

Mitigating Risk and Capturing Opportunity

The Future of Alternative Proteins

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Introduction

Food security is a cornerstone of human development, economic development, and national security. But the production of food can itself confer and exacerbate certain global risks—including competition for scarce resources, pandemic emergence, and climate change—that contribute to food insecurity.

The world 30 years from now will not only be larger—the global population is expected to approach **10 billion** by 2050—but **wealthier**, more **urbanized**, and consequently **hungrier** for meat and high-protein foods. Though projections vary, recent analysis finds that, relative to 2010 levels, total global food demand is expected to increase by as much as **56 percent** by 2050. As food demand continues to rise, new technologies and modes of food production will become increasingly necessary to ensure access to healthy, sustainable diets for all.

Recently, the fragility of global food systems has been thrown into stark relief. Global instability has challenged the food security of billions, with economic shocks and geopolitical conflict altering the production and flow of agricultural goods around the world. Amid the Covid-19 pandemic, food supply chains were **disrupted** by labor shortages, transportation bottlenecks, and supply and demand shocks. After the **Russian invasion of Ukraine**, grain shortages raised food prices, worsening dire conditions in the developing world and contributing to record food price inflation in the United States. Historic **drought** caused catastrophic levels of hunger in the Horn of Africa, which was then struck by heavy rains and lethal **flooding**. The coming years portend further disruptions to food security as the increasing effects of climate change, demographic transitions, and unpredictable economic shocks **stress food systems** further and threaten vulnerable populations.

Today, countries and companies are seeking to change the way they produce food to reduce the impact that food production contributes to climate and disease risks, as well as to improve domestic food security

through reduced vulnerability to global shocks. One solution to address these challenges may come from “new” types of food that provide the experience of meat but require fewer inputs, have shorter and more adaptable supply chains, produce fewer greenhouse gas (GHG) emissions, and can be made in settings and regions not capable of sustaining animal agriculture. These are known as alternative proteins.

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With the need to de-risk global food systems growing increasingly serious, many **high-income and import-reliant economies** are investing in alternative proteins as a means to establish a more sustainable and efficient domestic protein production. While the climate change **benefits** of alternative proteins have been fairly **well documented** to this point, relatively less is known about the ability of alternative proteins to allay risks inherent to today’s food systems. These include global risks associated with pandemic preparedness and disease prevention, as well as national security risks related to economic competitiveness and biosecurity across future agricultural markets.

With this specific potential in mind, the United States could find advantage in producing a good that is in increasing demand—foods high in protein—through a more sustainable source and expanding its position within a high-value and eminently emerging market. Should future agricultural disruptions and other economic forces further increase interest in alternative proteins from global markets like China, Brazil, and India, U.S. producers would stand to benefit.

Alternative Proteins Today

Alternative meat products constitute about **1 percent** of the U.S. domestic protein market, with domestic sales for plant-based alternatives reaching USD **1.4 billion** in each of the last three years and investment peaking at **USD 5.1 billion** in 2021. Some market projections suggest that the global alternative protein market could reach **USD 290 billion** by 2035, which would account for about 11 percent of annual global protein consumption.

Still in the nascent stages of development, today’s industry already includes more than **1,000 companies** working to develop plant-based or cultivated meat products.

There are three primary methods of production for these modern alternative proteins:

- **Plant-based:** **Plant-based alternative proteins** are some of the most widely recognizable in the current market. They are made with proteins derived from non-animal sources and are intentionally produced to provide the sensory experience and nutrition of animal meat. Two of the most well-known plant-based alternative protein producers today are Beyond Meat and Impossible Foods.
- **Fermentation-derived:** Fermentation can be used to both **produce and enhance** plant- and fungi-based alternative proteins, increasing the nutritional bioavailability of a product and overall

resemblance to animal products. **Quorn** is one of the most prominent producers of alternative proteins that use mycoprotein (fungi-based proteins) today.

- **Cultivated meat:** Cultivated meats are those derived from animal cell cultures. Cellular agriculture produces meat from animal inputs (cells) without the need to raise, kill, and harvest livestock. Recently, cultivated meat produced by both **UPSIDE Foods** and **GOOD Meat** received a “green light” from the FDA, an important step toward the commercialization of cultivated meat in the United States. Additionally, in 2021, Tufts University received a USD 10 million grant from the U.S. Department of Agriculture (USDA) to establish the **National Institute for Cellular Agriculture** to pursue the research and development of cultivated meat.

The consumption of these alternative protein products is ultimately driven by consumer preference—preference that is, in large part, determined by **taste** and **price** parity. With time, investment, and technological improvements, the parity gaps that currently exist between meat and alternative proteins will continue to **diminish**. Under specific economic circumstances, price parity has already been achieved. In mid-2022, for example, the **Netherlands** saw the price of plant-based alternative proteins drop below that of conventional meat, due in part to meat price increases caused by **European drought** and the Russian war in Ukraine, while the price of plant-based alternative proteins remained relatively unaffected. Shifting attitudes toward **climate change** and **increased market exposure** could additionally drive increased acceptance of alternative protein—particularly cultivated meat—in the future.

Given existing and projected protein demand, even subtle dietary shifts toward increased consumption of alternative proteins could have a profound effect on the rate of market growth. This growth will determine the magnitude of the impact that alternative proteins will have on the environment, human health, and the economy.

Mitigating Global Risks with Alternative Proteins

CLIMATE CHANGE

Recently, the Intergovernmental Panel on Climate Change reported that annual anthropogenic **GHG emissions climbed** to the equivalent of 59 gigatons of CO₂ in 2019. A study from the Joint Research Centre of the European Commission suggests that **one-third** of those emissions are linked to food systems, due to agricultural activity; land use and land use change (i.e., deforestation); and food production, packaging, and transportation. Within these food systems, animal agriculture has a particularly **outsized impact**, accounting for at least 16.5 percent of total global GHG emissions.

With meat demand expected to rise in response to population growth and demographic change, by 2031 global meat consumption is **predicted to grow** by 15 percent relative to 2019, with meat production reaching 377 Mt (1Mt = 1 billion kilograms). This demand will grow unequally, with low- and middle-income countries experiencing the greatest increases in demand. In Africa alone, for example, the demand for meat and other foods derived from livestock is expected to be about **80 percent** higher in 2030 than it was in 2010.

In the absence of sustainable solutions, environmental and health consequences of increased protein demand will likely worsen over the coming years and decades. Today, **more than a third** of all crop calories grown around the world are used for animal feed, while **about 35 percent**—or 37 million

km²—of habitable land is used for livestock production. Given global projections of meat consumption, these figures will likely grow. The need to keep pace with animal protein demands of this magnitude will necessitate **major changes** to agricultural intensification and expansion, leading to serious **environmental challenges**.

In response to these looming challenges, alternative proteins offer the opportunity for food production with fewer **GHG emissions** and **lower environmental impact**. While still a relatively young industry, the production of alternative proteins—particularly plant-based products—is already more efficient than traditional animal husbandry, producing fewer GHG emissions and requiring fewer inputs.

- **GHG Emissions:** Relative to their animal meat equivalents, plant-based alternative proteins produce up to **93 percent** fewer GHG emissions. The greatest difference is found in comparison to conventionally farmed beef; this figure varies between 34 and 87 percent for other meat sources, including farmed fish, poultry, and pork.
- **Grain:** Forty-one percent of all cereal crops that are grown worldwide are used for animal feed. However, the energy efficiency of meat production—the amount of energy provided from feed relative to the number of calories that is effectively converted to consumable meat—is very low. Efficiency rates vary from about **2 percent for beef production to just 13 percent for poultry**. While both milk and egg production have higher energy efficiencies than meat, they only achieve 24 and 19 percent efficiencies, respectively.
- **Fertilizer:** Recent analysis of animal and alternative protein supply chains found that the plant-based supply chain requires **3.3 times less fertilizer**—the manufacture and use of which contributes to GHG emissions and **eutrophication**—than the average pork supply chain.
- **Water:** Per 100 grams of protein produced, plant-based alternative proteins have a blue water (either surface or ground freshwater) footprint that is **79 to 89 percent** smaller than that of farmed meat. The blue water footprint relative to farmed fish is two orders of magnitude smaller.
- **Land:** Per 100 grams of protein produced, plant-based alternative proteins have a median land use that is **41 to 98 percent** smaller than farmed meat. Consequently, reductions in the land use burden of animal agriculture could result in strategically and sustainably repurposed land—be it for reinvestment in other modes of agriculture or investment in sustainable actions like alternative energy production or reforestation.

As countries continue to bear the consequences of climate change, alternative protein production may also be an important tool for climate adaptation within food systems. Rising temperatures and shifting climatological conditions have **already negatively affected** food security by slowing growth in agricultural productivity, with extreme events disrupting harvest stability and crop yields and reducing animal and dairy production. These factors will continue to affect food prices, availability, and security. Adaptation to these effects includes the development of new agricultural practices and subsequent changes in behavior and dietary choices over time.

ZOONOTIC DISEASE, ANTIMICROBIAL RESISTANCE, AND PANDEMIC PREPAREDNESS

De-risking global food systems—in combination with finding more sustainable methods of food production—is central to global health generally and pandemic prevention specifically. Among the challenges of meat production is the vulnerability of animal agriculture supply chains to **disease** emergence and transmission. Zoonotic diseases—those that originate from non-human animal hosts—describe most infectious diseases that affect human populations. In a 2005 review of pathogenic species that affect humans, it was found that about three-quarters of all emergent pathogens—those that are novel or rapidly appearing with populations—were **linked to animals**. Examples of zoonotic diseases include SARS-CoV-2 (responsible for the Covid-19 pandemic) and H1N1 (responsible for the Swine Flu pandemic of 2009), as well as Ebola, SARS, MERS, and monkeypox, among **others**.

In *Preventing the Next Pandemic*, a 2020 report produced by the United Nations Environment Programme and International Livestock Research Institute, the growing demand for meat and the increasing intensification and industrialization of modern animal agriculture were named as two of the seven major anthropogenic drivers of zoonotic disease emergence. With increasing demand for animal protein—and the requisite expansion of land use and livestock intensification required for production—humans and animals are likely to face increasing infectious disease risk into the future. A recent example of this risk can be found across **European swine farms**, where surveillance efforts carried out between 2015 and 2018 identified potentially transmissible swine influenza A viruses in **more than half** of the roughly 2,500 farms that were sampled.

By reducing or eliminating **human and wildlife contact** with livestock during meat production and the intensification with which animals are raised for meat, alternative proteins significantly diminish the risks of zoonotic disease emergence and exposure. Already, countries like Thailand have seen **increased consumer interest** in plant-based alternative proteins in response to outbreaks of **livestock disease** that have made meat products more expensive and less safe. Additionally, a protein supply that does not require antibiotics—like plant-based alternative proteins—avoids antimicrobial resistance (AMR) risks that are exacerbated by animal agriculture at multiple stages of its supply chain.

AMR compounds the concerns of zoonotic disease risk associated with animal agriculture. AMR, which results when bacteria, viruses, fungi, or parasites evolve immunity to antimicrobial or antibiotic treatments, is listed by the **World Health Organization** as among the most serious threats to global public health and development. In 2019 alone, it is estimated that **4.95 million deaths** were associated to all forms of AMR globally. Of those deaths, 1.27 million were found to be directly attributable to AMR infection—significantly more than were killed by HIV/AIDS or malaria in the same year. Without the necessary interventions to curtail the development and proliferation of AMR, it is feared that it could contribute to as many as **10 million deaths** annually by 2050, costing the global economy some USD 100 trillion by that date.

The all-too-common **misuse and overuse** of antibiotics in animal husbandry are significant contributors to the emergence of resistant pathogens. In 2007, a **comprehensive review** of the role animal agriculture plays in AMR and epidemics of infectious disease suggested that “the industrialization of livestock production and the widespread use of nontherapeutic antimicrobial growth promotants has intensified the risk for the emergence of new, more virulent, or more resistant microorganisms.” In the United States, about **80 percent** of all antibiotics sold are used in animal

agriculture. Recent **guidance** from the U.S. Food and Drug Administration (FDA) attempts to address this overuse. Globally, antibiotic use for livestock is likely severely **underreported** and projections suggest that by 2030 annual consumption of antibiotics for livestock will reach more than **200,000 tons**. The subsequent environmental spillover of animal waste that contains antibiotics can also further the spread of AMR pathogens. Combined with poor disease prevention, oversight, and awareness, this rampant abuse of antimicrobials exacerbates the domestic and global AMR risk.

The risks of zoonotic disease transmission and AMR are both **directly and indirectly affected** by animal agriculture and climate change. In combination, they pose a grave and growing threat to the health and well-being of populations worldwide, with emergent and resistant pathogens increasing **pandemic risk** at the global scale.

While alternative proteins provide a tool to mitigate the threats of zoonotic disease transmission and AMR, their efficacy depends in part on implementation. The geographic regions in which alternative proteins are produced and consumed will influence the extent to which they could mitigate these challenges locally. Most early alternative protein development will likely continue to take place in high-income economies; however, while zoonotic diseases are a threat all over the world, the **burden of zoonotic disease** is highest in developing countries. For example, the **zoonotic disease “trap”** of animal agriculture, which describes the scenario in which the two methods of increased meat production—expanded land use and livestock intensification—both result in greater risk of infectious disease transmission, is most acutely experienced in developing tropical regions. Likewise, **AMR** significantly affects developing countries, including those looking to grow their domestic **meat production**. Without reductions in cost that facilitate an increase in alternative protein production and consumption in developing countries, the degree of benefit inherent to alternative proteins with regard to pandemic protection in these regions will be lower in the short term.

Economic and National Security Considerations of Alternative Proteins

“People all over the world are struggling to cope with the effects of shared challenges that cross borders—whether it is climate change, food insecurity, communicable diseases, terrorism, energy shortages, or inflation. . . . They are at the very core of national and international security and must be treated as such.” – **United States National Security Strategy**, October 2022

SUPPLY CHAINS AND BIOSECURITY

Economic instability related to climate, conflict, and disease all pose significant threats to the global food system. In the United States, during the Covid-19 pandemic, increases in meat prices constituted half of the overall food price rise across the country. In 2022, the **Meat Price Index** produced by the Food and Agriculture Organization of the United Nations reached an all-time high, reflecting disruptions across animal protein supply chains including reduced availability of animal feed due to the Russia-Ukraine war and avian flu outbreaks in major poultry-producing countries. Across all commodity categories, 2022 **world food prices increased** compared to the previous year. Cereal prices and the Meat Price Index rose by 17.9 percent and 10.4 percent over 2021 prices, respectively. The rise in meat prices was determined, in large part, by rising costs of imports and overall demand reductions related to unexpected shocks.

The U.S. food supply is also susceptible to agricultural bioterrorism, such as small- or large-scale attacks targeting production infrastructure and the purposeful introduction of animal pathogens. In

his farewell address, former U.S. Department of Health and Human Services secretary **Tommy G. Thompson** issued a warning regarding the ease with which terrorist attacks could target and damage the U.S. food supply. The animal protein supply chain disruptions of the Covid-19 pandemic were sudden but relatively short-lived; a targeted attack on infrastructure or an unintentional or purposeful introduction of pathogens could have far-reaching consequences.

With this in mind, industry **concentration** is a present and growing concern that magnifies this danger. Today, just **four firms** control over 54 percent of the poultry market, 85 percent of the beef market, and 70 percent of the pork market across the United States. These numbers represent continual consolidation over the past five decades. At the same time, the USDA reports that livestock consolidation on U.S. farms, as measured by the **animal sales midpoint**, has grown over the past three decades, particularly for poultry, pork, and dairy cows.

The sheer extent of consolidation presents opportunities for malicious actors to have large impacts—on farming and meat processing operations, specifically, and on the U.S. economy, generally—through relatively small attacks. In **June 2021**, for example, an organization that was likely based in Russia hacked the computer networks of JBS—the largest meat processor in the world—holding its computer systems for ransom. This attack forced shutdowns of meat processing and risked food price increases at a time when food supply chains were still recovering from disruptions related to Covid-19.

Animal pathogens pose an additional threat to the functioning of global and U.S. animal protein supply chains. Today, the world is experiencing the deadliest **bird flu** outbreak on record. In the United States alone, the highly pathogenic avian influenza (H5N1 bird flu) led to the death of **nearly 59 million** birds, including millions of egg-laying hens, resulting in the significantly higher **egg prices** across the United States and abroad. Risks to economic stability and human health extend beyond poultry. Analysis provided by the Animal and Plant Health Inspection Service of the USDA suggests that the introduction of **swine or bovine pathogens** could compromise a significant proportion of animal protein supplies in a relatively short period of time.

Damaging a significant proportion of the animal protein supply chain—whether through attack to production infrastructure or the introduction of pathogens—has the potential to significantly affect the U.S. economy. The price increases that would result from a reduction in animal protein supply could also make nutritious diets less accessible.

Alternative protein supply chains may be less susceptible to bioterrorist threats than those of the current animal agriculture sector. Although alternative protein companies are growing rapidly in size and number, none currently come close in market share to the major animal protein companies. In addition to **pea protein**—which is expected to be a leading source for the plant-based protein market in the short and medium term—the alternative protein market also comprises soy protein, fungi, cultivated meat, and proteins from other non-animal sources, each with its own supply chain. Unlike with domestic animal agriculture, a bioterrorist attack on alternative protein production facilities would therefore be unlikely to affect a large proportion of the industry at once. Increased regional diversity of protein production afforded by the adaptability of alternative protein supply chains would additionally bolster overall resilience.

While a strength in one sense, the diversified nature of alternative protein supply chains also carries inherent risk. As no supply chain is perfect, plant-based protein production is vulnerable to shortages

of specialized **ingredients** necessary to their assembly (e.g., protein isolates and minerals). At the same time, significant **disruptions** to the biotechnology manufacturing sector, like those experienced due to the Covid-19 pandemic, could also detrimentally affect alternative protein production at scale. While all the supply chain implications of alternative proteins are still a matter for further research, the argument for increased resilience through diversity is already clear.

ECONOMIC COMPETITION

Across all agricultural sectors, technological advancements in food production and improvements to supply chains will affect the position of U.S. producers on the global stage.

In the light of growing global challenges, economic competitiveness is critical to U.S. national security. Both the **Biden administration** and the **Trump administration** have emphasized increased economic competition, particularly with China, as key to U.S. global interests. Domestic agricultural strategies—especially those that apply to rising **protein demand**—will be central to establishing a competitive economic advantage across future global food markets.

Several industries already enjoy the benefits of shifting policy to enhance economic competitiveness, such as pharmaceuticals, clean energy technology, and advanced chips for artificial intelligence. Food production technology could also be considered within this national security framework. In 2014, Agriculture Secretary Tom Vilsack highlighted the connection between agricultural investment and economic security when **stating**: “We must continue to make strategic investments in [agricultural] research and technology if we are to remain leaders in the global economy.” In the coming decades, global food systems will be tested by **population growth** and the progressive effects of **climate change**. The identification and development of solutions to these challenges could be a key part of the U.S. economic strategy.

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Today, the United States plays a leading role in the global food economy. In 2022, **total agricultural exports** reached a record USD 196 billion, with sales increasing across all 10 of the United States’ top export economies. Animal feed and animal proteins contributed significantly to this total, as about **half of export value** came from soybeans, corn, beef, and dairy (in addition to cotton and tree nuts). Conversely, despite being the world’s largest overall **agricultural producer**, China was once again a **net importer** of agricultural goods—and **the largest importer** of U.S. agricultural products, valued at a record USD 36.4 billion. As China continues to depend on foreign food production to keep pace with growing domestic demands, the United States is well positioned to maintain its favorable agricultural trade position globally.

Despite this, anticipating and adapting to the forces that will affect the future economic landscape will prove essential to maintaining the U.S. position relative to geopolitical competitors. A recent **meta-analysis** investigating future hunger risk projects that food demand will increase between 35 and 56

percent by 2050, relative to 2010. And a **2015 editorial** published by the president of the Agricultural Economics Society estimates that within this same timeframe, beef and pork consumption will increase by about 50 percent and poultry by 82 percent, with sheep consumption more than doubling. The ability to meet **sustainability goals** while achieving the increased agricultural productivity needed to feed a growing world will be a significant logistical and industrial challenge.

In 2022, the **White House recognized** the potential advantages of alternative proteins for developing a sustainable and secure bioeconomy through novel food sources. In the 2023 report **Bold Goals for U.S. Biotechnology and Biomanufacturing**, the Biden administration emphasized a commitment to the research and development of novel foods that can address global hunger, strengthen national security, and reduce GHG emissions. As stated in the report, “biotechnology and biomanufacturing can spur development of novel food sources with improved sustainability, including new crops and protein sources, which can augment our current food system and help provide equitable access to nutritious foods.” Within this context, and despite a relative dearth of public funding for alternative protein research, the United States finds itself in an advantageous position, already leading the world in the **number of companies** working to produce alternative proteins.

This lead is not a foregone conclusion. Governments **around the world**—including Singapore, Denmark, Canada, Israel, and the Netherlands—are all currently **funding research** to secure the future of alternative proteins in their countries. Earlier this year, the United Kingdom announced a **£12 million investment** for cellular agriculture research, while Canada announced a **CAD 150 million** funding renewal for Protein Industries Canada, a nonprofit organization seeking to enhance the agricultural and manufacturing sectors of Canada’s growing plant-based foods industry. China, too, has acknowledged the potential of alternative proteins to help ensure its own national security in its **2022 five-year agricultural plan**.

Technical innovation and **intellectual property** development within the alternative protein sector will also be important for the overall advancement of the industry, but it will stagnate if met with a lack of financial and political support. Already, a **plurality** of intellectual property documentation for plant-based alternative protein products are being filed in Asia, with the United States and Europe lagging significantly behind. The development and protection of alternative protein-related intellectual property, in conjunction with the advancement of specific alternative protein technologies for production and supply chain development, could prove advantageous for trade relations between the United States and those economies expected to experience increased protein demands.

While traditional animal protein production—animal husbandry and fisheries—is practically bound by geographic and temporal constraints, alternative proteins provide inherent production **flexibility**. Consequently, many countries that rely heavily on meat imports are seeking alternative protein production as a domestic solution to help safeguard their food security from external instability. Singapore, for example, which currently imports more than **90 percent** of its food, is building its alternative protein sector as a part of its goal to produce **30 percent** of its food supply domestically by 2030. As a country with limited arable land, Israel is **prioritizing** its alternative protein sector in the face of **national and food security challenges** posed by climate change. Additionally, China, which leads the world **in meat production** but still **struggles** to match food demand, is likely **pursuing alternative protein** development to both lessen its import burden and strengthen future food export potential.

The extent of the economic advantage that the current U.S. position affords will be determined in large part by the interaction between policy, innovation, and demand. A 2023 report by ClimateWorks Foundation and the Global Methane Hub suggests that the alternative protein industry could generate up to **83 million jobs** by 2050 if investment increases to levels that meaningfully impact dietary shifts. The degree to which the current U.S. alternative protein landscape depends on private investment leaves it particularly vulnerable within the broader agricultural sector. U.S. leadership in alternative proteins could produce significant economic benefits to U.S. companies and workers, while also generating global benefit through the shared development of novel sustainable food technologies for a growing world.

Conclusion

The current state of animal agriculture confers significant external costs related to global and national security—with implications for climate change, global health, and economic resilience.

In the face of these risks and vulnerabilities, investing in alternative proteins provides strategic benefit for the United States. The development and prioritization of domestic policy that enhances economic competitiveness already exists for other strategic technologies. Investment in food biotechnology generally, and alternative protein innovation specifically, would benefit from similar treatment.

As this industry is still in the nascent stages of its development, the future market outlook for alternative proteins remains to be seen. However, in general, the market for alternative proteins has experienced significant (if not entirely linear) growth since its inception, with domestic annual plant-based alternative protein sales having plateaued since 2020. Globally, **market outlooks** project room for a high volume of growth across all alternative proteins—including plant-based dairy and meat, and the yet-to-be-widely-available cultivated meat. Locally, the continued emergence of this new industry will necessitate the development of infrastructure, technologies, and manufacturing centers, **creating jobs** and bolstering local economies across the United States.

Changes in how closely alternative proteins mimic the experience of animal meat and **product costs**—which will be determined, in part, by investment and progress in research and development—will have a substantial impact on **consumer preference** and the size of the future alternative protein market, particularly in **high-income countries** where attitudes toward sustainable diets and animal welfare may be changing. Whether driven by shifting consumer preferences, government policy, or some combination of the two, the potential near-term scale of alternative proteins is significant.

The rewards of investment in alternative protein research and development are clear: realizing a food system with greater ability to provide adequate nutrition for all while mitigating global threats and enhancing U.S. strategic competitiveness. ■

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