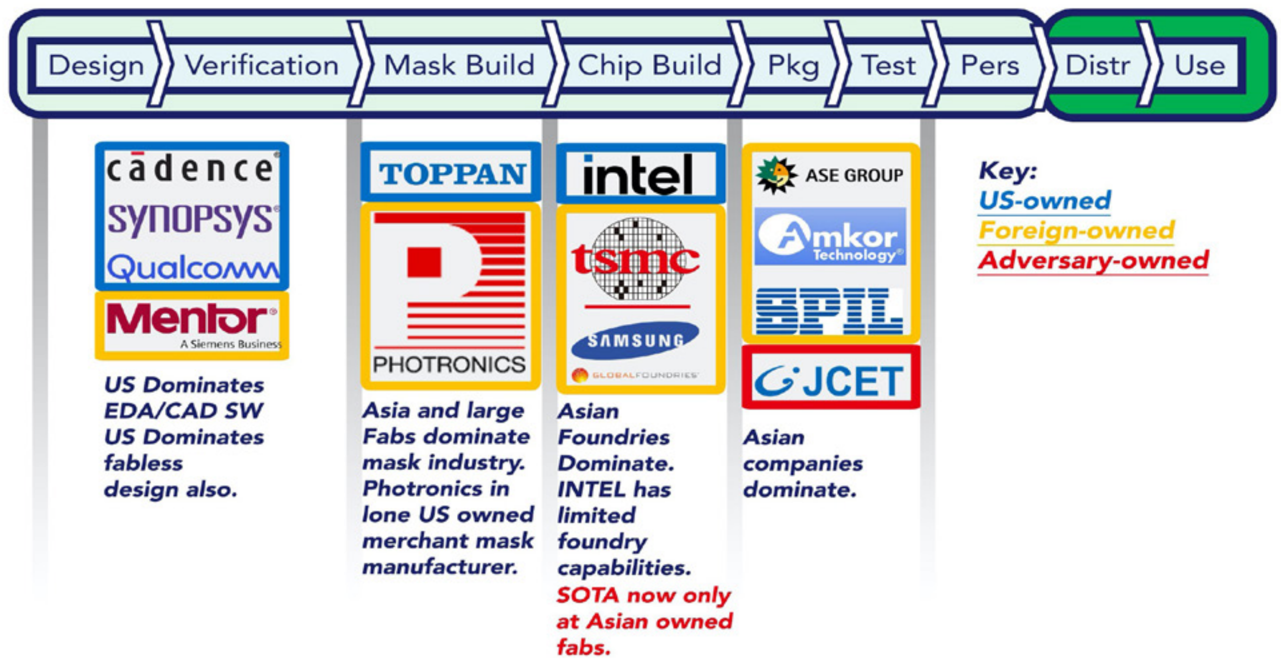


Figure 2. Semiconductor Supply Chain for Digital Logic (note the foreign dominance in fabrication and packaging and testing). Source: Potomac Institute for Policy Studies

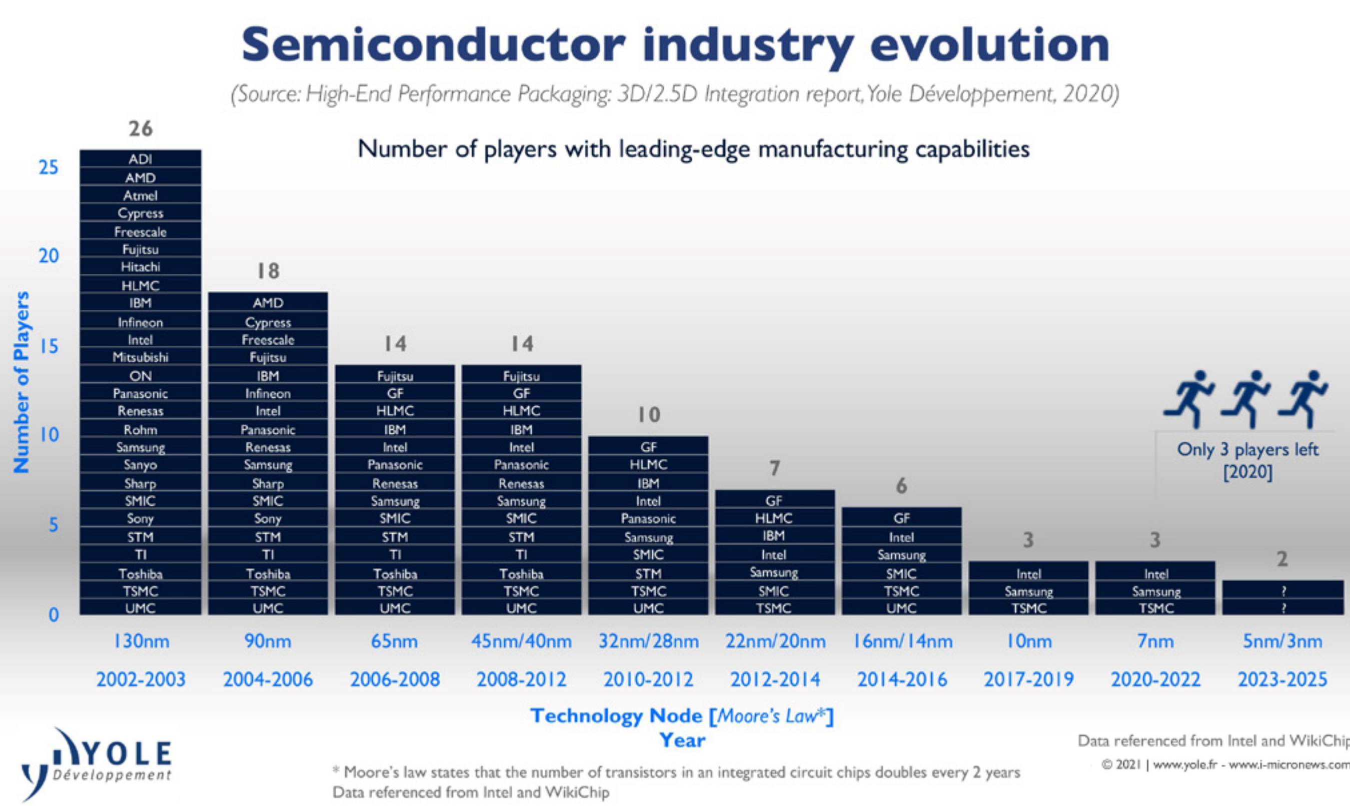


Figure 3. Consolidation of Semiconductor SOTA Fabs. Source: Yole Development. Used with permission.

particularly vulnerable. Historically, the US has used national security laws and classification authority to assure that the provenance and manufacturing of certain microelectronics parts was absolutely secure. However, with state-of-the-art fabrication facilities (fabs) all offshore, that level of security is no longer available for the most desirable parts.

China and Microelectronics

As part of the global competition in microelectronics, US adversaries are acutely aware of their own needs for assured access and trusted parts for use in their commercial, industrial, and military systems. China has been making very large investments to develop its own domestic semiconductor capabilities, as China is currently highly dependent on imports.[9,10] They have recently established funds worth approximately $150 billion and $30 billion to support state-owned acquisition of foreign semiconductor production capabilities.[11] They continue to invest in their own fabs and are stimulating the establishment of domestic fabless design companies. A modern fab facility run by TSMC has been established in Nanjing.[12] China's State Council issued a *Notice on Several Policies to Promote the High-quality Development of the Integrated Circuit Industry and Software Industry in the New Era* and has been instituting incentives and subsidies to promote their domestic semiconductor industry.[13]

Such subsidies pose a major challenge to the competitiveness of the US semiconductor industry. More than guaranteeing their own assured access to microelectronics, China's large investments and acquisitions represent a plan to gain global economic competitive advantages in the microelectronics sector, as detailed in the "Made in China 2025" plan.[14] As a result, China could, in the future, hold a monopoly position in the world's supply of advanced microelectronics.

Policies: Carrots and Sticks

The US needs a comprehensive national microelectronics strategy that responds to the changing geopolitical landscape. Policies need to be enacted that provide for assured access and trusted supplies. The same is true for other critical supply lines, but the characteristics of the semiconductor business are sufficiently different from other sectors that a unique approach is needed.

Typically, fabs take many years to build and require massive investments (tens of billions of dollars).[15] Further, they are only economically viable if they maintain a large market share and have a sufficiently long lifespan over which to amortize their high costs. Accordingly, fixing the microelectronics supply chain problem requires a long-term approach that uses both carrots and sticks to steer the microelectronics industry. Separate proposals exist for each.

The DoD has a requirement for a "Program Protection Plan" within all major defense acquisition programs.[16] That plan should ensure that all microelectronics used in a weapon system are procured through secure channels. The Potomac Institute, many years ago, recommended that FPGAs (microelectronics that are post-fabrication programmable) be bought by those programs from sources manufactured domestically, thereby creating a compulsory demand signal (a version of a "Buy America Act").[17] At the time, there were no domestically produced FPGAs.[18] A "Buy America Act" for all major DoD acquisitions would not provide a large enough market. Alan Shaffer, the former Deputy Under Secretary for Acquisition and Sustainment, has argued that domestically sourcing all microelectronics purchased for critical US systems—whether a weapon system, a US government desktop computer, or a node in the domestic electric grid—would constitute a much larger market that, if instituted over time, could create a sufficient demand for secure domestic microelectronics.[19] This regulation, which would be imposed as a "stick," could be justified on national security grounds. The US government could be yet more aggressive, although sweeping "Buy America" acts are considered anti-competitive, inefficient, and in violation of World Trade Organization rules.[20]

In the realm of carrots, one concept is to meet foreign subsidies with our own. Such legislation has been proposed in the US Congress.

The CHIPS Act, "Creating Helpful Incentives to Produce Semiconductors," proposes $52 billion through 2026 "to stimulate advanced chip manufacturing, enable cutting-edge research and development, secure the supply chain and bring greater transparency to the microelectronics ecosystem, create American jobs, and ensure long-term national security."[21] The act passed the US Senate in June, 2021, as part of the US Innovation and Competition Act (USICA),[22] and includes funding for the formation of a public-private partnership (PPP) called the National

Semiconductor Technology Center (NSTC).[23] USICA also addresses other technology sectors, with an additional $190 billion over several years. As of this writing, the proposed legislation has not passed the US House of Representatives. Other proposed legislation, such as the Facilitating American-Built Semiconductors (FABS) Act, would provide tax credits to incentivize American semiconductor manufacturing.[24] These legislative proposals are strongly supported by the Semiconductor Industry Association (SIA)[25] and have bipartisan support. They are nonetheless controversial,[26,27] as they single out particular technologies as "worthy" of advantageous "industrial policy" that amounts to welfare for certain corporate sectors.[28] China opposes the acts.[29]

The use of PPPs has historically been an effective method to help strengthen the economic competitiveness of the domestic semiconductor industry. In the 1980s and 1990s, the US government helped foster "Sematech," a consortium of semiconductor industries that pooled research and development.[30] The lessons learned from the Sematech experience should be incorporated into any new microelectronics focused PPP such as the NSTC. An appropriate research focus is important, in this case post-Moore technologies such as advanced packaging and cost-effective custom chip fabrication. The governing structure is also crucial where the independence of the managing organization from individual member desires is essential for long-term success. A PPP such as the proposed NSTC should have clear commercial transition paths for new technologies.

Under a PPP program today, government engineers could work collaboratively with industry experts to develop tailored semiconductor products. Chips with added security would be an especially welcome product that would satisfy needs across the DoD and other security conscious markets. Many critical infrastructure sectors outside of government exist, including sectors such as banking, the power grid, water utilities, medical providers, special communications, and transportation. Taken together with the DoD, these areas could represent a major and viable new premium market for more secure semiconductor hardware. The National Defense Industry Association suggests that this approach could satisfy 20-25% of world demand for secure microelectronics.[31]

US Air Force Research Lab scientists independently produced a government-owned design, and manufactured a chip for defense applications.[32] If such a program were scaled up with state-of-the-art technology and produced in conjunction with domestic fabs, a PPP with US industry might create a sustainable business. The US government could then ensure its position as first-in-line for acquisition and distribution of products. We have emphasized the US government and US industry roles, but it would also be important to work collaboratively with allies that have strong capabilities in the semiconductor fields (such as Taiwan and South Korea), encouraging them to locate facilities in the US.

Summary

The automobile industry and COVID-19 forced us to confront the fragility of the microelectronics supply chain. Whether for economic purposes or national security, guaranteed and secure access to advanced microelectronics is very important for the US. We hope that industry has learned the lesson of the vulnerability of "just-in-time" supply chain behavior for critical microelectronics. In the semiconductor industry, it is never wise to "lose one's place in line" for critical parts, as this leads to long delays and shortages. But ultimately, this goes beyond commercial bottom lines and consumer satisfaction. America needs a comprehensive national strategy to ensure access to advanced and trusted microelectronics that can serve the needs of the government and industry, alike.

The semiconductor industry is highly globalized with key parts of the supply chain dominated by overseas players. Continued outsourcing threatens not only assured access, but also the nation's place of relevance in a field we brought to fruition. The US is currently vulnerable to microelectronics supply chain disruptions, whether from a pandemic, sanctions, or conflicts. The US needs a comprehensive national strategy for microelectronics to ensure our security and economic prosperity.

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COUNTING THINGS THAT COUNT

Assessing the Fundamental Missions of Research and Development Organizations

James J. Richardson, PhD
Senior Fellow
Potomac Institute for Policy Studies

Introduction

The best competitors in any facet of life—whether businesses, schools, athletic teams, or individuals—understand that to succeed, they must clearly know what they do and how well they do it. This specialized wisdom to succeed applies equally to organizations that support research and development (R&D). Success requires insight from repeated analysis, mission prioritization, and dedication to development and incorporation of objective performance measures. This is true regardless of the field of activity, size, scope, or importance of the performing organization, but it is especially true for organizations that sponsor or perform R&D. Assessments are particularly difficult for R&D organizations because they provide complex services and often have long-term outcomes and sponsors with immediate expectations.

The first component of the assessment is the mission statement, which cites individual goals of an organization. Those goals, often addressed under constituent (lower-order) missions, are met through the employment of organizational functions. Organizational functions, or simply "functions," may be *R&D-oriented*, such as transitioning S&T into active systems, or *management-oriented*, such as meeting budget obligations, managing contracts, and promoting workplace diversity through hiring policies.

Although both types of functions are important to the assessment process described later, R&D functions are more challenging to evaluate than management functions for several reasons. Management functions are more quantifiable and, therefore, more open to comparative evaluation. Management functions consist of well-documented processes with built-in standards of success (as opposed to R&D in the science and technology [S&T] fields that can focus on esoteric subject matter with unproven utility). Management functions are overseen by specialists trained to identify well-known problem indicators. These individuals operate under management supervision as well as headquarter and corporate leadership. Accordingly, organizations often turn to measuring what is more easily measured—those functions associated with management. But while management functions are important to organizational effectiveness, they seldom directly measure an organization's fundamental output. Therefore, the value of functions related to technical output ("technical functions") should be the principal performance assessment focus for mission accomplishment. Indeed, on-time budget processing and excellent hiring strategies do not matter if the organization fails to advance its R&D mission.

This article outlines a performance evaluation methodology for an R&D organization in accomplishing its primary (technical) responsibilities, while considering other important aspects of program management. An R&D organization should advance S&T in accordance with its mission for the benefit of its parent sponsor. In some cases, the sponsor is the nation; in other cases, it might be a specific military service or corporation.

We will focus on a fictional R&D organization dedicated to developing and delivering S&T to service a parent establishment. The organization features divisions that collectively work various technology areas and which, through affiliations with a local university, perform scientific explorations. The organization may be government or private sector (we assume the latter has government R&D contracts).

The mission areas of such an organization may include:

1. Transition S&T into active systems,
2. Provide on demand technical support to components of a parent organization, and
3. Discover scientific truths.

Before providing an assessment template, consider why we might want to conduct a performance assessment in the first place. Most members of an R&D organization will simply want to do their work and will find the overhead of an assessment annoying. Furthermore, data collection and analysis will be costly and there is no guarantee that the assessment will be actionable. So why do it? Likely, because it will be required. Leadership must offer objective evidence of the organization's utility to maintain the investments required for continuing R&D. Assessments help in setting priorities, and thus maximizing benefit. Trends within certain performance parameters can help management know where changes need to occur to gain improvements. Self-reflection, even for an organization, can be beneficial. But the costs should not outweigh the potential benefits.

We will next outline a three-step approach to accomplish the assessment. The first two steps discuss how mission and performance might be defined to facilitate an assessment. The third step provides thoughts on the design and execution of the assessment process itself.

Assessing an R&D Organization

Defining and Prioritizing Mission Areas

Developing a tailored assessment process begins with understanding and prioritizing the overall organizational mission by identifying the critical components, which we will call critical missions. "Critical missions" define the organization's essential purposes and establish the expected output. The parent organization's mission must also be considered since the critical mission areas must clearly represent a principal benefit to the parent organization.

This prioritization reduces the burden of assessing every individual constituent mission—an onerous task, even for the most dedicated analyst. It also facilitates a regular review of the important mission components to ensure that they remain valid. This is often necessary when an organization's mission statement is subject to change, expansion, or scope reduction due, for instance, to mission oversimplification ("making a profit") or overstatement ("delivering the ultimate technology products"). These possibilities should be factored into the mission review.

Defining Critical Functions

We suggest identifying all the functions involved in serving the organization's critical mission, which often demands describing the organization and how it addresses its critical missions. Sometimes for example, there are business units for separate customer-related mission areas; or divisions with separate technical areas of expertise, which are matrixed to output functions, each serving a critical mission.

Such a task will typically produce pages of functions, some of which may seem too infrequently performed or trivial. But combined with others, these functions may be worth considering. To focus on an acceptable level of effort, two priorities are targeted. One of these, discussed above, involves the relative importance of the mission, leading to its designation as a critical mission. The other depends on the degree to which a function may be labeled a "critical function" that robustly addresses a critical mission.

Designing and Executing the Assessment Process

With an understanding of the critical functions that support critical missions, we may now outline a process to assess the technical performance of our R&D organization. This process has the following component parts:

Performance Metrics quantify the assessment of the organization's performance in meeting mission demands. Subordinate metrics collectively make up the overarching performance metrics.

Standards of Success are expectations for performance metrics values.

Subjective Inputs articulate important insights into the assessment process and its conclusions.

Databases house the data that inform the assessment process.

Rolled-up Metrics Values define the overall performance at higher levels**.**

Diagnostics offer clues to improving performance.

Performance Metrics

The first component in this list is performance metrics, which measure the performance of critical functions. There are many uses for, and definitions of, metrics (see Table 1), but for our purposes, metrics quantify the performance of functions in supporting missions. While *metrics* ask, "how much," *performance metrics* address "how well." Performance metrics can assess management functions, such as contracting or human resources, or technical functions, such as prototyping or technology integration. For the R&D organization, technical function metrics are most relevant to the assessment process. The selection of technical metrics will dictate which data should be collected and how the metrics are integrated into an overall assessment.

Performance metrics tend to be quite complex, requiring extensive data collecting, tracking, analysis, and synthesis. But they represent a unique opportunity to quantify current levels of performance. Even though we will focus on technical performance metrics, management performance metrics may also be employed. For example, a "gender performance metric" may be defined as "the balance of gender representation in the workplace" to grade the organization's performance in arriving at an appropriate level. Management techniques designed to improve performance of critical functions should be recognized in assessments.

Subjective Inputs

Subjective inputs, which include vignettes (or case histories) and customer endorsements, can provide important insights into the value of a function. There are numerous types and sources of subjective assessment factors. Surveys are often used to provide customer-based judgements on products and services, and vignettes can illustrate specific accomplishments and explain their value. While quantification provides the specificity and comprehensiveness on which to base an objective evaluation, subjective descriptions allow articulating the details of exciting facts and promises of S&T breakthroughs and adaptations to useful employment.

Subjective findings are valuable, and external independent evaluators might provide ways to convert them into numbers, but this is often viewed as an art form and subject to skepticism. However, in certain cases, vignettes can be subjected to formulas that compare the effort expended on a project to its impact upon completion. Impact is a key factor in a performance assessment, but its contribution is difficult to quantify. In an R&D organization, the impact often occurs much later than when the product emerges (e.g., after crossing the so-called "valley of death"), which further complicates the assignment of values.

Continued on page 50.

TECHNICAL PERFORMANCE METRICS WITH SUBORDINATE METRICS EXAMPLES

We provide examples of technical performance metrics of critical missions using our notional R&D organization. We express each performance metric in terms of subordinate metrics, such as "number of transitions." Critical performance and subordinate functions in this example were chosen from many alternatives, such as "technology transfer" and "degrees conferred." These incorporate organizational expertise and skillsets necessary to meet performance standards. Only after a thorough review of the critical mission will the performing organization understand which of these functions require measurement.

1. TRANSITION PERFORMANCE METRICS

Transition is frequently the key metric for R&D organizations. And yet, it can be the most difficult to measure. The six subordinate metrics listed below can contribute to an overall "Transition Performance Metric." At the core, however, it is the quality and impact of the transition that matters. This is often subjective, and not directly available to the organization. When assessing the value of a broad spectrum of transitioned products, degrees of scale, quality, and impact will vary widely.

Further, "transition" should be defined in each case to indicate whether the technology delivered is incorporated into a product used by operators, or simply moved to the next level of development. True transitions require a user or customer to "put skin in the game." Namely, it requires integration of the technology or product into their systems—an action that might be measured by the amount of funding devoted to development or integration.

With a suitable definition of "transition," the following subordinate metrics will produce the higher-order Transition Performance Metric:

- **Number of Transitions Metric:** The number of transitions successfully accomplished.
- **Transition Rate Metric:** The rate of transitions per attempt. In an assessment, the question most often asked is, out of all attempts or programs, how many were successful? This metric provides the answer for transition. The standard of success might not be a high rate, as too high a success rate may indicate a lack of risk tolerance.
- **Maturity Metric:** Technology maturity is a significant indicator of transition potential and is typically measured on a scale of the Technology Readiness Level.*
- **Transition Time Metric:** The time to insert a product after a transition decision is made should consider the time needed to realize returns from a research investment. External factors can affect the transition process, such as the state of the technology, the threat environment, or the state of available funding.
- **Impact Metric:** This, most difficult but most important metric of transition, can be measured by its impact on the customer or, more specifically, on the customer's capabilities.
- **Cost Metric:** The cost of a transition depends on such variables as the complexity of the transitioned item and the efficiency of the transition process. These variables make predictions of return on investment difficult and often encourage contingency efforts that may never directly pay off.

* NASA provides a clear definition of Technology Readiness Level at: https://www.nasa.gov.

2. TECHNICAL SUPPORT PERFORMANCE METRICS

Technical support can be an "unsung" role for an R&D organization. Although more difficult to track due to the many activities represented, these are often vital to the parent organization, providing an expert pool of researchers that can be called upon to solve pressing issues. Innovation can play a vital role in this function.

As with the definition of a transition, the organization should carefully define and analyze all support activities, such as:

- **Smart Buyer Metric:** Support involves helping organizations make smart purchases, acquisitions, or mergers. These activities ensure that acquisition yields the best deals and most effective products. An example is participation in source selection processes. Weighting factors can be defined by the size of the subject of the selection and the relative contribution represented by the technical support, which will usually involve a subjective component.

- **Technical Assistance Metric:** Technical personnel are often assigned to provide expertise as direct customer support. Technical assistance tasks are widely varied and may include problem-solving, testing, or advising on proposed system modifications. These tasks often require very high expertise in a particular technical area, as well as experience with the organization's technologies or product line.

- **Patents Metric:** Inventions are an indication of creativity, which can allow the organization free use of the technology or idea and can produce royalty revenue. The review process for a patent requires a threshold of evaluation, and thus, the number of patents can be a useful metric for an organization involved in technology development for future applications.

3. SCIENCE PERFORMANCE METRIC

By definition, basic research is conducted without a strong notion of intended application. Thus, basic research can be difficult to justify, especially when budgets become challenged. Yet, the discovery of S&T capabilities can have fundamental and pervasive applications. When assigning credit to new products, prior scientific advances are often overlooked, regardless of whether they contributed to a novel technology or a better understanding of the physical world. Nonetheless, payoffs of scientific discoveries can be enormous. For example, quantum theory is the underpinning of the development of the transistor, which led to microelectronics, personal computing, smart phones, and connected communications. Similarly, stealth technology, GPS, lasers, light emitting diodes, and other advancements all began with scientific breakthroughs.

At issue then, is how do we account for the value of scientific discovery when the applications and impact might be far in the future?* It is a practical question, because when budgets are tight, basic research is often the first to get squeezed. The scientific enterprise has developed its own metrics, which are relevant to organizations other than university departments:

- **Proof of Principle Metric:** A critical step in a discovery process, the scientific process requires testing the hypothesis. A carefully designed test, especially to determine the proof of principle, is a threshold to deeper exploration of a scientific truth. Counting of successful proofs of principle can provide a measure of the quality of intuition and discovery.

- **Publications Metric:** The number of publications, especially peer reviewed publications, is an established indicator of successful research activity.

* A performance assessment may depend on many aspects of an achievement. An organization that does superb discovery and development may not be perceived as successful if its output is never transitioned into use. This does not necessarily mean failure. Payoff is still possible if the results are preserved "on-the-shelf" for a later contingency, relegating the judgement to another realm of decision makers.

Table 1. Select Definitions of Metrics

SOURCE OF DEFINITION	DEFINITION OF METRICS
Cambridge Dictionary	A set of numbers that give information about a particular process or activity: • Rate of usage. • Performance metrics need to align marketing activity with corporate goals. • Market metrics such as market and segment size estimates. • Cost/financial metrics.[1]
Investopedia.com	Measures of quantitative assessment commonly used for comparing and tracking performance or production. Metrics can be used in a variety of scenarios. Metrics are heavily relied on in the financial analysis of companies by both internal managers and external stakeholders.[2]
Dictionary.com	A standard for measuring or evaluating something, especially one that uses figures or statistics.[3]
Management Study Guide	Numbers that tell you important information about a process under question. They tell you accurate measurements about how the process is functioning and provide base for you to suggest improvements. (Usually measuring results with one metric is not a good enough strategy. A combination of metrics is used to measure the effectiveness of the process.)[4]
Sage.com	Performance metrics are used to measure the behavior, activities, and performance of a business. This should be in the form of data that measures required data within a range, allowing a basis to be formed supporting the achievement of overall business goals. Measuring performance through metrics is key to seeing how employees are working and whether targets are being met.[5]

Rolling-up Metrics Values

The most contentious problem with a metrics-based assessment is how to derive (or "roll-up") the higher-level metrics values from those of the subordinate metrics measuring the individual actions, such as each transitioned technology or product. These measurements collectively define the overall performance. Perhaps it is best to explain this process using the accompanying example.

Describing transition performance begins with deriving a value for each of the six subordinate metrics. This can require setting their values for every transitioned item. The "Number of Transitions" and "Transition Rate" subordinate metrics are easy to handle, as they only require summation, but the other four demand that values be calculated for each transition. Each of the transitioned items will have its own impact, transition time, maturity, and cost, and each of these must be derived individually and then rolled up to define their contribution to subordinate metrics (e.g., "Maturity Metric"). Then, it must be decided how each subordinate metric contributes to the "Transition Performance Metric." The subordinate metrics supporting the "Technical Support" and "Science Performance" metrics require a similar process. This roll-up process is wickedly difficult and requires a case-by-case approach. It also demands a rich database with good retrieval capabilities, as suggested below.

Calculating a single performance metric value to describe the overall effectiveness of the organization in addressing its mission may be desirable. For instance, one could reach the judgement that the organization operates at an overall level of 85% effectiveness. This is, of course, a challenging judgement, demanding that each performance metric contribute to an overarching one in such a way that it predicts an overall potential. One might, for example, take a weighted linear combination of normalized performance metrics, but then one must decide what weight each metric carries. This often requires the ubiquitous comparison of "apples and oranges" if there is too much dissimilarity.

Standards of Success

Expectations must be set for performance metrics, subordinate metrics, and each project or program. For example, the number of transitioned technologies would mean nothing to an outside observer unless they knew how many transitions were expected. Standards of success should reflect the expectations of the organization and should be flexible to accommodate changing circumstances and priorities. Beyond the normal bureaucratic method of choosing last year's norms as this year's quota, management must set standards for success objectively. Current challenges may differ from those that dominated previous efforts, so standards of success may change. In developing expectations for success, one must understand the circumstances under which the organization operates, such as competing activities for which they are responsible. Also, greater values for some metrics may lower those for others.

Databases

Assessments require burdensome and costly data collection and analytical processes. To reduce these, links should be established to databases maintained for other purposes, such as supporting program records or management reviews. Also, new concepts such as a "lake" of databases, data analytics, text analytics, and automated information extraction can lead to greater efficiencies. Modern database management systems are a must. It should be possible to develop automated techniques to find correlates of such files with performance metrics, such as opportunities or probabilities for transition. While every R&D project should confront problems, success is not guaranteed. Statistical indicators of progress across projects might be extractible from "web crawlers" and data analytics. These approaches can improve efficiencies while being less intrusive, but one should remain skeptical of the output without further application of sound judgement. Computer aids to extract, analyze, and synthesize results can offer information, but the processing to extract wisdom will be labor intensive.

Diagnostics

In addition to providing insights into cause and effect, diagnostics may offer clues to improving performance. Diagnostics can be used to explain reasons behind current performance levels and to aid in assessing the effectiveness associated with strategies for improving performance. Diagnostics are not metrics but are indicators that can contribute to the success of an organization by acting as signposts pointing to what works and what does not work. For example, prototype testing could be included as a diagnostic for transition performance. Potential means to improvement should be analyzed or tested for positive or negative impacts on performance.


ASSESSMENT

Way Forward

Carefully analyzed performance metrics will continue to help in priority adjustments and decision processes. They will allow a rationale for choosing new paths and taking risks, or for defending existing missions and budgets. As related technologies improve, the collection of data and maintenance of sharable databases will increase communication and coordination among an organization's divisions. This will enable both competition and the sharing of mutual goals, priorities, and lessons learned. Assessments will be a tool for raising awareness of contributions, successes, and problems at the organization and division levels, as well as providing reasons for changes that will increase contributions and mitigate problems. Those benefits will accrue to the researchers, staff, and top executives.

Benefits will also accrue to customers and deepen their appreciation for value delivered, reminding them of ways the organization has supported them. It is sadly true that individual vignettes of even heroic contributions are often quickly lost in history. Quantified assessments at the program, directorate, or laboratory level stand as easily referenced judgements of the cumulative effects of those contributions.

It is likely that basic research would be more appreciated if there were metrics that could better predict the opportunity for future applications. Everyone agrees that basic research is a good thing, but that it often takes decades to mature. Thus, retrospective analysis is often the best means to justify basic research and the discovery components of R&D organizations, since it tracks past events into the present. But the need to predict success or failure far into the future applies to all aspects of R&D. The further in the future, the less certain is the estimate.

As a surrogate for a valuation of future transition, it is now common to attempt to assess the "innovativeness" of a discovery, idea, or advancement. Even given the risk that can accompany innovation, an innovative development can increase the likelihood of large payoffs for future transitions. Indeed, many of the game-changing technological advances of the last century were associated with multiple developments that could be labeled as innovative. However, this leaves open the questions of how to define innovation, identify it, and quantify and assess the degree of innovativeness. This is not to mention the difficulty of determining if a particular innovation really does presage useful purpose. Thus, while there is hope that innovativeness could become a useful performance metric, its utility is yet to be proven.

Calls for assessments of organizations is increasing, including (or maybe especially) for R&D organizations. However, countervailing pressure demands that assessments be efficient (less costly) and as accurate as possible—and that they include performance metrics. Less burdensome and more efficient assessments are possible through careful selection of mission areas, limiting inclusion of projects and program areas, less frequent assessments, and the use of outside independent assessors to reduce interruption to ongoing processes. Nonetheless, the demand and need for performance assessments continues.

Endnotes

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FREE OF CHARGE

Escaping China's Lithium-Ion Battery Dominance

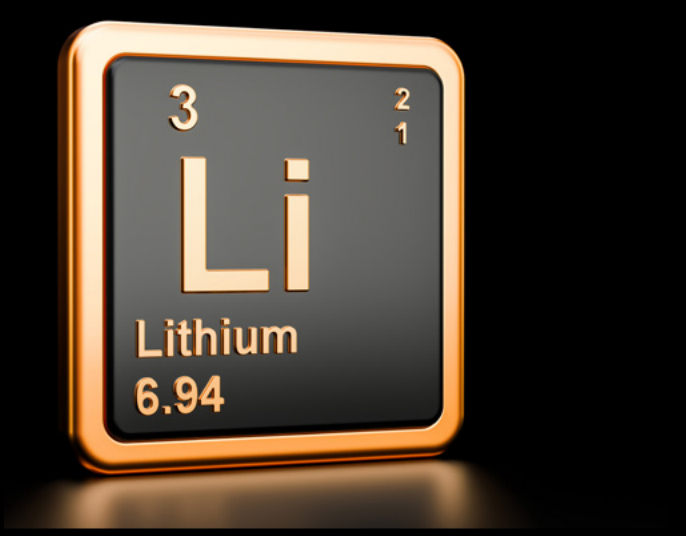
Moriah Locklear, PhD
Research Fellow, Potomac Institute for Policy Studies

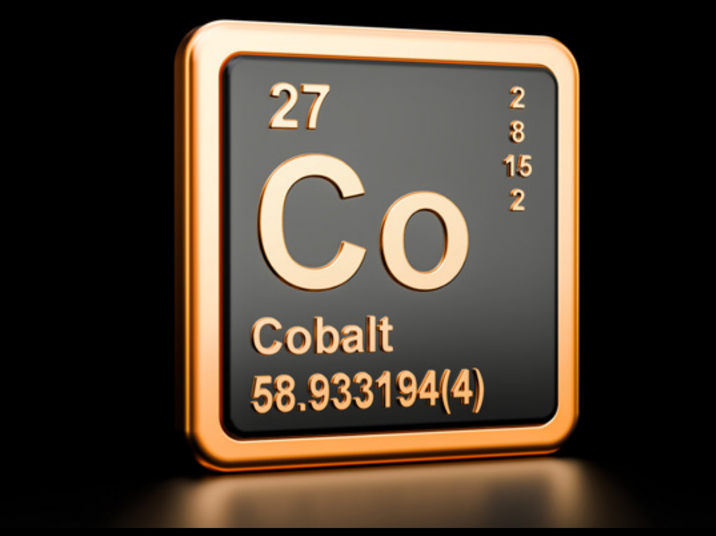
If you thought our dependence on foreign foundries for microelectronics was a significant supply chain problem for the United States, then you don't want to know about the situation with batteries.

It is not an exaggeration to say that modern society is beholden to the Li-ion battery. The large EVs that consumers want, the small electronics that protect warfighters, and the green revolution that we need are all powered by batteries. To date, Li-ion technology is the only battery type likely to meet our increasing battery power demands. Our reliance on a single type of battery has created a vulnerability—America's access to both the raw materials and the final product is flimsy, at best.

Consumer electronics are staples of modern American life. Li-ion technology, first developed in 1985,[1] is the most popular form of battery technology in small electronics for multiple technical reasons.[2] But, the impact of Li-ion batteries is not limited to small electronics. Military and in aerospace applications are driving the need for large battery technology.[3] Further, the coming electric vehicle (EV) revolution will use Li-ion batteries.[4] Even beyond EVs, renewable energy sources will not replace fossil fuels without battery technology. Wind, solar, tidal wave, and other intermittent energy production sources that cannot be "turned on and off" will require large-scale storage systems to support the electrical grid and intelligent storage systems will be needed to balance supply and demand.

A state-of-the-practice Li-ion battery has a lithium-cobalt alloy cathode, a graphite anode, and an organic solvent electrolyte. The biggest liabilities are our access to lithium and cobalt cathode materials, which are primarily extracted overseas; refining of the materials and manufacturing of batteries is dominated by China.





Lithium is obtained by either evaporating water from brine reservoirs (salars) located in high-elevation South American countries, such as Chile and Argentina, or from mining in Australia. Australian mining is the biggest supplier, but the largest reservoirs are in South America. [5] The need for batteries will outpace current mining capabilities but not worldwide capacity.[6,7] Complaints about environmental impacts of mining are increasing.[8]

Cobalt requires byproduct recovery from non-cobalt metal mining. Sixty percent of these processes are performed in the Democratic Republic of the Congo (DRC) by Chinese operators.[9] After mining in the DRC, China refines the vast majority of raw cobalt domestically.[10] Cobalt mining is associated with human rights violations[11] and has deleterious impact on ground water and arable land.[12] Relying on cobalt mining to this extent is neither economically safe for countries other than China nor physically safe for those involved in the process.

Accordingly, China has cornered the market for Li-ion battery production. Of the top ten Li-ion battery manufacturers, four are Chinese and the remainder are found in Asian nations. The top Li-ion battery manufacturer in 2020 was LG-Chem (Korea) with 26.5% of the market share followed by Contemporary Amperex Technology Company—CATL (China) with 25.8%.[13] In 2021, CATL surpassed LG, and now has a 32.5% market share of all worldwide Li-ion battery production.[14] The United States has lost the race for Li-ion battery dominance. Beyond our lack of control over Li-ion battery raw materials, we also are dependent on China for manufacturing. We can and will continue to purchase this technology from China for consumer products, military use, electric vehicles, and other applications, but this is a vulnerability.

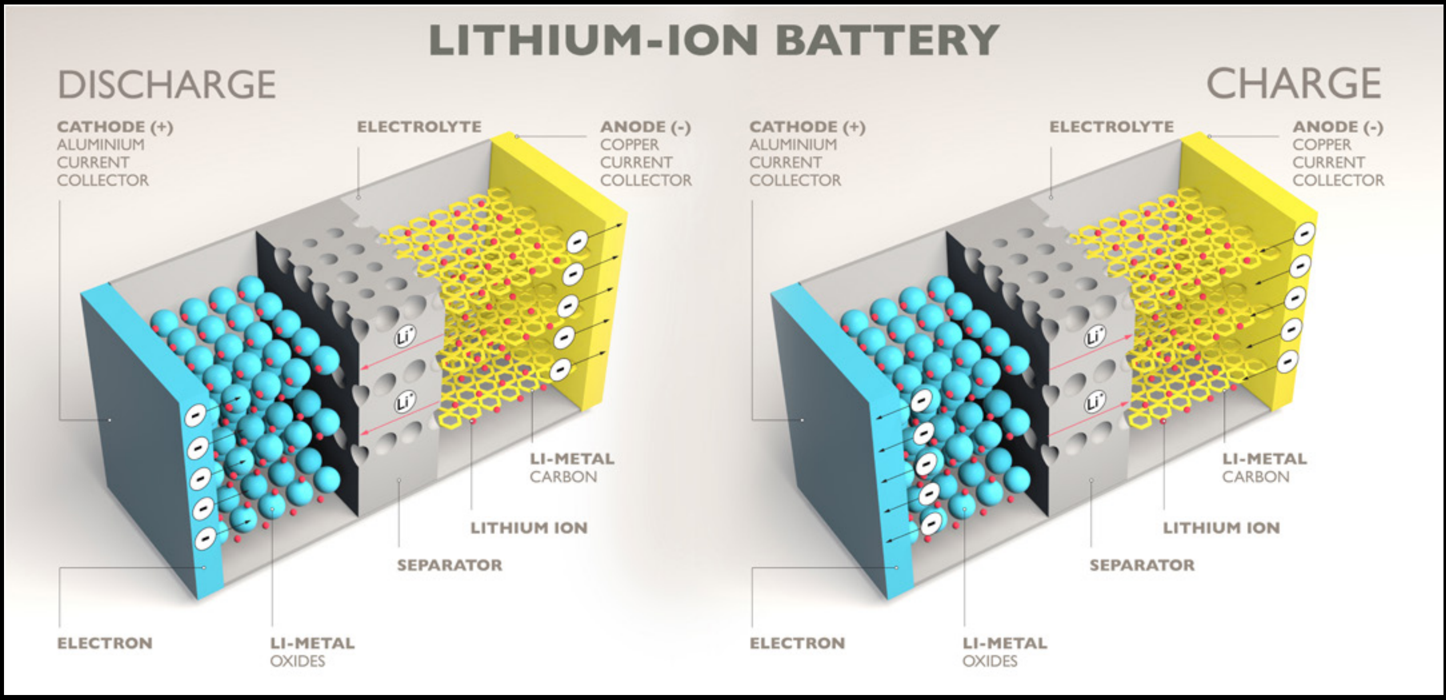
America will need batteries indefinitely and barring a major shift in manufacturing capabilities or alternate technology developments, America will remain dependent on China for Li-ion batteries. The United States will need to invest in the invention and manufacturing of novel battery systems to lead the next energy storage revolution.

What therefore are the prospects for reducing our reliance on Lithium-Ion battery technology?

In 1985, less than 40 years ago, we did not have Li-ion batteries and now they dominate the market. While foreign-made and -sourced Li-ion batteries will provide advanced capabilities for many years to come, alternatives should be developed to a commercially acceptable level.

Promising technologies under investigation include:

- Sodium-based batteries,[15] as sodium is abundant, easily extracted, and can be employed to produce a solid-state battery.[16,17]
- Nickel-hydride cells are viable, although nickel is not currently mined extensively in the US.[18,19]



- Lithium iron phosphate batteries have received recent interest because they do not contain cobalt or nickel and are less expensive than Li-ion cells. These batteries have a lower specific energy density (capacity per unit weight) and they still require lithium.[20]
- Iron-air batteries.[21]
- Hydrogen fuel cells—which, while not batteries, are being studied for vehicular applications.[22]

These research areas hold promise but will require optimization to become economically viable. Research will not be enough. Investments in manufacturing and packaging facilities must occur in tandem, or America will lose the battle for battery technology dominance.

Battery research continues in a quest to increase specific energy and decrease reliance on exotic materials. The Administration is funding a $3 billion initiative to strengthen the battery supply chain with a focus on vehicles and large-scale storage.[23] This initiative will focus on expanding domestic recycling and manufacturing facilities as well as advancing research and development. Separately, the Department of Energy has published a blueprint for Lithium batteries with a goal of achieving a secure supply chain by 2030,[24] and the Department of Defense has published an action plan concerning defense-critical supply chains that includes a section on energy storage and batteries.[25]

Replacing the Li-ion battery will require a mix of technologies, depending on the application. But the time to engineer the next generation technologies and ready the production capacity is now—before we are locked into risky supply chains, yet again.

Now you have another supply chain issue to worry about.

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The *Hypersonic* Conundrum

Robert (Bob) Hummel, PhD
Chief Scientist
Potomac Institute for Policy Studies

USAF Illustration/Mike Tsukamoto

The United States is behind Russia and China in the development of technologies and systems to field hypersonic missiles, and methods to defend against them. Both the Russians and Chinese have operational offensive hypersonic systems, which are aerodynamically maneuverable and are designed to defeat US defenses. The US is years from deploying comparable systems, and current missile defense systems were not designed to address hypersonic weapons.

The hypersonic development of both offensive systems and defensive capabilities involves more than new weapons systems that require new programs of record. These weapons completely change the strategic balance by countering western strategic and tactical deterrence. Specifically, hypersonic weapons can nullify air and ballistic missile defense and undermine the safety of the strategic nuclear arsenal, eroding the tactical advantage to global freedom of action that nuclear deterrence represents. How has this happened? At one point, twenty or thirty years ago, hypersonic technology was dominated by US science. Despite some US hypersonic technology developments initiated in the 1990s, much of that work was largely neglected as later budgets diverted funds to support the "War on Terror," and budgets for Overseas Contingency Operations dominated concepts for "Great Power" technology developments. In the meantime, those adversaries determined that to reestablish a credible deterrent and to defeat US missile defense systems, they needed to develop the technologies that we now call "hypersonic weapons," which is actually a suite of technologies that encompass much more than simply traveling fast (see box).

President Theodore Roosevelt established the "big stick policy:" stating "speak softly but carry a big stick." Russia and China now have big sticks, to which we are yet to have an effective defense. While hypersonic weapons can carry nuclear payloads, they are also suited to conventional precision payloads and can in some cases obliterate a target without explosives through the energy carried by their terminal speed. Without a defense or a comparable stick, the US is no longer feared. The geopolitical order is being rearranged based on a competition of missile and autonomous systems technology.

Similar to when the Nazis grabbed territory in 1938, annexing portions of Austria, Czechoslovakia, and Danzig, the US now confronts a situation where Taiwan and other territories claimed by adversaries are threatened by limited hybrid aggression, involving cyber and missile threats. Ukraine is actually invaded. While not the sole contributing factor, it does not help that the US can no longer answer the weapons that emboldened adversaries have developed.

Photo Credit: U.S. Army

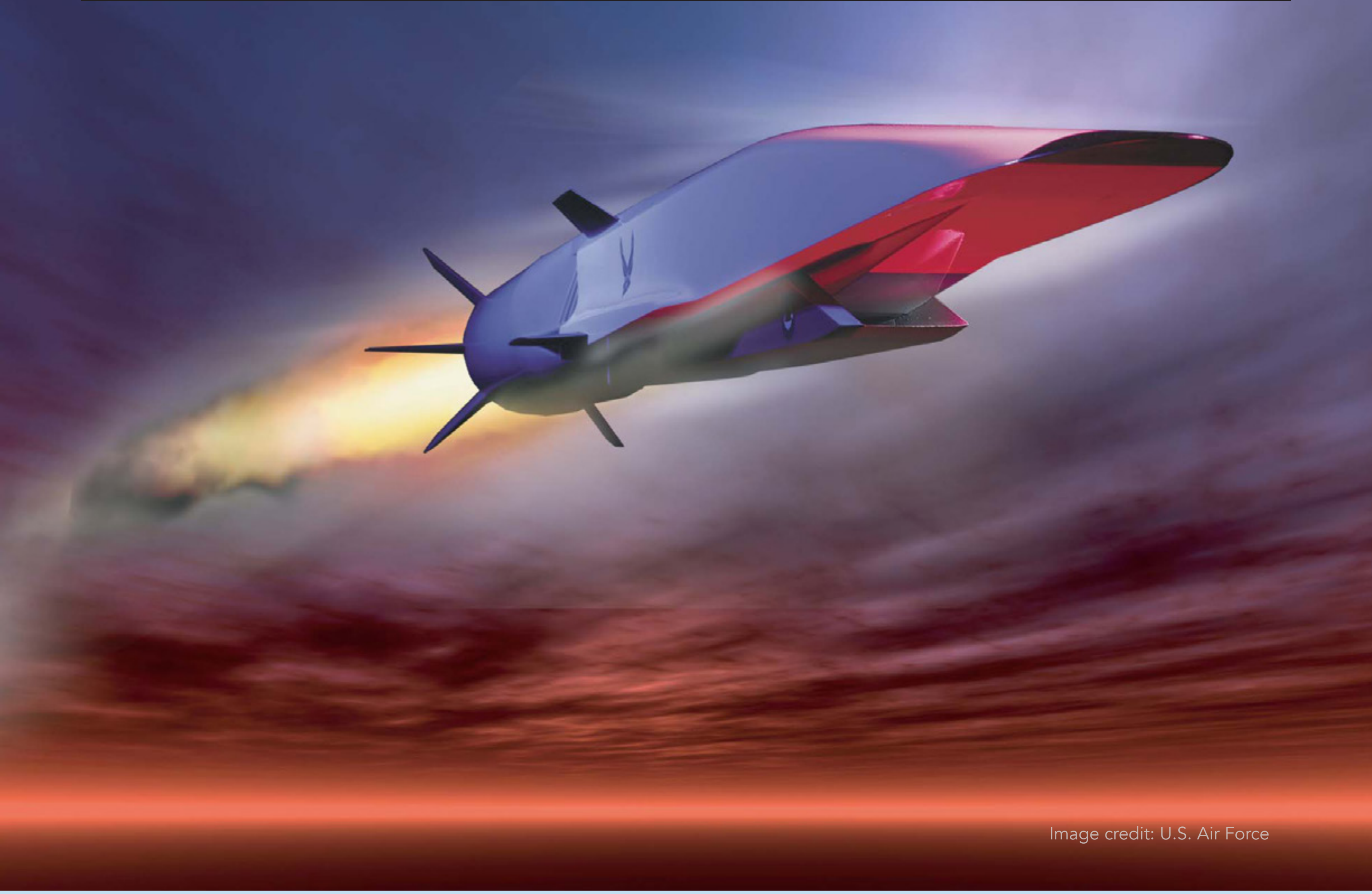

Image credit: U.S. Air Force

THE SUITE OF HYPERSONIC WEAPON TECHNOLOGIES

TWO SYSTEM TYPES

BOOST GLIDE SYSTEMS

Boost to near orbital velocity (Mach 15+) in space (approx. 17,000 mph), then separate glide body from rocket body, and glide in upper atmosphere (e.g., 200,000 ft) potentially for thousands of miles before maneuvering and diving to target.

POWERED FLIGHT SYSTEMS

Drop from moving aircraft and/or use rocket to accelerate to operating speed, and then use continuous thrust of engine designed to operate at speeds of Mach 5+, maneuvering at speeds of approximately 4,000-7,000 mph to target.

PARTIAL LIST OF TECHNOLOGIES

Computational fluid dynamics, high temperature materials, composite materials, scramjets and ramjets, control surfaces, center of gravity -based aerodynamics, hypersonic wind tunnel testing, radar and IR sensor seekers, heat pipes, navigation solutions, decoys deployment...

Numerous other technologies are needed for defensive systems.

The threat of escalating potential conflicts to ballistic nuclear attacks and counter attacks is not a desirable option and is not a reliable deterrent to our adversaries' use of conventional hypersonic weapons. Negotiating missile defense agreements is equally unlikely to be successful.

The Pentagon has begun addressing the new hypersonic developments, but with insufficient urgency. The Department of Defense is investing in hypersonic weapon systems development (and to a far lesser extent, defense against hypersonic systems) in the last few years, but they are approaching the problem with a weapons development mindset. They view the solution as a set of projects for development of a weapon, aligned toward future major acquisition programs as programs of record, with an eventual series of upgrades. But these technologies, weapons, and defense systems are not just simple weapon acquisition issues, but instead require an offset strategy that provides both strategic and tactical solutions to achieving stability and deterrence.

The largest programs, the "Conventional Prompt Strike" and the "Long-Range Hypersonic Weapon," use existing technologies, and thus are little more than smart rocks, albeit fast smart rocks. Further, they intend on developing prototypes, and won't be ready for regular operational deployment for at least five years. A dozen other projects, coordinated by the Research and Engineering branch of the Pentagon, have their own problems and limitations. Funding for defense technologies is a tenth of funding for offensive weapon developments. And in many cases, the necessary advanced technologies are not sufficiently mature for incorporation into weapons development.

At Congressional direction, the Department of Defense established the Joint Hypersonics Transition Office (JHTO) in FY2020 with a hundred million dollar Congressional add. According to the budget justification, the office "was created to establish a university consortium for hypersonics research and support workforce development; expedite testing, evaluation, and acquisition of hypersonic technologies…, integrate advanced technologies to speed the maturation and deployment of future hypersonic systems; develop strategies and roadmaps for hypersonic technologies to enable the transition of such technologies to future operational capabilities for the warfighter; and develop and implement a strategy for enhancing the current and future hypersonics workforce." These are critical goals, yet the FY22 budget request halved their funding.

It would be nice to avoid an arms race and have all agree to forego these weapons. But, the Bear is really out of the bag and it is too late for that option. If the US wants to remain relevant on the world stage of defense of freedoms and democracy, it must regain dominance in missile defense and missile strike.

The only way for the US to achieve hypersonic dominance in a relevant time frame is to aim to "leap-ahead" of Chinese and Russian capabilities. It is not enough to catch up over a period of years, oblivious to adversary developments and expanding capabilities. The Nation needs a focused effort that achieves, on its own, more deterrent capability than its Russian and Chinese counterparts.

The necessary goal can only be achieved through pursuit of aggressive government science and technology, married closely with industrial R&D and motivated defense industries, in a moonshot program that wisely pursues paired offense and defense strategies and gains strong collaborations on shared goals. We need tomorrow's technologies for hypersonic maneuverable missile systems and defenses against them, today.

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For Further Reading

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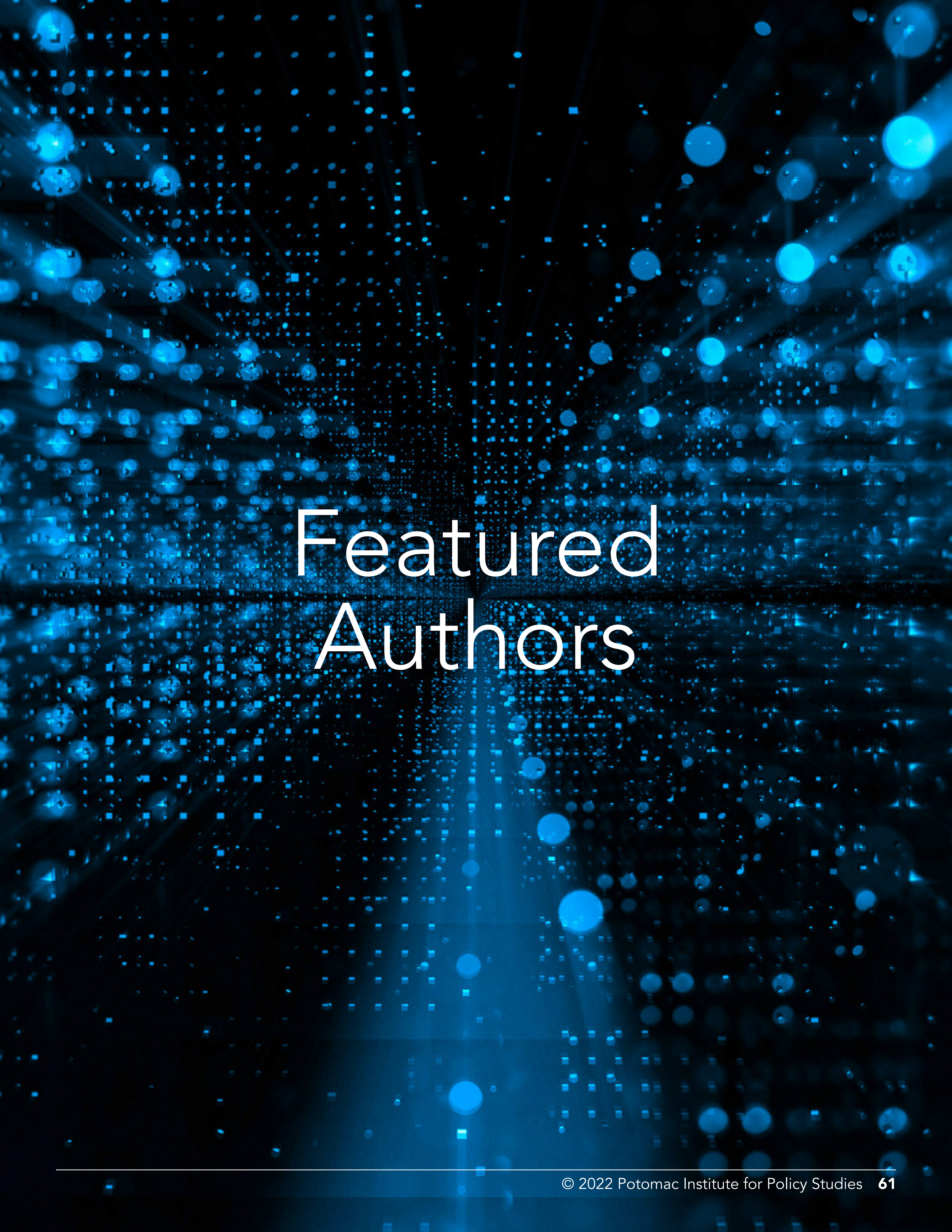

Featured Authors

Robert (Bob) Hummel, PhD

STEPS, Editor-in-Chief
Chief Scientist, Potomac Institute for Policy Studies

Dr. Robert Hummel serves as the Chief Scientist of the Potomac Institute for Policy Studies. He is Editor-in-Chief of the *Science, Technology, Engineering, and Policy Studies (STEPS)* journal/magazine (this publication), and the author of over a hundred academic articles and Potomac Institute reports. He completed a four-year IPA assignment to the National Geospatial-Intelligence Agency in 2020. Prior to joining the Potomac Institute, he served as a program manager at DARPA for nearly nine years, managing and initiating projects in information exploitation, computer science, and sensor design. Prior to joining DARPA, he was a tenured faculty member at NYU's Courant Institute of Mathematical Sciences in the Computer Science Department, where he did research in computer vision and artificial intelligence. Dr. Hummel has a PhD in mathematics from the University of Minnesota, and he holds a B.A. in mathematics from the University of Chicago.

Timothy W. Bumpus, PhD

STEPS, Associate Editor
Research Associate, Potomac Institute for Policy Studies

Dr. Timothy Bumpus received his PhD in chemical biology from Cornell University where, as a National Science Foundation Graduate Research Fellow, he designed and implemented new chemical tools to study lipid centric cell signaling processes. Prior to Cornell, Dr. Bumpus attended Luther College where he received his B.A., majoring in chemistry, biology, and mathematics. He now brings his diverse scientific expertise to bear on the many, varied science and technology policy issues facing the country as part of the Potomac Institute for Policy Studies' research staff.

Jennifer Buss, PhD

Chief Executive Officer, Potomac Institute for Policy Studies

Dr. Jennifer Buss serves as the CEO of the Potomac Institute for Policy Studies. The Institute develops meaningful science and technology policy options through discussions and forums and ensure their implementation at the intersection of business and government. She has extensive experience examining policy issues in support of NASA, and has been involved in their strategic planning processes for astronaut medical care and cancer diagnostics and therapeutics. She manages a variety of OSD programs including an outreach effort for the Department of Defense to the start-up community across the country to find innovative technologies to meet the challenges faced by the Services and Government agencies. Dr. Buss performs science and technology trends analysis and recommends policy solutions to some of the country's most pervasive problems. She has also directed and assisted research on numerous government contracts, including systematic reviews and gap analyses. Dr. Buss is an authority in her scientific field with national recognition in her area of expertise. She is responsible for major projects requiring integration/coordination across multiple scientific disciplines.

The Honorable Zachary J. Lemnios

Board of Regents Member, Potomac Institute for Policy Studies

The Honorable Zachary J. Lemnios is a Senior Executive with over 40 years of experience in industry, government and academia, who has led the development and application of advanced technologies for national and global security. He served as Vice President of Research Strategy and Worldwide Operations, Vice President of Physical Sciences, and Vice President of Government Programs, globally across IBM Research.

Prior to joining IBM, Mr. Lemnios served three terms in high level civilian leadership in the Department of Defense with detailed and extended interactions across the whole of US government and with leaders across US allied nations. Mr. Lemnios was confirmed as The Honorable Assistant Secretary of Defense (Research and Engineering) by the United States Senate. In this position, Mr. Lemnios was the Chief Technology Officer for Department of Defense and shaped the Department's technical strategy to support the President's national security objectives and the Secretary's priorities. He launched Department and international initiatives in large data analytics, decision support, engineering education, electronic warfare, cyber, autonomy, advanced propulsion, hypersonics, and directed energy concepts as future capabilities for the nation. Mr. Lemnios received special recognition from the Australian Government Department of Defence and was awarded Office of Secretary of Defense Medal for Exceptional Public Service and the Office of Secretary of Defense Medal for Outstanding Public Service.

Lemnios also served as the first Chief Technology Officer of MIT Lincoln Laboratory. He has authored over 40 papers, holds 4 patents in advanced GaAs device and MMIC technology and is a Life Fellow of the IEEE.

The Honorable Alan R. Shaffer

Board of Regents Member, Potomac Institute for Policy Studies

Since January 2021, the Honorable Alan R. Shaffer has been a private consultant and member of the Board of Regents of the Potomac Institute. Previously, he was Deputy Under Secretary of Defense for Acquisition and Sustainment (A&S), confirmed in January 2019. He served as the Director, NATO Collaboration Support Office in Neuilly-sur-Seine, France after serving as the Principal Deputy Assistant Secretary of Defense for Research and Engineering (ASD(R&E)) from 2007-2015, with two stints as acting assistant secretary. In these capacities, he is known for his service as the Executive Director of the Mine Resistant Ambush Protection (MRAP) Task Force, where he was responsible for oversight, fielding, and employment of 27,000 MRAPs across the Department of Defense. Before entering the federal government, Mr. Shaffer served 24 years as a commissioned officer in the United States Air Force and retired in the grade of Colonel. While serving, he held positions in command, weather, intelligence, and acquisition oversight with assignments in Utah, California, Ohio, Honduras, Germany, Virginia, and Nebraska. He holds a Bachelor of Science degree in Mathematics from the University of Vermont and a Bachelor of Science in Meteorology from the University of Utah, a Master of Science in Meteorology from the Naval Postgraduate School, and a Master of Science in National Resource Strategy from the Industrial College of the Armed Forces.

Mike Fritze, PhD

Senior Fellow, Potomac Institute for Policy Studies

Dr. Mike Fritze is a Senior Fellow and former Vice President at the Potomac Institute for Policy Studies. He is responsible for the Microelectronics related portfolio with interests and activities in the areas of secure access strategies, supply chain issues, support of legacy technologies, DoD innovation policy, outreach to Industry and strengthening the US Industrial Base. Customers have included OSD, DARPA, USAF and NNSA. Dr. Fritze is active on the NDIA Electronics Division co-chairing the Policy subcommittee. Prior to his affiliation with the Institute, Dr. Fritze ran microelectronics Programs at USC-ISI and was a Program Manager at DARPA MTO. Prior to that, he was a staff member at MITLL.

James J. Richardson, PhD

Senior Fellow, Potomac Institute for Policy Studies

Dr. James Richardson is a Senior Fellow at the Potomac Institute for Policy Studies. He previously served as Vice President for Research and Chief Scientist of the Institute, where he led technology and technology management studies funded by the Defense Advanced Projects Agency (DARPA), NASA, the National Intelligence Council, IBM Corporation, the National Science Foundation, and other agencies. From 1987 to 1994 he served as Director of the Land Systems Office of DARPA. He was also Special Assistant to the Director and Scientific Advisor for the US Ambassador to the Conventional Forces in Europe treaty negotiations in Vienna, Austria. He led the development of new combat technologies, represented DoD in the "Partnership for a New Generation Vehicle" (Clean Car) initiative, and directed the DARPA/Army/USMC Joint Armor Anti-Armor program chartered by the Secretary of Defense. His office was involved in the development of advanced materials, unconventional lethality and survivability technologies and hypervelocity projectiles, the first large (9MJ) electromagnetic gun and a "smart minefield." Prior to DARPA, Dr. Richardson held several positions at the U.S. Army Missile Command at Redstone Arsenal, AL. He has a BSME from North Carolina State University, an MSE from the University of Alabama, and a PhD in Theoretical & Applied Mechanics from the University of Illinois.

Moriah Locklear, PhD

Research Fellow, Potomac Institute for Policy Studies

Dr. Moriah Locklear is a Research Fellow at the Potomac Institute for Policy Studies. Prior to joining the Institute, Dr. Locklear obtained her PhD in organic chemistry from University of Nebraska at Lincoln where her graduate research focused on the study of peroxides for the construction of drug-related functionalities. Simultaneously, Dr. Locklear served as a legislative intern in the Nebraska State Legislature focusing on a variety of issues related to veteran affairs, technology policy, and green energy. She received her bachelor's degree in pharmaceutical sciences with minors in chemistry and comparative religion at Ohio State University.

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