2021
PUBLIC-PRIVATE
ANALYTIC EXCHANGE PROGRAM

THREATS TO FOOD
AND AGRICULTURAL RESOURCES

EXECUTIVE SUMMARY

The Food and Agriculture Sector accounts for 20% of the national economy and has been designated a Critical Infrastructure Sector by the U.S. Department of Homeland Security. This sector consists of an extensive, open, globally interconnected, diverse, and complex array of privately owned "just in time" networks; and encompasses a variety of goods and services including the production and manufacturing of crops, livestock, poultry, and seafood products and by-products. As such, the threats to food and agricultural resources will come from various sources including foreign and domestic events, naturally occurring and/or human-induced, and the interdependencies of Food and Agriculture Sector with other critical infrastructures.

Given the broad scope of these threats, the Threats to Food and Agriculture Resources (TFAR) teams focused on two (2) problems areas:

- A critical need for a public / private partnership model risk-based framework centered around food and agriculture information and intelligence sharing for better research coordination; and,

- A critical need for concerted national and international efforts to detect and prevent the transboundary spread of known or unknown, and naturally evolving or synthetically-derived, pathogens that are catastrophic to the agriculture and food industries.

The goals were to identify the myriad of threats that could disrupt or devastate supply chains within the vast food and agriculture system of the U.S.; examine shortfalls in U.S. capacity to prevent and mitigate the threats; and, recommend best practices, policy, and research priorities that will foster preparedness and resilience of the food and agri-business sectors against all threats. The TFAR teams, composed of participants from the government, academia, and sectors of the private industry, relied on shared knowledge, literature search, and information provided by invited subject matter experts in accomplishing these goals. The TFAR discussions centered on terrestrial and aquatic environments in the context of food and agricultural systems, climate change, food adulteration, disruptions in the transportation sector, water shortages, globalization of trade/travel, biosurveillance limitations, social culture, cyberthreats, agro / bioterrorism, and economic coercion.

In-depth capability and vulnerability analyses of the Food and Agriculture Sector have identified the following threats for utmost attention by the public and private sectors, with recommendations to prepare for and address the likelihood of emerging threats that could severely impact the food, agriculture, and aquaculture industries, namely:

- The natural emergence of known and unknown pathogens, including zoonotic and phytonotic spillover, antimicrobial resistance, crops, and livestock biosecurity
- Aquatic / seafood safety and biosecurity

- Convergence of technologies with dual-use applications
- Cyberthreat and cybersecurity
- Interdependencies of the Food and Agriculture Sector to critical infrastructures

The TFAR teams envisioned that, for the next 10 years, globalization will remain the determinant factor to the world's economic, technological, and social progress; with caveats that geopolitical disputes amongst dominant world powers for access to natural resources, including agricultural and aquaculture products, may change the dynamics of the food and agricultural supply chain. This will significantly impact the Food and Agriculture Sector and its interdependence with other critical infrastructures. COVID-19 notwithstanding, trade and international travel will continually present significant pathways for transboundary movement and spread of vectors and pandemic-class of pathogens that could devastate the U.S. crops, livestock, poultry, and aquaculture industries. Known and unknown pathogens will continue to evolve with anthropogenic environmental pressures and increase contact of humans with both wild and domestic animals. The proliferation of new pathogens may be exacerbated by the convergence of artificial intelligence, gene editing, and genome synthesis that will endow organisms with novel functions. The global biothreat landscape will keep on changing at a pace that will render international sanitary controls and government regulations ineffective. As border inspections rely on these enforcement regulations, these will present a critical gap in safeguarding against the accidental or deliberate introduction of harmful pests and diseases that will continue to widen unless dramatic measures, tenable to the public and private sectors, are put into place. The findings of this report can be leveraged to support and address a variety of research requirements embedded within existing U.S. government policy and doctrine. In particular, six key recommendations are provided:

1. It is recommended that the U.S. government and the private industry consider engaging with international partners to develop quantitative risk assessments of cross-interdependencies with the Food and Agriculture Sector
2. The U.S. government must update its GOFR and LOFR policy and lead an international verification effort on this type of research
3. The U.S. government and the private industry must develop quantitative threat risk scores for known and unknown biothreats of the Food and Agriculture Sector
4. The U.S. government should lead research coordination of public-private partnerships for information sharing standards and risk mitigation
5. The U.S. government should invest resources in the training of the next-generation workforce in the Food and Agriculture Sector Defense
6. The U.S. government needs to promote domestic aquaculture for food production

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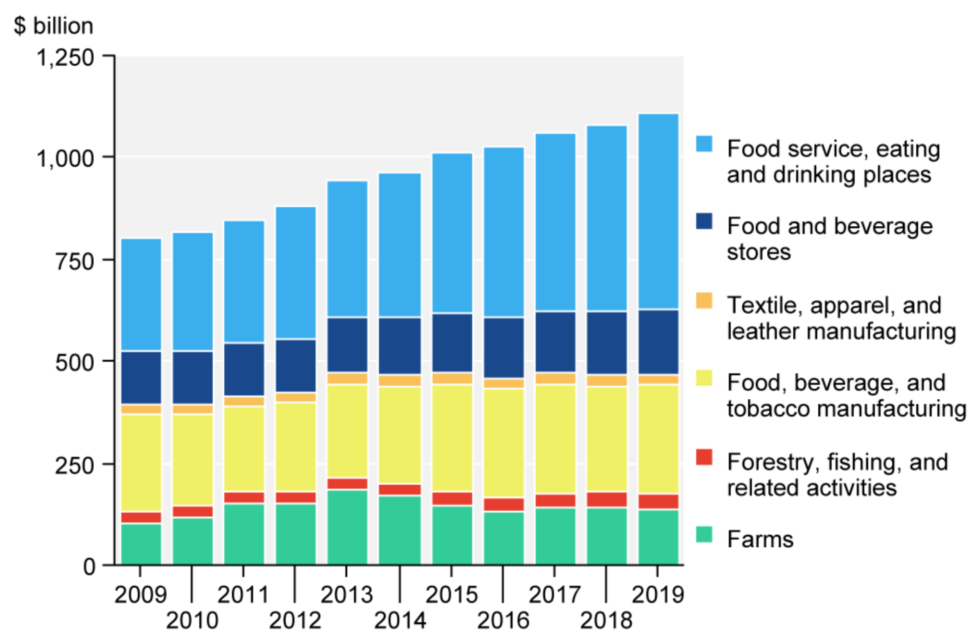
FOOD AND AGRICULTURE SECTOR OVERVIEW

The U.S. enjoys abundant, affordable, and high-quality foods that are among the world's safest; this is grounded by the efficiency and productivity of 2 million crop and animal farms and millions of food retailers that secure a quality food supply. Agriculture is a strategic sector for the U.S. because of its more than $3.9 trillion economic contributions, representing 22% of the domestic GDP, and because families, family partnerships, or family corporations operate 98% of the U.S. farms. In parallel, the food retail and food services sales amount to approximately 6.2 trillion U.S. dollars each year. This broad sector encompasses a variety of goods and services, including the production of crops, livestock, poultry, and seafood; the manufacturing and retailing of foods and beverages; the production of textiles, apparel, and leather; and forestry and fishing.[1]

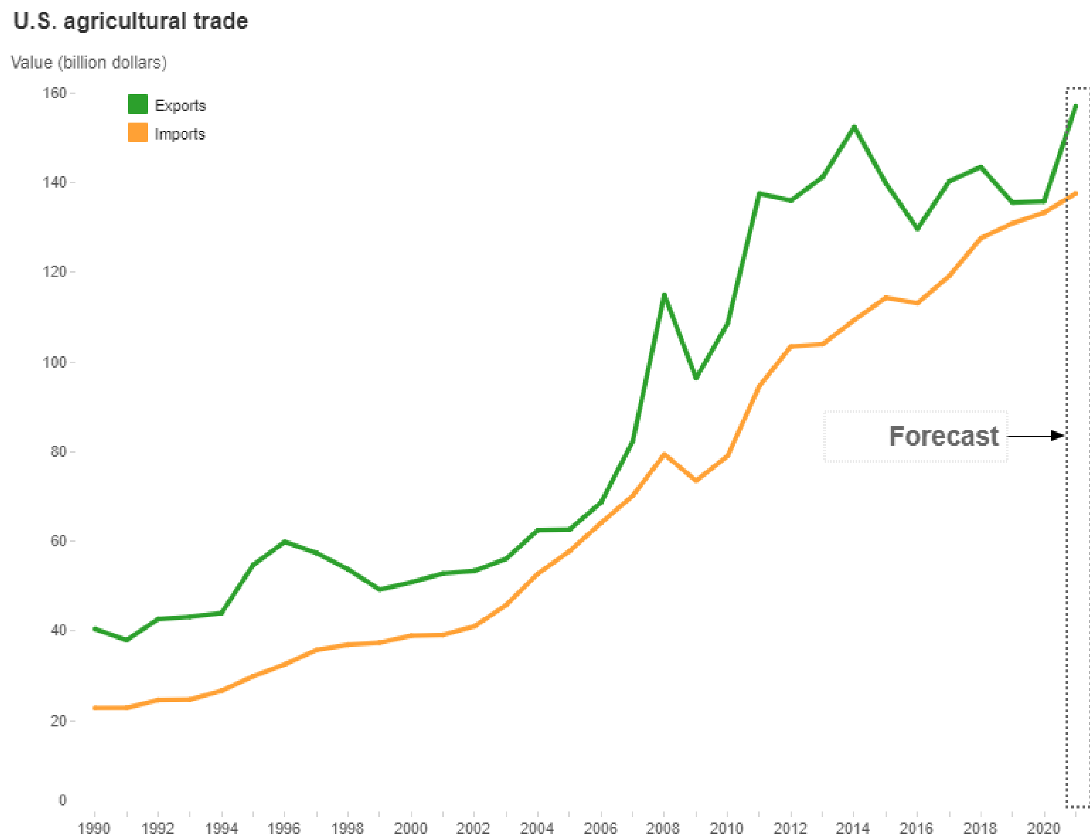
As for household spending, food accounted for 13% of U.S. household expenditures in 2019, just behind housing and transportation expenditures.

Value added to GDP by agriculture and related industries, 2009-19



Note: GDP = Gross domestic product.
Source: USDA, Economic Research Service using data from U.S. Department of Commerce, Bureau of Economic Analysis, Value Added by Industry, data as of September 30, 2020.

One-fifth of U.S. agricultural production is exported, generating over $145 billion in 2020. U.S. agricultural exports in Fiscal Year (FY) 2021 are projected at $157 billion, largely driven by higher oilseed and grain export forecasts.[2]



In 2019, 22.2 million full- and part-time jobs were related to the food and agricultural sectors—10.9% of total U.S. employment. Of these, the U.S. food and beverage manufacturing sector employed 1.7 million people at thousands of food and beverage manufacturing plants located throughout the country for transforming raw agricultural materials into products for intermediate or final consumption.[2]

The Food and Agriculture Sector has been designated a Critical Infrastructure Sector by the U.S. Department of Homeland Security (DHS) Cybersecurity and Infrastructure Security Agency (CISA). Critical infrastructure sectors are considered essential to the U.S., such that their disruption would most certainly cripple national security, global economic activity, and national public health and safety.[3,4]

> The Food and Agriculture Sector accounts for 20% of the national economic activity and has been designated a Critical Infrastructure Sector.

Existing policy to support defense of the U.S. Food and Agriculture Sector include the following considerations presented as a review; specific details are provided for each as context relevant to the topics discussed within this report.

The 2004 Homeland Security Presidential Directive 9 (HSPD-9) directed the DHS to coordinate the overall national effort to protect the Food and Agriculture Sector and its critical infrastructure and key resources from terrorist attacks, major disasters, and other emergencies.[4] In 2017, the Securing our Agriculture Food Act was passed, which defined the specific Countering Weapons of Mass Destruction Office (CWMD) within DHS that is responsible for oversight and management of the HSPD-9 and lead DHS policy initiatives on defense, countermeasure research development, and national preparedness related to agricultural and food security and veterinary health.[5] At border stations and ports of entry, the U.S. Customs and Border Protection (CBP) enforces these regulations on behalf of other agencies of the U.S. government, including the U.S. Department of Agriculture (USDA), Centers for Disease Control and Prevention (CDC), and Fish and Wildlife Service (USFWS) by inspecting import commodities entering the country commercially or hand-carried by travelers. On a typical day in FY2020, for example, U.S. CBP processed 650,179 passengers and pedestrians; 187,049 incoming privately owned vehicles; 77,895 truck, rail, and sea containers; $6.64 billion worth of imported goods; and 90,000 entries of merchandise at our air, land, and seaports. U.S. CBP intercepted 250 exotic plant pests and seized 3,091 quarantine significant materials (*e.g.,* plant, meat, animal by-product, and soil)[147]. In addition, policies and programs maintained by the U.S. government seek to prevent and prepare the U.S. for the natural, unintentional, or intentional introduction of pathogens of concern.

Presidential Policy Directive 8 National Preparedness (PPD-8) describes the nation's approach to preparing for the threats and hazards that pose the most significant risk to the security of the U.S., including Critical Infrastructure Sectors.[6] There are five overarching areas of focus: prevention, protection, mitigation, response, and recovery.[7] There are opportunities to enhance Food and Agriculture Sector preparedness in each of these areas. Novel diagnostics and treatments for pests and diseases, application of new technologies to mitigate the impacts of climate change, the identification or development of alternate production input raw material sources, and new predictive tools are just a few examples. A coordinated research program can provide valuable information and the tools needed to increase preparedness and address emerging and re-emerging threats to the Food and Agriculture Sector.

The Food Safety Modernization Act (FSMA) Section 108 identifies the need for a "coordinated research agenda" within the National Agriculture and Food Defense Strategy (NAFDS).[8] The Biennial Report to Congress on the Food Safety and Food Defense Research Plan (110g) is the first step in documenting progress toward a coordinated, risk-based, and mission-critical federal food safety research strategy.[9] The U.S. Food and Drug Administration's (FDA) New Era of Smarter Food Safety calls out the need to consider how to develop public-private “data trusts” to be established and developed between government, industry, and academia in the hopes of furthering the mission of the Agency to protect and promote public health and well-being.[10] The collaborative mindsets that are needed to ensure the success of this effort can be rooted in Food and Agriculture Sector joint meetings. The transparency needed to ensure data are non-attributably shared is something that warrants the immediate attention of all stakeholders within the Sector.

Finally, the Food and Agriculture Sector-Specific Plan (SSP) for 2020 was put on hold as the Federal partners that led this effort were also responsible for leading the U.S. government response to the pandemic. The Sector Annual Report (SAR) was being developed as well during the writing of this DHS Analytics Exchange Program (AEP), and notes from those draft reports that this AEP considered are contained within Appendix 2.

CRITICAL INTERDEPENDENCIES

AEP Project Overview: While the Food and Agriculture Sector has been extensively studied elsewhere and while much is known about the system's current state that comprises the U.S. Food and Agriculture Sector, there is much to be learned about the "unknown unknowns" within the Sector.

The food, agriculture, and veterinary production critical infrastructure systems are comprised of an extensive, open, globally interconnected, diverse, and complex array of privately owned "just in time" networks. For example, according to the USDA, while the U.S. is the world's largest beef producer and second-largest beef exporter, it is also the leading beef importer, as feeder cattle are frequently sourced from Mexico and Canada to sustain the U.S. feedlot operations. One-fourth of the total agricultural commodities imported by the U.S. are from more than 250,000 foreign establishments from 180 countries. Fifty percent of U.S. agricultural imports are horticultural products[11], and approximately 95 percent of cocoa / coffee / spices and fish / shellfish consumed in the U.S. come from overseas.[12]

> **"Everything is connected to everything else", Leonardo de Vinci**

Due to its essential role in the health of the U.S. population and the economy, the Food and Agriculture Sector is considered one of the 16 critical infrastructure components of the U.S.

The Food and Agriculture Sector has numerous interdependencies (mutually reliant relationships between entities) with other Critical Infrastructure Sectors. The nature and extent of these interdependencies increase the risks borne by the Food and Agriculture Sector, based on the function and role of those interdependencies, and may lead to future integrations and collaborations to assist with the identification and fortification of existing vulnerabilities. As an ongoing example of an asymmetrical threat that can severely disrupt the automobile industry, what is the Food and Agriculture Sector micro-chip equivalent? As described in Appendix 18, this information is currently not "visible" or consolidated within the food and agriculture sector and is representative of how Sector stakeholders can help share information to plan for and mitigate against disruptions of critical interdependencies in the supply chains for key resources to keep America's food supply chain moving.

It is important to highlight the critical interdependencies of the Food and Agriculture Sector with several other Critical Infrastructure Sectors, including:[13]

Water and Wastewater Systems Sector and **Dams Sector**, for clean irrigation and processed water for food production, human consumption, manufacturing, and animal feed formulation and control irrigation and watershed management for agricultural lands.

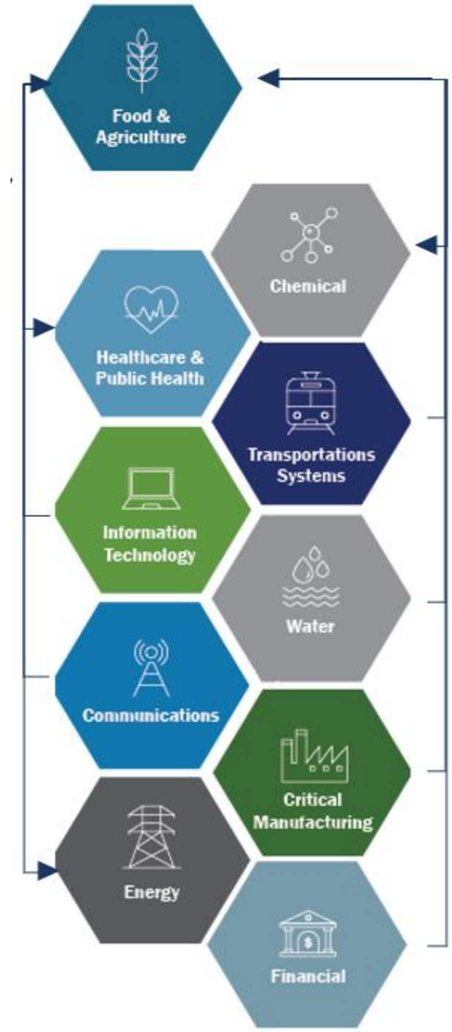
Transportation Systems Sector, for movement of food products, livestock and seedstock, feeds, fertilizers, and other necessary supplies and equipment both domestic within and foreign import.

Energy Sector, to power the equipment needed for agriculture production, crop harvest, butchery, food processing, and post-harvest warehouse or refrigerated storage of food products.

Chemical Sector, for fertilizers, pesticides, antibiotics, fungicides, and other compounds required for the production of crops and livestock, including animal feeds and feed ingredients and packaging materials for food products.

Communication Sector, for broadband and cellular network connectivity.

See Presidential Policy Directive 21 (PPD-21): *Critical Infrastructure Security and Resilience* advances a national policy agenda to strengthen and maintain secure, functioning and resilient critical infrastructure.[14]



The DHS CWMD is required through HSPD-9 and the Securing our Agriculture and Food Act (P.L. 115-43) to carry out a program to coordinate department efforts related to defending the food, agricultural, and veterinary systems of the U.S. against terrorism and other high-consequence events that pose a risk to homeland security (*i.e.,* intentional, unintentional, or natural major disasters and other emergencies). In accordance with its authorities, DHS CWMD Food, Agricultural, and Veterinary Defense (FAV-D) Division, and the Science and Technology Directorate developed a joint strategic plan that lays out the intent of CWMD to cooperate on activities associated with DHS investments into research, development, testing, and evaluation (RDT&E) efforts that may be executed across the national incident management and response continuum. Additional information on those concepts can be found in **Appendix 3**. Additionally, **Appendix 4** includes a review of the food and agriculture risk landscape regarding the National Infrastructure Protection Plan (NIPP 2013).[15,16]

FOOD AND AGRICULTURE SECTOR THREATS

The threats to the Food and Agriculture Sector are complex and dynamic, and constantly changing. They can come from various sources such as climate change, foreign animal diseases, exotic plant pests, food adulteration, chemical contamination, economic coercion, cyberthreats, agro / bioterrorism, aging workforce, and its dependence on other critical infrastructure components. Left uncontrolled, each of these threats can devastate part or even the entire agricultural industry, threaten our food supplies, and cost billions of dollars to recover.

In what seemed to be a weekly basis, the high-level "scoping" conversations that we embarked upon helped us realize that we needed to put a stake in the ground to move forward. To address challenges and threats to the U.S. Food and Agriculture Sector, the team implemented a consensus-based discussion centered on answering the fundamental question, "What are the shortfalls in U.S. capacity to respond and mitigate threats?" This effort led to the examination of the risk-capability-vulnerability matrix of the U.S. food and agriculture sub-sectors (Appendix 1). The analysis centered on terrestrial and aquatic environments in the context of food and agricultural systems, climate change, food adulteration, globalization of trade/travel, social culture, cyberthreats, agro / bioterrorism, and economic coercion. The expertise of experts from the public and private industries was leveraged to provide the current state of knowledge and bridge the team's knowledge gaps. Based on the analysis and knowledge sharing, the team identified and prioritized strategic research and policy recommendations of best practices that will foster preparedness and resilience of the food and agri-business sectors against these threats.

As we commenced evaluating research gaps in the Food and Agriculture Sector as a threat itself, there were many thoughts, ideas, and perspectives. What follows is the culmination of our work in identifying potential research areas. Among these threat factors, global trade, travel and tourism, food and water quality, and changing climate were associated with 61% of the infectious disease outbreaks.[17] As we have experienced with the recent SARS-CoV-2 (COVID-19) pandemic, the global spread of zoonotic pathogens is, fortunately, less frequent events. However, our recent experiences and understanding will hopefully help alleviate the future emergence of novel pathogens and other threats and their impacts on human and animal health and the food supply.

> ***"There was just a systemic failure across government to keep its eye on this threat"*, Caitlin Durkovich, Assistant DHS secretary for infrastructure (2012 to 2017)[18]**

This AEP panel provides the following definitions and additional threats or hazards of significant concern to the Food and Agriculture Sector.

Definitions

Threat: "natural or man-made occurrence, individual, entity, or action that has the potential to harm life, information, operations, the environment, and / or property"[19]

Vulnerability: "physical feature / attribute that renders an entity, asset, system, network, or geographic area open to exploitation or susceptible to a hazard"[19]

Risk: "potential for an unwanted outcome resulting from an incident, event, or occurrence, as determined by its likelihood and the associated consequences"[19]

Food Safety: "addresses the accidental or unintentional contamination of food products"[20]

Food Defense: "the effort to protect food from intentional acts of adulteration where there is an intent to cause wide scale public health harm"[21]

Food Security: "accesses to an ample, nutritious food supply"[22]

Food Protection: "a concept that leverages the outputs of food safety and food defense activities"[23]

Food Terrorism: "is defined as an act or threat of deliberate contamination of food for human consumption with chemical, biological, or radionuclear agents for the purpose of causing injury or death to civilian populations and / or disrupting social, economic, or political stability"[22]

Natural Emergence of Known and Unknown Pathogens

Anthropogenic changes in the environment, travel, and the international exchange of commodities have increased the geographical range of infectious disease vectors and fomites, favoring the dispersion of more than 6,000 invasive and pathogenic species and skewing the pathogen-host population dynamics towards amplifying and spreading the disease in humans, animals, and plants[24,25]

> **Known and unknown microorganisms and toxins are emerging and spreading at unprecedented rates impacting global health, trade, and security.**

Importers either unintentionally or intentionally do not declare or mis-declare prohibited items or deliberately obfuscate attempts to import restricted commodities, as they either do not fully comprehend the importation process or perceive it to be too cumbersome and restrictive. Foreign nationals seeking to bring culturally significant foods or religious relics from their home countries often attempt to smuggle restricted items into the U.S. These items (*e.g.,* bushmeat) may be contaminated with pathogens hazardous to human and animal health. For example, the hemorrhagic fever viruses (*e.g.,* Ebola, Marburg) or African swine fever virus can readily spread among human or animal populations, causing disease and death and billions of dollars in losses.

A single case of a World Organization for Animal Health (OIE) reportable disease can trigger an immediate halt to exports causing losses of billions of dollars. A prolonged outbreak could devastate an entire production sector, its associated businesses, and inter-dependent sectors that rely on outputs or a steady stream of products from the Food and Agriculture Sector. The establishment of the African Swine fever virus in susceptible native wildlife populations in the U.S. could serve as a reservoir for recurrent reinfections of domestic livestock that will be very challenging to control and eradicate. The environmental persistence of pathogens could be devastating for U.S. agriculture and change the trading landscape.

To mitigate the multi-dimensional effects of a future threat to the Food and Agriculture sector, the U.S. government implemented a series of strategies and policies. The U.S. Department of Agriculture (USDA), Animal and Plant Health Inspection Services (APHIS) regulates the importation of animals and plant products and by-products, and the U.S Fish and Wildlife Service (USFWS) regulates the importation of wildlife materials according to the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). The Food and Drug Administration (FDA) regulates the importation of drugs and products related to animal and human health. The Center for Disease Control and Prevention (CDC) regulates the importation of biological materials with nexus to public health.

Research Area: Phytonoses

Like zoonotic pathogens, pathogens of plant origin causing clinical disease in people or animals can be transmitted via the consumption of fresh products or contaminated crops, known as phytonoses.[26] There is a limited amount of research dedicated to understanding the ecology and complexity of phytonoses. This evolving field plays a significant role in understanding food disease outbreaks. Regulatory bodies, including Federal / State / Local / Tribal / Territorial (FLSTT) agencies and departments, academia, and private industry, are beginning to assess the interconnectivity of the environment with animal-human-plant health. They are starting to analyze the transmission pathways facilitated by the interconnected food production systems and food consumption.[27]

Antimicrobial Resistance

The U.S. food supply is among the safest globally *albeit* people still get sick from foodborne illness. The bacterial contamination of produce and meat poses additional threats to food and agriculture. They lead to hundreds of thousands of foodborne illness cases and hundreds of deaths in the U.S. each year.[28] One crucial pattern emerging from animal production in both terrestrial and aquatic environments is antibiotic use. While judicious use of antibiotics in animal farming is endorsed in the U.S., overuse, off-label, or misuse of antibiotics in the U.S. and abroad presents a public health and environmental hazard — and is one of the sources of the rise of antimicrobial disease resistance.

Driven by worldwide consumer demands for animal protein, narrow- and broad-spectrum antibiotics are widely used for animal health and productivity. Residues of certain antibiotics found in animals and their tissues can cause illnesses when consumed; similar, antibiotics are shed in animal waste and contaminate the soil and water.[29] Antibiotic-resistant bacteria have been associated with the treatment of animals with antibiotics below the recommended effective dose. These resistant bacteria can spread in animal populations and are of concern to human health either directly by contact with the animal or indirectly via the food chain or contaminated water or soil.[29] Treatment of animals and humans with antibiotics can result in genetic resistance (*i.e.,* antimicrobial resistance) of pathogenic or commensal bacteria. Genetically resistant bacteria can horizontally transfer their resistance gene/s to other bacteria of the same species and even close and distant species.

There have been increasing incidences of antimicrobial-resistant bacteria causing diseases like columnaris, foulbrood, campylobacteriosis, salmonellosis, and emergent diseases like citrus greening. The losses caused by these diseases increase production costs and can be financially devasting to impacted producers.[30,31,32,33]

Antibiotics are also employed to treat fruit crops, leading to antimicrobial resistance to fruit-associated microorganisms. Research on antimicrobial resistance on field crops is relatively new and the mechanisms are not fully understood.[34]

With the emphasis on reducing the use of antibiotics that are important to human medicine in agriculture and the commonality of bacteria causing foodborne illnesses, effective, **alternative treatments that address the threat of antimicrobial resistance are needed.**

Research Area: Known and Unknown Disease Surveillance

Lessons learned from the current COVID-19 pandemic are that the response speed is critical, and delays in awareness and response to the threat agent could result in exponential amplification and uncontained spread of the pathogen. Efficient and reliable surveillance and early outbreak warning systems are vital for monitoring infectious diseases and pests within the U.S. and globally.

According to the World Health Organization (WHO) and the OIE systems, high-quality data are needed to evaluate an infectious disease outbreak that cannot be acquired through a passive surveillance approach. Whereas passive surveillance systems receive data from as many health facilities as possible, an active sentinel surveillance system deliberately involves only a limited network of carefully selected reporting sites monitoring notifiable diseases. SARS CoV 2 virus underscores our current vulnerability to ecological intrusion from an unknown virus in the wild. The USAID Emerging Pandemic Threats PREDICT project estimated that 1.67 million viral species remain yet unexplored in wildlife. Approximately 38 to 50% of these unknown agents can be transmitted from animals to humans.[35]

Research Area: Phage Therapy

Phages are naturally occurring viruses that infect bacteria. They have the potential for broad application across the food and agriculture sector. Instead of using antibiotics, phages can be used as biocontrol agents for managing and eliminating the bacteria that cause diseases or contaminate food. Many research studies have been done demonstrating the proof of concept for this approach. The infusion of funding specifically for food and agriculture focused phage research could lead to the economically viable antimicrobial replacement options so desperately needed at this time.[36,37,38,39,40,41]

Research Area: Aquatic Disease Surveillance and Biosecurity

As aquaculture typically involves the farming of aquatic organisms that are quite evolutionarily diverse from humans (plants, finfishes, and shellfishes), and also that they are typically reared at temperatures much cooler than that of the human body ("cold blooded"), the likelihood of zoonotic transmission of diseases from seafood to a human being is low. As such, the primary mode of transmission of a disease from fish / seafood to a human would most likely be oral and in the form of "food poisoning". For example, eating raw shellfish contaminated with *Vibrio*.[42,43] Reducing the U.S. importation rates of seafood and thus possible means of introduction, increased biosecurity measures, and surveillance of farmed populations or processed seafood products are possible means to protect against this threat to aquaculture organisms and persons consuming the final products.[44] Additional supporting information and discussion is provided in Appendix 5.

Aquaculture and Seafood Production

Aquaculture is the farming of aquatic organisms, which primarily includes plants, finfishes, and shellfishes. This is a $150 billion per year global industry, yet the U.S. component of this market share is less than 1%, and the country is the number one global importer of seafood in the world.[45,46,47,48]

> **The national seafood trade deficit is in excess of $16 billion annually, and 9 out of 10 seafood products consumed by Americans originate from other countries.**

A concern here is based both on economics and public health. For example, since 90% or more of the seafood consumed in the U.S. is imported, the country is mostly reliant on foreign sources to provide this commodity. This dependency creates an economic and food supply vulnerability.

Research Area: Aquaculture Production

In May of 2020, Executive Order 13921 *Promoting American Seafood Competitiveness and Economic Growth* was released that detailed improving American competitiveness in the global seafood market to help detract from this massive economic impact of the trade deficit and to re-direct priorities toward securing the domestic U.S. seafood supply.[49] These priorities also align with Executive Order 14017 to secure *America's Supply Chains* (February 2021) and Executive Order 14036 on *Promoting Competition in the American Economy* (July 2021).[50,51] USDA announced in July 2021 that it intends to make significant investments to expand processing capacity and increase competition in meat and poultry industries to make agricultural markets more accessible, fair, competitive, and resilient for American farmers[52] and this also is an opportunity to address, in part, the deficit in domestic seafood production, including fostering U.S. aquaculture and seafood production capabilities. In many cases, the technical feasibility of culturing aquatic organisms is known, however regulatory and permitting issues with federal, state, and local governments is the impediment. Additional information is provided in Appendix 6.

Research Area: Seafood Safety

As above, with economic and supply chain concerns also comes concerns with seafood product safety and health impacts to the American public. As an example, many seafood products imported into the U.S. originate from Southeast Asia by volume.[53] Countries in Southeast Asia often raise or harvest seafood products using unsustainable practices (*e.g.,* concerns of CITES, environmental stewardship, and labor welfare) or husbandry conditions that are not in compliance with current USDA and FDA regulatory standards. It, therefore, becomes the duty of the federal government to regulate and identify these import cargos at all U.S. ports of entry to ensure that the imported products are safe, reliable, and adhere to minimum standards for consumption by the American consumers.

Given the high volume of seafood imports into the U.S., this poses concern with being able to accurately screen the volume of products as well as then providing foreign actors with the opportunities to intentionally deliver agents into the U.S. food supply chain (*i.e.,* "slipping through the cracks"). As many seafood products are often sold raw (*e.g.,* fresh, refrigerated, or frozen) or unprocessed, this poses a risk for using it as a vehicle to introduce both biochemicals as well as active biological agents into the country. Additional information is provided in Appendix 7.

Threats to Wildlife Resources Including Fisheries and Other Natural Aquatic Resources

The U.S. has ample marine and freshwater resources to supply irrigation for agriculture, provision of municipal water supplies, generating hydroelectric power, and providing control of flood plains as well as other human needs.[54] However, given the geographic scale, it is difficult to protect and maintain all of this resource infrastructure simultaneously. For example, poisoning or sabotage of fresh drinking water may include cyberterrorism through the internet (see also Appendix 10) as well as physical acts such as the introduction of chemical or biological agents into the water. However, physical damage to waterways, levees, dams, or other infrastructures that may affect roadways, transportation, and flooding in developed urban or rural areas also are possibilities.

Many of the municipal freshwater drinking and irrigation reservoirs are aging as they were created by the U.S. Department of Interior and / or U.S. Army Corps of Engineers from the late 1800s until around the middle of the last century (*i.e.,* after WWII).[54] Indeed, infrastructure failure does not necessarily need to be directly due to sabotage as warning signs of impending failure (*i.e.,* neglect) of levees and other waterway infrastructures have been identified. It is estimated that of the more than 90,000 dams in the U.S., 15,000 are at risk of failure due to deterioration, which may lead to substantial economic and land use losses as well as the potential for human casualties.[55,56]

Regarding offshore fisheries in the exclusive economic zone (EEZ), it may become more problematic in the future due to unwanted, illegal commercial fishing by foreign vessels within these zones, and there may need to be adequate detection / surveillance methodologies and also protocols in place for how to deal with this when it is encountered (*e.g.,* U.S. Coast Guard chasing off a fishing boat when it is encountered in U.S. waters).[57,58] This may possibly become more problematic for domestic, commercial fishing vessels as well as U.S. fisheries regulations become more restrictive in the future due to the current overexploitation status of many wild fisheries stocks.

Additional information is provided in **Appendix 8**.

Climate Change and Water Scarcity and Contamination

Americans rely on proper drinking water and wastewater treatment and the maintenance of water distribution and utility infrastructure to assure safe, secure, reliable, and sustainable water supplies for public consumption as well as to support wildlife and agricultural resources.[59] However, water and land use trends change, infrastructure ages, and the climate of the earth is dynamic. Among these, climate change threatens aging water utility infrastructure and land use through increasingly frequent and intense storms, risk of flooding, and sea-level rise resulting from shifts in long-term climate patterns.[60] Coastal water utilities are at risk of flooding from saltwater intrusion (sea-level rise and storm surge) that may impact coastal surface and ground waters as well as arable land use.[61] Sea-level rise may worsen storm surge impacts and threaten to inundate infrastructure over time. Climate change can also complicate operational capabilities of agricultural infrastructure through more frequent and intense drought events, storm flooding, saltwater intrusion, and impacts on source water quality. Additionally, increased risk of storms and flooding can lead to greater pollutant runoff that may adversely affect source water quality; drought can concentrate such existing pollutants in desiccating water systems. Additional information is provided in **Appendix 9**.

Research Area: Cyberattack Threats to Drinking Water

Other examples of events pointing out the vulnerability of fresh drinking water resources include recent cyberattacks to poison drinking water in San Francisco Bay (January 2021), Tampa Bay (February 2021 around the timing of the NFL Super Bowl sporting event), as well as three incidents of Iran attempting to do so in Israel during heatwaves over the summer of 2020 (as examples of an international event coinciding with disturbances already caused by the COVID-19 pandemic).[62,63] Most of the more than 50,000 drinking water facilities in the U.S. are nonprofit entities that lack robust cybersecurity capabilities, making drinking water a vulnerable resource.

Disruptive Technological Development

The Fourth Industrial Revolution allows computers and machines to communicate interactively and independently by artificial intelligence (A.I.) systems leading to exponential improvements in bio-design and bio-fabrication. The resulting technological progress offers significant potential to improve the production of food, at the same time, poses a significant risk since the Food and Agriculture Sector is a vulnerable soft target for domestic and foreign extremism. Malicious actors can take advantage of disruptive technologies and agricultural production with limited personnel, large spaces of unsupervised facilities, and frequent encounters with wildlife movements. Intensive livestock farming and reliance on monoculture crop production make U.S. agriculture susceptible to heavy losses from pathogens designed to target specific animal breeds or plant varieties. Genetic manipulation of genes responsible for the transmissibility[64], host immune responses[65], and antimicrobial or pesticide resistance can be optimized to develop a new generation of biological weapons[66]. This new generation of biothreat agents could be used for economic coercion and for creating financial pressures to obligate nations to adopt a specific trade policy.

Research Area: Convergent Biotechnology

As open-source information accumulates exponentially, it becomes increasingly difficult for intelligence agencies to interpret the implications of disruptive technologies and the dual nature of biotechnological convergence; thus, increasing the risk of the new generation of potential bioweapons. Many organizations within the Food and Agriculture Sector may not have the technical expertise to adapt to the interoperability requirements, understand disruptive technological progress, and develop countermeasures. Governments might fail to recognize, deploy, and regulate new technologies such as *in situ* combinatorial DNA synthesis[67] converging with quantum computing and artificial intelligence. These disciplines can generate *in silico* unknown genomic profiles exponentially, using the genome of known pathogens as a template.

Pathogens can be genetically engineered *in silico* within hours and grown and amplified *in vitro*, and / or *in vivo,* and target specific Food and Agriculture Sector. Easy access of the technology even to the novice presents a clear and present danger. Successful constructs of the complete microbial genome have already been accomplished[68,69,70], and considering that the genomic information of more than 1 million different isolates of known highly pathogenic organisms are grown and genetically manipulated in the academic, military, and private / commercial research laboratories worldwide.[71] In addition, data of their genomic architecture is available in digital form in public genomic repositories. As high-performance computing and synthetic biology research are democratized and become more accessible and modular, the barriers for accessing pathogenic microbes by state and non-state actors are rapidly decreasing. Synthetic biology may be defined as "concepts, approaches, and tools that enable the modification or creation of biological organisms".[72]

> **The dual-use nature of synthetic biology can exacerbate the risks of proliferation of engineered, virulent organisms and potential misuse.**

In addition, rapid shifts in economic power derived from the convergence of biotechnology and quantum computing could create new economic coercion and espionage challenges.

Research Area: Gain-of-Function Research (GOFR) and Loss-of-Function Research (LOFR)

We define GOFR as the type of experiments in different biological systems that seek to address scientific gaps in knowledge related to the biological function of a gene or protein in an organism with pandemic potential. The AEP panel and supporters of the experimental work involving pathogens argued that GOF experiments help study host-pathogen interactions, virulence, pathogenesis, and advance countermeasure development. For example, *in vitro* or *in vivo* pathogen passage can improve the understanding of pathogenesis and the development of animal models where treatments can be tested. GOF experiments are sometimes the only approach to address important questions about the biology of a pathogen.

Because of the unique characteristics and impact on human and animal health, GOF experiments in the U.S. have stringent guidelines for approval of experiments under the Dual Use Research of Concern (DURC) framework[73]. This is not only because of biosecurity concerns but also because this research is deemed "dual-use research of concern", yet results are published in open-source journals. GOFR, however, carries significant risks despite stringent biosafety guidelines and conduct in highly secure BSL-3/4 laboratories. There is no governing body vis-à-vis the international commission that conducts a security risk assessment and ensures compliance with biosafety protocols. Quantifying risk is complex due to an incomplete understanding of the outcome and a lack of countermeasures. Yet, assessment of the benefit and risks of GOFR rests solely on the individual researcher.

Just because an experiment can be done does not mean that it should be done. This should be the basis of all GOFR performed worldwide. **One should not perform them to "see what would / could happen" without solid evidence that it could happen naturally.** If performed, these experiments have to use strict biocontainment infrastructure, and follow biosecurity and biosafety procedures. However, more countries engage in GOFR on high-risk pathogens. This led to two main risks: (a) GOFR confer greater access to pandemic-class microbial systems that may favor the offense development or know-how. (b) Complacency in the conduct of GOFR may result in an accidental infection and/or release of a potential pandemic-class pathogen.

There is a significant body of knowledge about gene function gains with LOFR. LOFR mutations including in-frame deletions, CRISPR-based, and transposon-mutagenized libraries, can generate beneficial regulatory changes without the need for rare, specific mutations to fine-tune enzymatic activities. LOF mutations occur at a much higher frequency than GOF. While in nature the mutational landscape done in experimental settings can lead to a higher number of selective pressures, mutations are unlikely to be found in the wild. LOF mutations play a substantial fitness benefit, including antimicrobial resistance and even growth in exotic nutrient combinations or new enzymatic functions. For example, at least 210 genes are involved in making a functional spore of *Bacillus anthracis.* The LOF of the plcR regulon in increased sporulation frequency in *Bacillus anthracis* the pXO1 plasmid.[71] This LOF mutant had reduced macrophage toxicity, which increases the transport of the strain to peripheral lymph nodes.[74]

Cybersecurity

The U.S. food and agriculture industries are complex and entail various activities, including farming / production, preparing, processing, preservation, marketing, distribution, and serving foodstuffs to consumers. It involves many different industries: biotechnology, agriculture, manufacturing, transportation, logistics, restaurants, and retail. Most of these industries, if not all, rely heavily upon digital and cyberspace technologies and communications such as Global Positioning Systems (GPS), Positioning, Navigation, and Timing Systems (PNT), industrial computer programmable logic controllers (PLCs), and electronic databases.[75] The risks are not to any specific part of the supply chain nor to any one type of criminal—the entire supply chain is at risk due to its complex and interconnected nature.

> **Sharing information about cyberattacks can help strengthen the entire industry.**

The recent COVID-19 pandemic highlighted how fragile the global food chain is and the vulnerabilities that cyber criminals can capitalize upon. These are not new risks, but as the food industry increases its dependence upon technology, the likelihood, and severity of a crippling cyberattack increase.

> **The entire supply chain is at risk due to its complex and interconnected nature**

Cybersecurity has been reviewed by the U.S. Department of Homeland Security in 2018 (including precision agriculture) and has its section in this AEP program.[76,77] However, the aim here is to illustrate the vulnerability of critical interdependencies as well as the importance of cross-communication between Sectors regarding threats and vulnerabilities, centralization / decentralization, and redundancy in networks related to the resiliency of the entire Food and Agriculture Sector system. Worldwide threats to cybersecurity are reviewed by the Office of the Director of National Intelligence.[78] Key examples particular to the Food and Agriculture Sector are highlighted in Appendix 10.

> *"In order to increase awareness of potential process control system exploits, there is a need to share information from control system cyber incidents across all critical infrastructure (CI) industries. Because the food and agriculture sector "as a whole" does not have an information sharing and analysis center (ISAC) as many / most other CI sectors do, it makes it harder for food and beverage manufacturers to share information in a trusted environment."*, Joe Weiss, Food Engineering

As the world faced the COVID-19 pandemic, food manufacturers experienced a great number of supply disruptions, abnormal spikes in sales and have been impacted by consumer fears that the food supply could be in jeopardy. During this time, U.S. consumers increasingly relied on e-commerce in cyberspace, and this trend in commerce is poised to remain high moving into the future. This current market situation makes cyberattacks and cyberextortion appealing to the hacking community because the repercussions of bringing down a food manufacturer, distributor, or retailer could be economically disastrous and disrupt the food chain. Actors could bring down all systems or parts of one system.

True threats of high consequence could be intentionally coordinated or coincidentally uncoordinated events that might completely cease a supply chain or other input / output of the Food and Agriculture Sector—targeting the water, electric grid, and fuel supply simultaneously or in combination. These broad sectors together would impact almost every segment and level of U.S. food production systems, which rely heavily on the Water and Wastewater Systems, Energy, and Transportation Systems Sectors (*i.e.,* the *alpha* of production through the *omega* of consumption). Therefore, the critical interdependencies of the Food and Agriculture Sector make cybersecurity an essential component for thwarting a coordinated attack. Another way of stating this is, for example, an attack against the Energy Sector is also an attack against the Food and Agriculture Sector, which must be realized.

Research Area: Cybertheft of Genome Information

Innovation is a crucial aspect of the Food and Agricultural Sector. The U.S. public-private R&D sector is developing plant varieties and new terrestrial and aquatic animal breeds, biomanufacturing processes, and omics profiles (microbiome, transcriptome, proteomics, metabolomics, and epigenomics) profile that provide competitive commercial advantages with national security relevance. However, R&D within U.S. organizations are the target of foreign cyber espionage, trade secret, and intellectual property theft. Food and Agriculture key R&D players, including large corporations, are not the only victims. The most vulnerable are small and emerging corporations, universities, and government research organizations. Cyber intrusions can be used to replicate the owner's products and compete in global markets in high-value food sectors. Cybertheft of data and algorithms can provide competitive advantages and coercion points on aggressive corporate takeovers of U.S. corporations.

The pervasive risk of cyber threats to the U.S. government is leading an effort to counter its effect. According to the National Counterintelligence and Security Center (NCSC), China and other countries have been stealing DNA data to advance their economic, security, and foreign-policy goals[79]. While collecting pathogen genomic data from infected individuals or agricultural and food products during disease outbreaks can improve biosurveillance, protecting the privacy of individuals, growers, and retailers in the Food and Agricultural Sector is another major cybersecurity challenge. As genomic data become linkable to other data sources, individuals, animal, or plant breeds become identifiable and potentially a target of malicious activities.

Regulations for the trade of genetic material safeguarding providers' rights of these genetic resources could change with the access of digital DNA sequences. Considering the global and interconnected nature of the Food and Agriculture Sector, R&D is evaluated worldwide. The cybersecurity vulnerability in many countries is an uncharted and dynamic legislative territory.

> **Regulations for the trade of genetic material safeguarding providers' rights of these genetic resources could change with the digital access of DNA sequences.**

Research Area: Encrypted Information Transfer

Genome sequencing generates significant data that could reach 2,000 to 40,000 petabytes per year.[74] Much of this data and the algorithms to mine this information reside in private repositories that state and non-state actors can target to steal, destroy, modify, and therefore disrupt years of costly research. At the same time, these attacks can modify genomic information to decrease the bioforensic and attribution capabilities of the U.S.

Cyberattacks can modify genomic information to decrease the bioforensic and attribution capabilities of the U.S. government.

Various methods have been used to secure the data, including watermarking[80], cryptography[81], and steganography[82] to protect intellectual property and safeguard against improper use and attacks *albeit* these techniques can also be used to covertly transfer information to nefarious actors. New techniques have been developed to use DNA as a data storage medium. This can lead to a storing capacity of 215 petabytes (215 million gigabytes) in a single gram of DNA that can be shipped outside of the U.S. with key information relevant to the Food and Agriculture Sector, but also for national security. Encrypted messages may include DNA sequences of engineered organisms, algorithms for creating/replicating virulent viruses / bacteria, and other information for recipients to decrypt the message accurately.

Agricultural Energy Consumption, Fossil Fuels, and the Supply Chain

The U.S. economy will not function without a stable energy supply and thus the Energy Sector importantly enables all of the other Critical Infrastructure Sectors including the Food and Agriculture Sector.[3] Large amounts of fossil fuels are required to power heavy farming machinery, to process foods, to refrigerate foods during transportation and storage, to produce packaging materials, and to manufacture and transport chemicals and other inputs such as fertilizers, pesticides, and livestock feeds.[83,84]

The Energy Sector importantly enables all of the other Critical Infrastructure Sectors including the Food and Agriculture Sector

Supplying / moving water for crop irrigation and watering of livestock also is an energy-intensive task (*e.g.,* pumps, wells). Chemicals used by the agricultural industry are a subset of the bulk chemical industry (Chemical Sector) and include fertilizers, pesticides, feed additives, packaging materials, and food preservatives, among many other compounds. Nitrogenous (ammonia-based) fertilizers require large amounts of natural gas as a feedstock and require heat and power for processing. As examples, the production of livestock feed also consumes energy for milling, mixing, processing, and extrusion. **Appendix 11** provides additional details on Agricultural Energy Consumption, Fossil Fuels, and the Supply Chain, and **Appendix 12** provides details on Transportation of Food and Agricultural Products.

Research Area: Agricultural Energy Consumption

An overall important consideration of the Energy Sector is cybersecurity.[85,86] Since disruption of the Energy Sector will indirectly disrupt the Food and Agriculture Sector due to critical structure interdependence, this also indicates that cybersecurity of the Energy Sector should be a concern for the Food and Agriculture Sector. There are existing documents on cybersecurity for the Energy Sector[85] and this itself is not "new news", but the potential impact on agriculture should be emphasized given the heavy reliance on energy—if the power grid goes down[86], animals die only once; if transportation is delayed or refrigeration fails, food spoils only once.

In regard to the 2018 U.S. Department of Homeland Security AEP report on Threats to Precision Agriculture (**Appendix 13**, the Energy Sector is not explicitly mentioned, however "Timing of Equipment Availability" and "Disruption to Navigation / Communication / Internet" are detailed in the context that if these systems were to fail, there would be a consequence.[77] The authors of that report consider independent attacks on those particular infrastructures (*e.g.*, online tractor navigation equipment), however something as simple as "eliminating the power grid" to stop / take down all systems of communication / internet or "reducing fuel availability" for equipment required to conduct precision agriculture is not mentioned. Such broad attacks to the Energy Sector, if accurately timed, could have significant consequences to the Food and Agriculture Sector. Cross communication between Sectors in this regard should be considered critical.

Research Area: Critical Interdependencies of the Food and Agriculture Supply Chain

When meat supply shortages at local grocery stores appeared in 2020 during the COVID-19 pandemic, The MITRE Corporation conducted a network analysis of U.S. food supply chains.[87] That analysis shows that the U.S. food supply chain would be significantly impacted if certain key hubs were disrupted. As an example, disruption of only five key hubs in the U.S. food supply chain with high meat production, cold storage, and transport would completely disrupt the entire U.S. meat supply. Even disruption of one of these hubs would result in a significant consequence of food supply to some parts of the U.S.

> **"*The Food and Ag Sector is vulnerable in its efficiency*", Bill Kruger, ORISE Fellow, Food and Agriculture Sector Specialist, DHS Office of Infrastructure Protection, Partnerships and Outreach Division[88]**

KEY FINDINGS

The scope, variety, and complexity of the research needs identified within this report—stemming from numerous angles across the Food and Agriculture Sector—helps to illuminate the ***need for a coordinated, informed research strategy*** considering critical threats to the Food and Agriculture Sector. The table below indicates threats to the Food and Agriculture Sector and potential research collaboration areas for mitigation. **Appendices 14** and **15** provide additional context to these findings.

Response Functional Pillar	Food and Agriculture Threat Category	Potential Research Collaboration Area
Prevention and Preparedness		
Measures designed to provide more permanent protection and readiness to respond to events	**Agro / Bio-Terrorism** ▪ Cybersecurity – hacking of production systems, transportation, supply distribution, theft of intellectual property (IPR), e-commerce ▪ Development of enhanced virulence biological agents ▪ Novel concealment methods of bioweapon delivery / IPR theft (e.g., DNA stenography) ▪ Open publication of dual-use technologies ▪ Intentional adulteration and cooption of food manufacturing by adversarial actors ▪ Sole source / limited suppliers e.g., fertilizer	Research and development for a vaccine that can be used to differentiate vaccinated from unvaccinated animals (DIVA) Research and development for an Emergency Use Live-Attenuated Vaccine for a novel transboundary animal disease Threat / Hazard / Risk Assessment or Gap Analysis study to identify vulnerabilities and R&D targets.

Response Functional Pillar	Food and Agriculture Threat Category	Potential Research Collaboration Area
Protection and Detection		
Surveillance and monitoring of vulnerabilities and threats that may lead to an event	**Human Factors/Political** ▪ Anti-agriculture activism ▪ Misinformation / disinformation / Lysenkoism ▪ Public / Private sharing of sensitive information ▪ Insider Threats **Naturally emerging, re-emerging, and rapidly evolving pests and diseases** ▪ Exotic plant pests ▪ Foreign Infectious Animal Diseases ▪ Fish diseases, shellfish contaminants, contamination of water resources and seafood ▪ Human diseases ▪ Invasive species / injurious wildlife ▪ Antimicrobial / treatment resistance	Pre-deployment validation study for newly developed fieldable diagnostic test (e.g., FMD ELISA test kit) Research and develop a point of care diagnostic test (e.g., lateral flow assay test strip) for use in the field Public education and information campaigns Research and develop novel lab-bench diagnostic surveillance tests for use at diagnostic laboratories Surveillance of imported food products and biosecurity

Response Functional Pillar	Food and Agriculture Threat Category	Potential Research Collaboration Area
Mitigation		
Efforts to reduce losses by lessening the impact of events	**Environmental** ▪ Climate change / weather extremes / drought / salinization ▪ Water scarcity and contamination – surface and groundwater	Research and development of an Artificial Intelligence / Machine Learning algorithm and associated GUI/software interface Cybersecurity in water resource facilities Responsiveness to changing climate
	Economic, Trade, and Travel ▪ Contaminated agriculture and food commodities imported via trade and travel ▪ Dependence of agriculture and food production on foreign raw materials ▪ Lack of animal traceability and inadequate data management – up and down supply chain increasing potential for disease spread ▪ Energy and transportation	Research to rapidly characterize new pathogens Decontamination, disinfection, and disposal study for high consequence pathogens, infected animals, and environmentally contaminated surfaces Expansion of seafood and aquaculture industries Protection of utility infrastructures, supply chain network analyses, and infrastructure redundancies Dept of Energy / National Alliance for Water Innovation (NAWI) work at New Mexico State University

KEY RECOMMENDATIONS

1. *It is recommended that the U.S. government and the private industry consider engaging with international partners to develop quantitative risk assessments of cross-interdependencies with the Food and Agriculture Sector.*

The private sector owns and operates the overwhelming majority of food and agriculture systems, nodes, and networks based critical infrastructure related to the food supply in the U.S. Therefore, the U.S. government, in collaboration with the Critical Infrastructure Cross-Sector Council and Government Coordinating Council for Food and Agriculture, must continue to identify cross-interdependency vulnerabilities with the Food and Agricultural Sector. From this process, a risk-based, coordinated research agenda with medium and long-term goals should be established, and accountability be assigned to Agencies / Departments to ensure the tracking and status report-outs on these research priorities and goals.

As the U.S. and other nations compete for agricultural and food products, many nations suffer from internal political instability and external economic pressures, making them vulnerable to economic coercion. The U.S. government must engage the 20 most relevant trading countries, particularly the European Union, following the same model as the Critical Five established in 2012, to identify overlapping critical sectors within the Food and Agricultural Sector (as examples see Appendix 15). This international engagement effort should improve food governance backed by an Intergovernmental Panel outlined by the 2021 United Nations Food Systems Summit.[89] Under this framework, the U.S. government and the private sector must implement a quantitative risk assessment of each choking point of the Food and Agricultural Sector to ensure resilience and access to healthy and sustainable food.

As described earlier in this report, MITRE completed a supply chain analysis on several USDA commodity networks and systems and identified a vulnerability in the efficiency of the system. In consideration of a risk-based approach to identifying other potential vulnerabilities, other data sources can be used to assess output (food products) consumption patterns, geographical distribution, and demands, availability, and supply of the raw materials (inputs and ingredients) to ensure the stability of these outputs. By beginning with a domestic focus, lessons learned can be extrapolated internationally.

Excerpt from National Critical Infrastructure Security and Resilience Research and Development Plan 2015:

> *"The Plan builds on past and ongoing CISR R&D activities across the critical infrastructure community, including extensive efforts by government, the private sector, and academia. The National CISR R&D Plan is intended to* ***reinforce and augment successful advances in CISR R&D and identify and fill gaps and unmet needs through active collaboration with stakeholders****.*

The ability to identify and assess threats and hazards, address them before and as they arise, and understand and quantify the related consequences is a critical element of risk management and a primary driver for CISR R&D efforts. ***The National CISR R&D Plan provides an overview of the risk environment and emphasizes the need to sustain and grow partnerships to enable a collaborative approach to managing critical infrastructure risk.****"*[90]

"The development of complementary and comprehensive risk assessment methodologies across the critical infrastructure community will enable the effective and coordinated application of resources;"[90]

2. **The U.S. government must update its GOFR and LOFR policy and lead an international verification effort on this type of research**

COVID-19 has killed more people than past nuclear weapon detonations. Yet, the approximately 1% fatality rate of SARS CoV-2 is miniscule compared to the 80-100% mortality of pigs to African swine fever (ASF). Given our vulnerability, any early disclosures of novel ways of generating more virulent pathogens should be considered equivalent to giving thousands of actors access to nuclear-class weaponry. The pace in the emergence, discovery and genetic manipulation of microbes transcends current regulatory and biosecurity protocols.

While the Dual Use Research of Concern (DURC) policy governs GOFR in the U.S., there is a lack of global governance on high-consequence pathogen research. The U.S. government should engage with key players in creating a governing framework for assessing the risk and benefit of GOFR, enhancing biosafety laboratory protocols, and safeguarding tools, techniques, and pathogens against wrongful use. The U.S. government must also work with international and national partners working on GOFR on policy guidelines to safeguard againsts early disclosures of information concerning novel ways of generating pathogenic variants that may favor offense.

A transparent public review of all GOF and LOF experiments before their commencement is critical. This will ensure that updated policies address the needs of GOFR to answer medically / scientifically essential questions. All laboratories performing GOFR on highly pathogenic organisms should be required to adhere to a standard set of international protocols and procedures, including international standard biosecurity operational procedures and verification processes. In this regard, the U.S. should lead a concerted effort with key GOFR countries to implement verification and enforcement procedures on GOFR. These rules and regulations should be agreed in two stages: (a) with key countries engaging in this type of research (*e.g.,* China, Japan, U.K., France, The Netherlands, Australia, and New Zealand and (b) a joint meeting led and adopted by members of The Biological and Toxin Weapons Convention (BTWC).

3. *The U.S. government and the private industry should develop quantitative threat risk scores for known and unknown biothreats of the Food and Agriculture Sector.*

As interconnected global economies spread pathogens and pests, the terms "foreign animal disease," "exotic plant diseases," "select agent," or "priority list pathogens" are becoming less relevant. Therefore, an inter-governmental dialogue with the global scientific community to create a framework for characterizing the biological threat and quantitating risk is required, which would encourage accountability and oversight for biosafety, and promote ethical and transparent information sharing and safeguards against release of pathogens with high pandemic potential.[91] This approach changes the biosecurity measures paradigm beyond preventing the disease's introduction and spread, and focus on proactive engagement.

Paramount to this dialogue is participation from the industrial sectors; in particular, those autonomous, well-funded institutions that use cutting-edge techniques to produce novel strains of microorganisms for biomedical, agricultural, and environmental remediation. The framework would also address biological import-export regulations on a global scale and conflict between information transfer and government protection of information that is tenable to commercial enterprises. While frequent external evaluation may not be required, close monitoring of countries' self-reported outcomes is highly recommended. Nonetheless, data protection and privacy should be high on the discussion and implementation to protect the interests of governments, industries, and citizens in many jurisdictions. This development should also facilitate governance arrangements and connecting key actors and resources of data exchange.

> **The best prevention countermeasure against the spread of the disease is containment at the source.**

Technical and administrative challenges create disparities among and within nations to report a pest or disease outbreak within the optimal time frame to minimize the impact of diseases and pests in the U.S. Food and Agriculture Sector. Decreasing the latency reporting period from 10 days to 5 days and no more than three working days after the date of observation and confirmation provides a dynamic timeframe that could address these challenges, including the resources for rapid diagnostics and better surveillance. For an early warning system of a threat to be effective, monitoring should not rely on the symptoms of the disease or detection systems of known DNA sequences since very few viruses have been sequenced to date.[92]

By sharing and collecting data in near real-time, infectious disease capability assessment can measure each country's ability to mitigate specific known and unknown diseases and provide immediate evaluation of a particular policy's success or failure to mitigate risks. A key area of investment should be the ability to perform updates on records for timely operational decision support. A specific country policy can be analyzed to meet the nations' expectations where building capability is required.

4. *The U.S. government should lead research coordination of public-private partnerships for information sharing standards and risk mitigation*

This recommendation underscores the need for a multi-sectoral framework and strongly advocates a whole government approach that will extend capacity among agencies. The Department of Defense is in the forefront of surveillance intelligence and developing bioweapon countermeasures which could be extended to support the agricultural and public health realms. Sharing expertise is critical in preparing for and responding to a biological incident. Additionally, data from trade, food, and animal production trends, critical infrastructures, institutional diversity, research capacity, publications, genomics research, etc., provide a dynamic source of information. The data exchange systems and stakeholders with the U.S. government, academia, and the private industry must work jointly to improve, harmonize, standardize, and analyze this information and find early warning patterns. This is not to generate more reporting burden but rather unify the reporting data generated from different organizations in a format that can be federated.

Excerpt from Critical Infrastructure Security and Resilience National Research and Development Plan 2014:

> "***Enhance the partnership between the public and private sectors*** *in securing and enhancing the security and resilience of critical infrastructure and their functional systems, physical assets and cyber networks*".[93]

Excerpt from DHS Science and Technology Directorate National Critical Infrastructure Security and Resilience Research and Development Plan 2015:

> "***Effective implementation of the National CISR R&D Plan will require collaboration across the critical infrastructure community. Stakeholders should work collectively to define R&D requirements and design and implement solutions that meet identified needs.***"[94]

Because this type and volume of information overwhelms human cognitive capabilities, emerging A.I., including but not limited to deep learning analytics and natural language processing, can generate extractive and abstractive summaries from documents with conflicting information. These analytical techniques can autonomously access and organize data, translate information from different languages, reduce human cognitive load and error, and provide operational decision support. This approach could provide a more realistic assessment of risk, vulnerability, and capability and contextualize the risk at the strategic and tactical / operational levels. The capability assessment network could support enhanced collection, integration, and data management using these standards as guidance.

> **The diversity, scale, and speed of data growing at exponential rates is overwhelming human cognitive capabilities.**

Investments to support evidence-based dynamic policymaking, analytical modeling, and visualization for interpreting and communicating information to key stakeholders can enhance the Food and Agriculture Sector defense by providing five classes of interconnected networks, namely: (a) diagnostic laboratories of each nation, (b) data-driven and risk assessment modeling teams, (c) data standardization and management specialists, (d) advanced visualization, and (e) decisionmakers and program managers.

Efforts in these scientific areas can be expanded, enhanced, or strengthened to ensure adequate Food and Agriculture Sector resiliency by improving activities that intersect with the five mission areas of prevention, protection, mitigation, response, and recovery, as outlined in the DHS FEMA's National Preparedness Goal[95]. This will help ensure that defense, security, and protection initiatives continue to address the emerging and evolving catastrophic pathogens that threaten the food and agriculture infrastructure, health, and economic security of the United States.

5. ***The U.S. government should invest resources in the training of the next-generation workforce in the Food and Agriculture Sector Defense***

The Food and Agriculture Sector must develop a coordinated research agenda to serve two essential purposes: (a) as a "consolidation" effort of the various research components currently underway within / across the Sector. (b) To enable "future" research as described elsewhere in this document, where there is a need for disclosure / awareness of research gaps (*e.g.,* FSMA 108; HSPD 9; Food and Agriculture Sector-Specific Plan (SSP); Food and Agriculture Sector Annual Report).

The federal government has invested significant resources to build research and training programs across the nation to enhance the food safety research needs in alignment with several policies. While these efforts have created a sustainable network, improved the overall catalog of available training, and facilitated the formation of rapidly responsive veterinary and support teams, there is room for expansion into plants, fishes, and other susceptible commodities that are integral to the Food and Agriculture Sector.

The nature of technological progress in the animal and plant health realms is shifting from an exclusive domain of veterinarians, entomologists, and plant pathologists towards an all-around operators with technical background in the physical, chemical, material, big data, and life sciences. No single discipline could give a good understanding of the risk and how far, for example, synthetic biology is implementable and scalable. Detection, diagnostics, and surveillance intelligence of products develop from synthetic biology that are of food and national security concerns would require technical know-how in these field of science.

The establishment of higher education programs to help secure America's agriculture infrastructure is also required in HSPD-9 (paragraphs 20–22), with DHS cooperating with the USDA to establish expanded opportunities and advanced learning tools for veterinarians, veterinary students, and related animal health practitioners which can be accessed through FEMA's Center for Domestic Preparedness (CDP), FEMA's Rural Domestic Preparedness Consortium (RDPC), APHIS Veterinary Services National Training and Exercise Program (NTEP), or various S&T's emeritus and current Centers of Excellence (*e.g.,* IIAD, CEEZAD, FPDI, and CBTS). For additional details, see **Appendix 16**.

Excerpt from the 2010 Agriculture and Food Critical Infrastructure and Key Resources Sector-Specific Plan:

> *"**To track the many R&D activities within the sector and to prioritize R&D needs**, the [Food and Agriculture Sector Government Coordinating Council] GCC and [Sector Coordinating Council] SCC have established the Food and Agriculture Sector Joint Committee on Research. The mission of this committee is to assess and advise the Food and Agriculture Sector (GCC and SCC) on homeland security researchable needs and goals. **The committee will make use of existing vulnerability work, consider threat information, review current R&D projects, make discovery of operational needs in the sector, consult or involve the research community as needed**, and refine or update recommendations periodically."*[96,97]

> *"The committee will annually provide to the GCC and SCC a collective and **coordinated list of researchable food and agriculture priority needs from both the perspective of those in operations and implementation (the private sector and the States)**, and the government agencies involved in maintaining homeland security coordination and oversight (the SSAs)."*[96,97]

The DHS and USDA have historically collaborated and cooperated to review current Foreign Animal Disease (FAD) training and educational programs to expand educational opportunities and significantly enhance the educational experience.

Perceived gaps in the knowledge of our food safety / food science / food production resilience training curricula also are realized as critical for preparing the next-generation for taking on this task in the future. This challenge is compounded as the average American is now 2 or 3 generations (or more) removed from a familial agrarian background (*i.e.,* the rural and urban divide). Academic curriculum content in this realm should provide foundational knowledge in chemistry, physics and mathematics, biological sciences, microbiology, nutrition, statistics, and oral and written communication and also include basics of food safety and quality, food safety management systems (including HACCP), overview of critical infrastructure / protection of U.S. agriculture, food supply chain resilience, and also familiarity with intentional adulteration and disruptive, emerging technologies described above (such as A.I.).Excerpt from Homeland Security Presidential Directive / HSPD-9 Defense of United States Agriculture and Food:

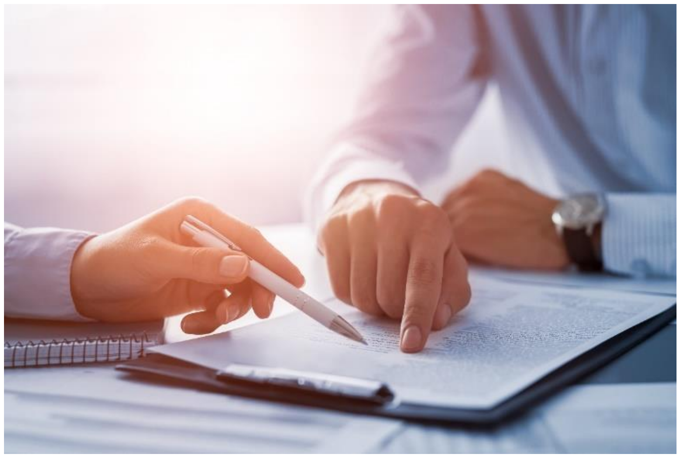
> "*(21) The Secretaries of Agriculture and Health and Human Services, in consultation with the Secretaries of Homeland Security and Education,* ***shall support the development of and promote a higher education program to address protection of the food supply****. To the extent permitted by law and subject to the availability of funds, the program will provide capacity-building grants to universities for interdisciplinary degree programs that combine training in food sciences, agriculture sciences, medicine, veterinary medicine, epidemiology, microbiology, chemistry, engineering, and mathematics (statistical modeling) to prepare food defense professionals.*"[4]

> "*(22) The Secretaries of Agriculture, Health and Human Services, and Homeland Security shall* ***establish opportunities for professional development and specialized training in agriculture and food protection****, such as internships, fellowships, and other post-graduate opportunities that provide for homeland security professional workforce needs.*"[4]

6. The U.S. government needs to promote domestic aquaculture for food production

Since 90% or more of the seafood consumed in the U.S. is imported, the country is mostly reliant on foreign sources to provide this food commodity. This dependency creates an economic and food supply vulnerability. A future focus of the Food and Agriculture Sector should be to promote domestic U.S. aquaculture production to meet this seafood demand and efforts should extend beyond regulations of seafood imports. This will be critical for meeting future food-animal protein demand of the American publics.

IMPACT TO GOVERNMENT AND PRIVATE SECTOR



One person alone can rarely solve a problem: it takes state-federal government-business-academic partnerships to make significant impacts to overcome challenges.

> **"Great discoveries and improvements invariably involve the cooperation of many minds", Alexander Graham Bell**

There are nearly 40 conferences on Food and Agriculture Sector security, so a wealth of information is available for dissemination. However, an excessive number of meetings leads to information overload and disassociation of critical information sharing. There needs to be coordination of information sharing, research goals, and involvement of the associated government, academic, and industry partners moving forward to help address the Key Recommendations presented above and the Forecasts 2030 below. Accurate and timely communication and coordination is required for the Food and Agriculture Sector to remain nimble in its resiliency.

For example, the Agriculture Organization of the United Nations (FAO) / World Health Organization (WHO) / African Union (AU) International Conference on Food Safety is co-organized by FAO, WHO, World Trade Organization (WTO), and AU, bringing together Ministers and representatives of national governments, senior policy makers as well as representatives of non-state actor groups from all regions of the world to engage in an urgent reflection on agriculture and food safety challenges to:

- Identify key actions and strategies to address current and future challenges to food safety globally.

- Strengthen commitment at the highest political level to scale up food safety in the 2030 Agenda for Sustainable Development.

> **"Great things in business are never done by one person", Steve Jobs**

As an example of the importance of prospective and completed research sharing performed at conferences with a nexus to food protection (*food safety, food defense, food terrorism, food security*) in July 2021, the DHS CWMD and DHS CSAC provided four separate presentations on topic areas pertinent to this report as it relates to the new / expanding FAVD architecture as well as updates on the chemical threat agents of concern to food terrorism.[98] While this was a "new" audience for the DHS presenters, it is hoped that leverage can be taken moving forward to create special tracks or presentation sessions that focus on critical infrastructure protection and resilience-related offerings. The four presentations from the International Association of Food Protection conference in 2021 included:[98]

1.) "Potential Utility of the Intentional Adulteration Assessment Tool (IAAT) – Survey of Food Industry"
2.) "Communication, Outreach and Education; Food Defense; Food Law and Regulation; Epidemiology"
3.) "Characterization and Prioritization of Ingested Chemical Threats"
4.) "Food, Agriculture, and Veterinary Defense (FAV-D) Architectural Framework"

A proposal here is for enhanced information sharing to improve research coordination across the nation for the Food and Agriculture Sector. This recommendation is the Project ASIPU: Applied Solutions & Integration Promoting Understanding (Project A.S.I.P.U.) with the aim to develop a coordinated research agenda within the Food and Agriculture Sector to serve two key purposes (see also Appendix 17):

1.) To serve as a "consolidation" effort of the various components of research that are currently underway within and across the Food and Agriculture Sector;

2.) To enable "future" research as described elsewhere in this document, where there is a need for synthesis, disclosure and awareness of research gaps (FSMA 108; HSPD 9; Food and Agriculture Sector Specific Plan (SSP); Food and Agriculture Sector Annual Report, etc.).

Additionally, the Project ASIPU can help with ensuring the success of the DHS CWMD's response to the Office of the Inspector General's report (July 2020):

> *"CWMD plans to announce reconstitution of Food, Agriculture, and Veterinary Defense and will work with the Science and Technology Directorate to develop a research and development (R&D) Strategic Plan to reprioritize and better align food and agriculture defense R&D across the Department. CWMD estimates a completion date of September 30, 2020."*[91]

The following documents provide similar recommendations to improve research coordination and communication and to ensure the resilience of the Food and Agriculture Sector:

Excerpt from the 2010 Agriculture and Food Critical Infrastructure and Key Resources Sector-Specific Plan:

> "***To track the many R&D activities within the sector and to prioritize R&D needs****, the [Food and Agriculture Sector Government Coordinating Council] GCC and [Sector Coordinating Council] SCC have established the Food and Agriculture Sector Joint Committee on Research. The mission of this committee is to assess and advise the Food and Agriculture Sector (GCC and SCC) on homeland security researchable needs and goals.* ***The committee will make use of existing vulnerability work, consider threat information, review current R&D projects, make discovery of operational needs in the sector, consult or involve the research community as needed****, and refine or update recommendations periodically."*[97]

> *"The committee will annually provide to the GCC and SCC a collective and* ***coordinated list of researchable food and agriculture priority needs from both the perspective of those in operations and implementation (the private sector and the States)****, and the government agencies involved in maintaining homeland security coordination and oversight (the SSAs)."*[97]

Excerpt from DHS Science and Technology Directorate National Critical Infrastructure Security and Resilience Research and Development Plan 2015:

> "***Effective implementation of the National CISR R&D Plan will require collaboration across the critical infrastructure community. Stakeholders should work collectively to define R&D requirements and design and implement solutions that meet identified needs.***"[94]

> **"The committee will annually provide to the GCC and SCC a collective and coordinated list of researchable food and agriculture priority needs from both the perspective of those in operations and implementation (the private sector and the States), and the government agencies involved in maintaining homeland security coordination and oversight (the SSAs)", Joint Committee on Research (JCR); 2009**

FORECASTS FOR 2030

Globalization will continue to contribute to the development of economic, technological, and social progress. However, there is an increasing understanding that the world order will be dominated by three large regions or countries: the United States, the European Union, and a China-centric Asia. These political and military power centers will increasingly dispute access to natural resources, including agricultural and aquaculture products. As a result, they will take vastly different approaches to social issues, public health, economic policy and trade, technology, and international affairs. This multipolarity, sometimes called the “gray zone” conflict, will produce dynamic challenges for which the U.S. and its multilateral organizations may be unprepared, and include:

- Interdependencies between the Food and Agriculture Sector and the other Critical Infrastructure Sectors will continue to increase in complexity, will exacerbate current vulnerabilities, or create new ones throughout the myriad of food and agricultural supply chains. These relationships need to be better studied and understood in order to increase resiliency, as single points of failure for production, processing, distribution, and safety of food will cause the Food and Agriculture Sector to be susceptible to a wide diversity of natural threats and attacks sponsored by state and non-state actors.

- Consolidation within the Food and Agriculture Sector, in addition to foreign acquisitions, has led to a small number of transnational companies dominating significant portions of the domestic food and agricultural supply chain. As a result, sole-sourcing or single-sourcing procurement of food, raw ingredients, equipment, and / or critical supplies integral to domestic production will amplify other threats and vulnerabilities, including those stemming from the interdependencies with other sectors. Multiple or parallel sourcing strategies, incentivization for re-/on-shoring, and analyses evaluating domestic versus global sourcing risks may alleviate these supply chain vulnerabilities.

- Increased reliance on the digital technology transformation that occurred during the COVID 19 pandemic will lead to a more substantial systemic cybersecurity risk across all sectors, including Food and Agriculture.[60] As U.S. consumers increasingly rely on e-commerce and corporate Operational Technology (OT), Industrial Control Systems (ICS), and Operations Management Software (OMS) become more interwoven with the internet-of-things, cyber vulnerabilities will become a critical unaddressed liability. Domestic food and agricultural e-commerce capabilities will be threatened by the U.S.' lack of capability to regulate or safely manage cyber-transactions and inability to detect, prevent, and respond to malicious cyber-intrusions or ransomware incidents[61].

- Despite the geopolitical differences, citizens from all countries will actively continue to travel and exchange food and agricultural commodities with one unintended - or in some cases intended - consequence for the Food and Agricultural Sector: The accidental or intentional transboundary movement and spread of known and unknown pests and diseases. These biological threats will have negative impacts on animal and human health, trade, and the security of our nation.

- The global rise and impact of known and unknown aquatic and terrestrial pathogens in humans, animals, and plants will continually evolve due to a combination of complex factors related, but not limited, to climate change, agricultural production practices, antimicrobial use, and the risk exerted by the close contact of humans with both wild and domestic animals[62]. In addition, the increase of international trade and travel will continually present critical pathways for transboundary movement of pathogens and the spread of vectors and diseases capable of contaminating U.S agricultural systems.

- The global push to reduce carbon emissions and climate change will likely cause a rapid rise in the plant-based food products industry, especially in developed countries, as an alternative to traditional animal-based foods.

- Unless immediately addressed, the importation of food and food products, such as seafood, will increasingly pose enormous biosecurity risks as a mode of entry of disease and chemical threats into the U.S. The U.S. must remain a global net exporter of food and not a consumer to maintain its food security position.

- The demand for imported seafood in the U.S. will have unintended geopolitical and economic consequences. China, the Russian Federation, and other nations will increasingly deploy transoceanic vessels for illegal, unreported, and unregulated fishing that is exerting its presence in disputed territorial waters and challenging exclusive economic zones.

- The fourth industrial revolution and increased human-machine teaming that occurred during the past few years will lead to the convergence of disruptive technologies that may endow organisms with novel genetic and phenotypic features with enhance virulence, resistance to treatment, or environmental persistence. There seems to be a reticent trepidation to discuss risks associated with unregulated GOFR or LOFR, gene-editing approaches, and synthetic biology. The lack of foresight on how these technologies may converge with advanced A.I. capabilities may lead to novel synthetic pathogens that could have devastating effects on plants, animals, and humans. This new generation of biological threats should be assessed and evaluated before they cause catastrophic impacts to the terrestrial and aquatic components of the U.S. Food and Agricultural Sector.

- GOFR will continue to be performed in many countries around the world with ever-evolving novel technologies. At the same time, the rules and regulations in the U.S. will not allow being competitive in this area of research. The gap between the U.S. and other countries working less regulated in this area will grow larger over time, and our countermeasures will become less efficient.

- The global biothreat landscape will keep on chaning in ways and pace that may render international sanitary controls and governmental regulations ineffective. As border inspections rely on up-to-date information on these enforcement regulations, stagnation in this area represents a critical gap in safeguarding against the accidental or deliberate introduction of harmful pests and diseases into the U.S.

- The Food and Agriculture Sector will increasingly become susceptible to the weaponization of economic investments to undermine global competition and manipulate the rule-based trading system. A China-centric economy and its increasing footprint for influencing international or regional policies will increasingly shape the trading policies of countries with whom the U.S. has historically been the leading economic partner. As China actively trades with countries in Africa, Latin America, and Europe, new bilateral agreements might conflict with international obligations, and instances of economic coercion, espionage, and the theft of natural diversity, trade secrets and/or intellectual property will become prevailing issues for the U.S. Food and Agriculture Sector.

- Water resources critical for agricultural and other human needs are vulnerable to natural and man-made disasters, cyberattacks, deteriorating infrastructure, and climate change. Water demands and supplies are changing, and in the future forecast, most of the water demand will be driven by agriculture and food production. Desertification will continue to be a growing problem in Africa, the Middle East, and other regions. This situation will further exacerbate existing shortages and conflicts over access to water resources and arable land and impact the U.S. access to food products from these regions.

- Facilitation of accurate and timely cross-communication, information sharing, and research coordination between Sectors and government, academic, and private industry partners will be critical to identifying, understanding, and mitigating threats while designing appropriate countermeasures to ensure resiliency of the Food and Agriculture Sector. The absence of a protected information sharing environment greatly impacts the ability of private-sector owners and operators to engage in dialogue with the government.

> **"UNLESS someone like you cares a whole awful lot; nothing is going to get better. It's not.", The Lorax, Dr. Seuss.**

ANALYTIC DELIVERABLE DISSEMINATION PLAN

Office of the Director of National Intelligence (ODNI)
Office of Science and Technology Policy
U.S. Federal Bureau of Investigation (FBI), including Office of the Private Sector, Weapons of Mass Destruction Directorate, Counterintelligence Division, Counterterrorism Division, and Criminal Division
U.S. Department of Homeland Security (DHS) Headquarters and Components, including Component Intelligence Offices, U.S. Customs and Border Protection, FEMA, and U.S. Coast Guard
Department of State Global Health Programs, Biological Engagement Program
DHS Association Partners, including but not limited to BENS, ASIS, ISMA
Previous participants in the DHS AEP and IC Analyst-Private Sector Program
U.S. Agency for International Development (USAID)
U.S. Department of Commerce Export Control Unit and National Oceanic and Atmospheric Administration (NOAA)
U.S. Department of Defense, Defense Threat Reduction Agency, Cooperative Biological Engagement Program
U.S. Department of Agriculture (USDA) APHIS, Office of Homeland Security
U.S. National Institute of Health, National Institute of Infectious Disease
Health and Human Services, Center for Disease Control and Prevention, Global Health Security Program, U.S. Food and Drug Administration (FDA)
U.S. Environmental Protection Agency (EPA)
U.S. Geological Survey (USGS)
U.S. Department of the Interior
U.S. Department of Energy, Biological Defense Program
U.S. Army Corps of Engineers
Academic institutions
Food and Agriculture Sector (bi-annual meeting)
Infragard National Members Alliance (Food and Agriculture Sector)
Extension Disaster Education Network
Food Safety Tech / Food Defense Consortium Conference
Food and Agriculture Related conferences
DHS / CISA / Protective Security Advisors
Public health partners including but not limited to APHL, national associations

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Appendix 1: Threat-Capability-Vulnerability Matrix. Two vulnerability scenarios were selected and served as the focal framework for in-depth analysis of capability gaps, namely; (a) emergence of novel diseases in wildlife, environment, and production settings contaminating/disrupting the food and agricultural supply chain; and (b) genetically manipulated pathogen/s that undermine detection, prophylactic and therapeutic countermeasures in plant, livestock, or aquaculture production systems. Additional work is needed in this area to perform a gap analysis of current capabilities and research needs to address the real and perceived threats to the Food and Agriculture Sector as described in the Key Findings (Potential Research Collaboration Area).

Industry/Host/ Carriers	Determinants of Risk	THREATS				
		Agro/Bioterrorism	Resistance to Treatments/AMR	Zoonoses/Human Health Aspect	Adulteration	Economic Coercion[1]/Manipulation
Crops	Capability	• Diagnostics network • Plant/disease identification capability • Threat recognition and reporting • Border inspections	• Application of molecular genetics • Diagnostics capability	• Toxicology laboratory capability • Molecular diagnostics capability • Availability of treatments	• Next Generation Sequencing • Detection capability • Biosurveillance capability	• Diplomacy • I.C. community • Policy regulations in place • Trade agreements
	Vulnerability	• More than 6,000 pest/pathogens • No genetic resistance/non-resilient crops • Inadequate plant/disease identification capability	• Natural evolution/genetic resistance to treatments • Indiscriminate use • Contamination of environment	• Phytonoses • Food-borne pathogens • Phytotoxins • Allergens	• Poor processing biosafety/ biosecurity protocols • Intentional adulteration of processed products • Poor regulatory enforcement for adulteration	• Transnational criminals • Low supply/high demand for product • Competition for global market share • Supply chain disruption; foreign acquisition • I.P. theft • Lack of cybersecurity

[1] The term 'economic coercion' has traditionally been difficult to define. As a starting point, the term can be defined broadly to include the use, or threat to use, 'measures of an economic—as contrasted with diplomatic or military—character taken to induce [a target State] to change some policy or practices or even its governmental structure' (Lowenfeld 698)

Appendix 1. Threat-Capability-Vulnerability Matrix continued ...

Industry/Host/ Carriers	Determinants of Risk	THREATS				
		Agro/Bioterrorism	Resistance to Treatments/AMR	Zoonoses/Human Health Aspect	Adulteration	Economic Coercion/ Manipulation
Livestock/ Poultry	Capability	• Vaccine availability • Biosurveillance and risk assessment capability • Threat recognition and reporting • CRISPR technology • Border inspections	• Vaccines availability • New antibiotics • Diagnostics capability • Policy regulations in place	• Use of efficient biosafety/ biosecurity protocols • Diagnostics capability • Biosurveillance capability • Regulations for import of live animals and products in place • Border inspections	• Database of adulteration events • Next Generation Sequencing/ diagnostics • Product specialists	• International agreements • Health and safety standards • Consolidated markets
	Vulnerability	• Unknown pathogens –lack of recognition/detection technology • Modern animal husbandry • Non-resilient livestock • Non-standardized biosafety/biosecurity protocols • Easy access to highly pathogenic organism	• Natural evolution and intentional manipulation of bioagents • Lengthy regulatory procedures for licensing of vaccines and drugs • Non-resistant livestock/poultry • Lax standards of regulation for usage of antibiotics	• Range of vectors are extending • Identification system for animals non mandatory • Increased human-(livestock)-wildlife contact • Globalization of travel and trade • Susceptible feral/wildlife populations • Close contact with pathogen in pre- and post-harvest environments • Lax standards of regulation for usage of antibiotics • Cheap meat substitution	• Increasing demand for specialty products • Lax regulations for post-harvest processing and inspection • Cheap substitutions/mislabeling for profit-making • Complicit consumers	• Lack of cybersecurity • Consolidated markets • Takeover of important supply chain entity by foreign investors • Rapid shift of demand • Trade war

Appendix 1. Threat-Capability-Vulnerability Matrix continued …

Industry/Host/ Carriers	Determinants of Risk	THREATS				
		Agro/Bioterrorism	Resistance to Treatments/AMR	Zoonoses/Human Health Aspect	Adulteration	Economic Coercion/ Manipulation
Aquaculture	Capability	• Strict regulatory requirements • Toxicology laboratory/detection capability • Traceability of product • Threat recognition and reporting	• Detection methods • Policy regulations in place • Biosurveillance capability	• Treatment and vaccines available • Diagnostics capability • Policy regulations in place	• Detection • Next Generation Sequencing • Supply chain traceability	• Diplomacy • I.C. community • Policy regulations in place • Trade agreements
	Vulnerability	• Intentional dispersal of invasive/pathogenic agents • Genetic manipulation of pathogens or aquaculture species	• Lax regulations for treatment/ production in exporting countries • Pathogen adaptation to ocean acidification (e.g., *Vibrio* spp.) • Climate change effects on production system • Unintentional dispersal of invasive/pathogenic agents	• Poor regulatory enforcement and lack of regulations in export countries • Lack of diagnostic capability • High dependence for fish and shellfish imports • Lack of transparency	• Poor processing biosafety/ biosecurity protocols • Mislabeling for profit-making • Poor regulatory enforcement for fraud • Customer acceptance of cheaper products	• Lack of cybersecurity • Exclusive fishing zones • Critical dependence on foreign imports • Inadequate Coast Guard • Geopolitical water resource manipulation • Military presence

Appendix 1. Threat-Capability-Vulnerability Matrix continued …

Industry/Host/ Carriers	Determinants of Risk	THREATS				
		Agro/Bioterrorism	Resistance to Treatments/AMR	Zoonoses/Human Health Aspect	Adulteration	Economic Coercion/Manipulation
Vectors (arthropods)	Capability	• Molecular diagnostics capability • Better control methods • Good threat recognition and reporting • Sentinel surveillance • Genetically modified vectors	• Molecular taxonomic identification • Sentinel biosurveillance • GMO bacteria which restore susceptibility	• Vaccines availability • Biosurveillance • Point-of-care diagnostics • Ecological knowledge • Better pesticides/ repellents	N/A	• Molecular diagnostics • Better control methods • Threat recognition and reporting • Sentinel surveillance • Regulations for import of products in place • Border inspections • International agreements
	Vulnerability	• Expanded trade • Transboundary spread through natural wildlife migration and global travel of humans, animals and plants • Genetically modified vectors	• Evolution of resistance genes/morphogenes is • GMO vectors with resistance • Indiscriminate use of pesticides • Horizontal gene transfer	• Climate change-induced emergence of vectors • Transboundary spread through natural wildlife migration • Global travel and trade • GMO-mediated susceptibility and adaptation/ behavior • Horizontal gene transfer	N/A	• Delayed pest reporting from trade partners • Costly control/eradication/ treatment/vaccines • Trade

Appendix 1. Threat-Capability-Vulnerability Matrix continued …

Industry/Host/ Carriers	Determinants of Risk	THREATS				
		Agro/Bioterrorism	Resistance to Treatments/AMR	Zoonoses/Human Health Aspect	Adulteration	Economic Coercion/Manipulation
Companion Animals (incl. reptiles/birds)	Capability	• Biosurveillance capability • Diagnostics capability • Threat recognition and reporting • Availability of vaccines • Policy regulations in place • Intelligence capability • Border inspections	• Molecular diagnostics • Policy regulations in place	• Biosurveillance • Point-of-care diagnostics • Regulations in place • Vaccines availability • Global consciousness on humane animal welfare • Border inspections	• Detection method for falsified, substandard, and counterfeit pets • Next Generation Sequencing for species identification (SNPs)	• Policy regulations in place • Intelligence • Trade agreements
	Vulnerability	• "Vector/fomite" for introduction of bioagents • Lax importation rules for pet animals not birds/reptiles • Inexperience of primary clinicians with pet reportable diseases • Border inspections	• Mutation/ adaptation of bioagents • Non-resilient companion animals (birds, reptiles etc.) • Low surveillance • Indis-criminate use of antibiotics	• Zoonoses • Susceptibility of pets to zoonotic diseases • Mixing vessel capabilities • Domestic terrorism	• High demand for specialty/exotic pets • Critical dependence on foreign feed and veterinary supplies • Complicit consumers	• Critical dependence on foreign feed and veterinary supplies • Ecological impact

Appendix 1. Threat-Capability-Vulnerability Matrix continued …

Industry/Host/ Carriers	Determinants of Risk	THREATS				
		Agro/Bioterrorism	Resistance to Treatments/AMR	Zoonoses/Human Health Aspect	Adulteration	Economic Coercion/Manipulation
Wildlife, CITES	Capability	• Better intelligence/information sharing • Good threat recognition and reporting • Participation of the airline industry • Good communication with NGOs • Molecular Diagnostic Laboratory capability • Policy regulations in place • Border inspections	• Diagnostics capability • Policy regulations in place	• Use of efficient biosafety/ biosecurity protocols • Diagnostics capability • Biosurveillance • Regulations for import of live animals and products in place • Border inspections	• Database of adulteration events • Next Generation Sequencing/ diagnostics (SNPs) • Product specialists • Broad enforcement authorities • Awareness/ training • International Customs coordination	• Not critical for wildlife • Trade agreements
	Vulnerability	• Transnational illicit wildlife trafficking • Traditional Asian medicine demand • Use of wildlife as pathogen spreaders • Highly profitable business	• Natural evolution and intentional manipulation of bioagents • Non-resistant wildlife • Lax standards of regulation for the usage of antibiotics	• Increased human-(livestock)-wildlife contact • High commercial demand for wildlife and wildlife products • Expanded global travel • Transnational illicit wildlife trafficking • Traditional Asian medicine demand	• Increasing demand for specialty wildlife products • Lax regulations for post-harvest processing and inspection • Cheap substitutions/mislabeling for profit-making • Complicit consumers	Not critical for wildlife

Appendix 2: *Food and Agriculture Sector Annual Report: Information Sharing*

The Food and Agriculture Sector has been actively engaged in providing critical information related to threats to critical infrastructure within the food and agriculture environment. The Sector ensures that notices and bulletins published by the Department of Homeland Security (DHS), Cybersecurity and Infrastructure Security Agency (CISA), and / or the Federal Bureau of Investigation (FBI) are passed along to all Government Coordinating Council (GCC) and Sector Coordinating Council (SCC) partners in a timely manner. Recently, in addition to on demand electronic communications, the GCC co-chairs, USDA and FDA, implemented a weekly newsletter that is sent out to the community via electronic mail to ensure a mechanism to provide information in a regular cadence to those stakeholders that are members of Food and Agriculture Sector.

Specific examples of on demand communications include immediate notices on support related to Hurricane Laura, the SolarWinds software vulnerability, and threats from Domestic Violent Extremists. Through the weekly email communications and separate communications as necessary, the Sector shared toolkits and other resources which may be valuable for public and private sector partners.

The Food and Agriculture Sector also hosts a Joint Membership Meeting between the GCC and SCC twice a year in the fall and spring. For both 2019 and 2020, the Food and Agriculture Sector has had a sector risk or threat related topic as a main agenda item. These threat briefings focus on some aspect of security issues relevant to the food and agriculture industry, covering a range of topics from state actor cyber threats, UAS information security, and Position, Navigation, and Timing vulnerabilities. In recent years, the sector has focused on physical and cyber threats to food and agriculture along with the spread of foreign diseases and economic issues that impact food and agriculture.

Overview of Food and Agriculture Sector Goals

The Food and Agriculture Sector's goals support the Joint National Priorities (JNP) developed in 2014 by the national council structures described in the *National Infrastructure Protection Plan 2013: Partnering for Critical Infrastructure Security and Resilience* (NIPP 2013).[14] These goals guide and integrate the Sector's efforts to improve security and resilience and describe how the Sector contributes to national critical infrastructure security and resilience as set forth in Presidential Policy Directive (PPD) 21. Critical infrastructure protection, particularly in the Food and Agriculture Sector, is not the responsibility of any one department or agency in government, but rather is a partnership effort between all levels of government and private sector owners and operators. Continually since its establishment, the Sector has recognized the value and importance of the partnership between government and the private sector, as this linkage is vital to increasing homeland security and resilience. Food and Agriculture Sector partners in the public and private sectors have taken significant steps to reduce sector risk, improve coordination, and strengthen security and resilience capabilities through achievements towards these five goals that guide future Sector progress.

2015-2019 Food and Agriculture Sector Goals	
Goal 1	Continue to promote the combined Federal, SLTT, and private sector capabilities to prevent, protect against, mitigate, respond to, and recover from manmade and natural disasters that threaten the national food and agriculture infrastructure.
Goal 2	Improve sector situational awareness through enhanced intelligence communications and information sharing among all FA Sector partners.
Goal 3	Assess all-hazards risks, including cybersecurity, to the FA Sector.
Goal 4	Support response and recovery at the FA Sector level.
Goal 5	Improve analytical methods to bolster prevention and response efforts, as well as increase resilience in the FA Sector.

The National Infrastructure Protection Plan (NIPP) 2013: *Partnering for Critical Infrastructure Security and Resilience* provides the overarching framework for a structured partnership approach between the government and the private sector for protection, security, and resilience of critical infrastructure.[14] The NIPP establishes the mechanisms for collaboration between private sector owners and operators and government agencies.

The NIPP 2021 also organizes the nation's critical infrastructure into 16 sectors and identifies sector-specific agencies (SSAs) for each of the Sectors. Now due to the 2021 National Defense Authorization Act, there will be Sector Risk Management Agencies and also, establishment of the requirement for partnerships between the federal government, critical infrastructure owners and operators, and state, local, tribal, and territorial (SLTT) government entities.[99]

Nationally significant incidents have also driven closer coordination between the partnership and the National Preparedness System, including the creation of a new Emergency Support Function (ESF #14 – Cross-Sector Business and Infrastructure), which was introduced to focus on engaging private sector interests and infrastructure owners and operators—particularly those in sectors not currently aligned to other ESFs—and conducting cross-sector analysis to help inform decision making. ESF #14 relies on other ESFs aligned with a critical infrastructure sector to continue coordination with their corresponding sector during response efforts. ESF #14 coordinates multi-sector response operations between (or across) the government and private sector for natural or human-caused catastrophic incidents that jeopardize national public health and safety, the economy, and national security.

The partnership has evolved to meet these challenges, and the national doctrine organizing and describing the partnership must also evolve. The 2021 refresh is designed to ensure that this plan remains authoritative: current, accurate, and effective in guiding and describing the functions of collaboration.

Appendix 3: *U.S. Department of Homeland Security (DHS) / Countering Weapons of Mass Destruction Office (CWMD) Food, Agriculture, and Veterinary Defense (FAV-D) focused research & development (R&D) project areas for high consequence / catastrophic events.*

DHS/CWMD is required through to carry out a program to coordinate the Department's efforts related to defending the food, agricultural, and veterinary systems of the United States against terrorism and other high-consequence events that pose a risk to homeland security (*i.e.,* intentional, unintentional, or natural major disasters and other emergencies). In accordance with its authorization from Homeland Security Presidential Directive 9 (HSPD-9) and the Securing our Agriculture and Food Act (SAFA) P.L. 115-43, DHS CWMD / FAV-D and Science and Technology (S&T) developed a joint strategic plan that lays out the intent of CWMD and S&T to cooperate on activities associated with DHS investments into research, development, testing, and evaluation (RDT&E) efforts that may be executed across the national incident.

The joint strategic plan aligns with mission-based goals and objectives and is centered on the four focus areas of countermeasure development, capacity and capability building, risk management, and data analytics and information technology (IT) systems in order to:

- Enhance U.S. Food and Agriculture critical infrastructure security and sector resilience;
- Mitigate and defend against the intentional, natural, or unintentional introduction of high consequence animal or plant diseases, and pests that threaten the homeland (and endemic areas globally);
- Strengthen food/water defense and protection efforts, particularly response capabilities to ameliorate the introduction and detection of adulterants throughout the entire farm to fork continuum;
- Improve Food and Agriculture sector intelligence gathering and data analysis to help predict, thwart, and reduce the impact of catastrophic and intentional insults; and
- Foster internal and external stakeholder capacity building in order to advance programmatic decisions, operational planning, and policy development for prevention, protection, mitigation, response and recovery activities.

Successful RDT&E initiatives will need to respect regional and industry-specific vulnerabilities and capabilities, integrate with pre-existing preparedness systems and mitigation strategies, and will eventually need to be accompanied with viable transition / transfer and operational implementation plans to facilitate deployment or execution by frontline operators and field personnel in the mission space. Joint RDT&E initiatives will also need to take into consideration and leverage existing approaches and international systems, as well as best practices from related efforts within government and industry, and evolve with emerging threats, policy revisions, process development, advancements in research, and technological breakthroughs.

The joint strategic plan serves as a guide to influence CWMD and DHS investments that ensure operational components, intra and/or interagency partners, and other stakeholders have validated tools and technologies to fulfill their respective missions. An initial list of R&D focus areas is included as follows.

The list of topics is provided in no specific order of importance.

1. Pre-deployment validation study for newly developed fieldable diagnostic test (example: FMD ELISA test kit)

2. Research and development (not commercial production, or dose procurement) for a vaccine that can be used to differentiate vaccinated from unvaccinated animals (DIVA). *R&D timeline = 4yrs

3. Research and development for an Emergency Use Live-Attenuated Vaccine for a novel transboundary animal disease (not commercial production, or dose procurement). *R&D timeline = 4yrs

4. Research and develop a point of care diagnostic test (*e.g.,* lateral flow assay test strip) for use in the field.

5. Research and develop a lab-bench diagnostic test (e.g. ELISA or IFA test for ASFv) for use at a National Laboratory.

6. Research and development of an Artificial Intelligence / Machine Learning algorithm and associated GUI/software interface.

7. Decontamination, disinfection, and disposal study for high consequence pathogens, infected animals, and environmentally contaminated surfaces. *R&D timeline = 6m to 3yrs

8. Research to characterize a new pathogen (infectivity, survivability, transmissibility, etc). *R&D timeline = 3yrs

9. Threat/Hazard/Risk Assessment or Gap Analysis study (e.g. Food grid/supply chain infrastructure, cybersecurity, etc.) to identify vulnerabilities and R&D targets. *R&D timeline = 2yrs

10. Research, Development, Testing and Evaluation (RDT&E) of the efficacy of an existing vaccine for a transboundary animal disease in a different species (e.g. FMD vaccine for swine). *R&D timeline = 2yrs

11. In-line / Off-line Modeling study (example: food grid resilience, supply chain upstream/downstream impacts, import disease/pest introduction risk). *R&D timeline = 3yrs

Appendix 4: *Food and Agriculture Risk Landscape*

Risk, in the context of the NIPP 2013, is defined as the potential for loss, damage, or disruption to the Nation's critical infrastructure resulting from destruction, incapacitation, or exploitation during some future manmade or naturally occurring event.[14] Several threats and hazards are of significant concern to the Food and Agriculture.

Food Contamination and Disruption (Accidental or Intentional)

- Contaminated food in the United States is estimated to be responsible for approximately 48 million illnesses, 128,000 hospitalizations, and 3,000 deaths, costing the Nation more than $14 billion a year in terms of medical care, lost productivity, chronic health problems, and deaths.
- Violent extremists and terrorists consider America's agriculture and food production tempting targets and have indicated an interest in poisoning the food supply, which has great potential to cause costly economic losses in the supply chain for implicated foodstuffs, create public panic, and lead to a public health crisis with considerable mortality and morbidity.
- A general disruption, such as an attack on a critical transportation or energy node, could impact the Food and Agriculture Sector even if the action was not targeting a Food and Agriculture Sector component.
- For the present, the U.S. food supply chain will continue to depend upon human labor. Therefore, the public health of labor and containment of disease must be a consideration.

Disease and Pests

- The accessibility of crops and animals on the farm and the extensive international and interstate movement of animals and products increase the Food and Agriculture Sector's vulnerability to rapidly spread disease.
- Modeling estimates and historical evidence demonstrate that a domestic outbreak of a foreign animal disease (FAD), such as Foot-and-Mouth Disease (FMD), would cost the United States billions of dollars due to loss of livestock, production, and international trade.

Severe Weather (i.e., Droughts, Floods, and Climate Change)

- Natural hazards are a constant risk to the Food and Agriculture Sector and critically influence farm productivity.

- Climate change poses a major challenge to U.S. agriculture because of the critical dependence of the agricultural system on climate and the complex role that agriculture plays in rural and national social and economic systems.
- Weather and climate characteristics, such as temperature, precipitation, carbon dioxide, and water availability, directly impact the health and wellbeing of plants and livestock, as well as pasture and rangeland production.
- The harmful effects of severe weather coupled with global climate change are currently affecting U.S. water resources, agriculture, land resources, and biodiversity. This trend is expected to continue as production of all agricultural commodities will become more vulnerable to the direct impacts (*e.g.,* changes in crop and livestock development and yield) and indirect impacts (*e.g.,* increasing pressures from pests and pathogens) which result from changing climate conditions and extreme weather.[100]

Cybersecurity

Cyber threats and attack tools evolve rapidly as the cyberattacking community shows ingenuity. Most attacks can be blocked by continuously updated computer security programs. Such programs involve adherence to procedural safeguards for the system; an effective, continuously adaptive firewall; the application of intrusion detection and intrusion prevention systems for detecting, reporting, and preventing external threats to the network and information systems; surveillance programs for detecting insider threats; the continuous training of system users on proper security procedures; use of passwords resistant to hacker compromise; and related safeguards. Sector partners use cybersecurity measures as part of good business practices.

Data security is a subset of Cybersecurity that must be addressed as well. Future data breaches may have catastrophic implications on the food supply chain as the majority of food passes through fewer and fewer designated supply chains which increases the potential for disruptions. The growth of third party logistics (3PL) suppliers in the food supply chain can create great data security exposures for large-scale distributors and e-commerce service providers.

One area of interest for the Food and Agriculture Sector is the use of Industrial Control Systems (ICS), such as Supervisory Control and Data Acquisition (SCADA), by many food production and processing facilities. With the vast majority of ICS developing to enhance connectivity and remote access, the vulnerability of these systems to cyber threats needs to be better understood. As the Food and Agriculture Sector becomes increasingly reliant on technology, the sector will continually revisit the issue of cybersecurity.

Chemical, Biological Radiological and Nuclear (CBRN) Threats

Our nation is prepared for and protected from natural, accidental, or deliberate chemical, biological radiological and nuclear (CBRN) threats.

Whether naturally occurring, accidental, or intentional, these threats can have major impacts on global public health, the economy, and national security.

Potential targets within the Food and Agriculture Sector include: farm animals and field crops, animal feed, items in processing, transportation, and distribution, market-ready foods, agricultural facilities and infrastructure, and food and agriculture workers.

Continued focus on the risks involved with CBRN threats will better prepare the Food and Agriculture Sector to protect public health, agriculture, and the environment against ongoing and future threats.

Other Risk Areas

Another area of interest for the Food and Agriculture Sector is the dependency of the use of Precision Agriculture (PA) on Position, Navigation, and Timing (PNT) services provided through the Global Positioning System (GPS) and enabled by broadband telecommunications. Precision Agriculture helps farm operators fine-tune their production practices in real-time during planting, field applications, and harvesting. The interruption of PNT or broadband services could result in lower crop yields, poorer crop quality, and missed planting times. Precision Agriculture supports the reliability of our national food supply.

Appendix 5: *Aquatic Diseases*

As aquaculture typically involves the farming of aquatic plants, finfishes, and shellfishes, considering that these organisms are quite evolutionarily diverse from humans, and also that they are typically reared at temperatures much cooler than that of the human body ("cold blooded"), the likelihood of zoonotic transmission of diseases from the cultured products to a human being is very low. For example, avian influenza or other zoonotic diseases may move from an animal host such as a chicken or a pig to a human as these vectors are essentially all "warm blooded". As such, the primary mode of transmission of a disease from fish / seafood to a human would most likely be oral and in the form of "food poisoning". For example, threats might include eating raw shellfish contaminated with *Vibrio* or imported fish fillets containing malachite (a heat tolerant poison used in some countries to treat infections of fishes, but it is not approved for use in the U.S. and may remain as a residue in some seafood products). In these cases, surveillance or screening of seafood products is warranted. There are some known aquatic zoonotic diseases, such as "fisherman hand", which is caused by genus *Erysipelothrix* and / or *Mycobacteria* (the same genus of organism that causes tuberculosis), however this is fairly uncommon, typically must be introduced through an open wound, and can be treated.

Alternatively, a disease could be intentionally introduced into the aquaculture or fisheries production systems such that a pathogen could spread among the crop or the population of wild fish with the intent to infect, damage, or destroy it. Weaponized diseases for aquaculture would probably be a virus. Diseases such as Tilapia Lake Virus (TiLV), for instance, may pose a substantial risk to the aquaculture industries of the U.S. if they were to be introduced following failure of appropriate biosecurity measures. The vast importation of fresh or frozen seafood may serve as the vehicle for introduction of such an agent into the country (both intentional and unintentional). Such an intentional act would most likely be conducted for the purposes of economic gain (*e.g.,* eliminating the crop of a domestic competitor) or to destroy valuable lines or strains of breeding / domestic animals. The impacts of an introduced disease on commercially valuable wild populations of fishes and shellfishes could possibly have a more significant effect and also be more difficult to contain.

In regard to marine aquaculture "offshore", there are similar concerns. For instance, contamination of crop in offshore cages, equipment tampering with the intent to release animal crops into the wild, and / or illegal harvesting of crop. This could be intentional or unintentional. For example, the intentional dumping of an agent into or nearby an offshore cage facility with the goal of contaminating a product that is also not under surveillance. Or unintentional, for instance, container ships dumping contaminated bilge water nearby a facility that may contain some foreign, biological agent or injurious wildlife and thus subsequently impacting the animal crop (or wildlife) at the nearby facility. Such contaminants could be dumped a considerable distance away from the actual target and then carried to destination by ocean currents.

Sabotage on an intensive "on-land" aquaculture operation could be conducted much more simply, however. For example, failure of a utility grid (electricity or water) or simply turning off a pump or aerator by switching off a breaker could be sufficient to kill a large number of fish on most rural on-land operations and this does not require any complex introductions of biological or chemical agents. In this regard, even a gallon of household bleach dumped into a tank will result in an adequate consequence. Therefore, any such sabotage or terrorism related to targeting seafood production within the U.S. would probably be small in scale and aimed at economic incentives (*e.g.,* to put someone out of business by disrupting operation in order to gain economic advantage in the market share). This act however might have economic consequences, but overall minor impacts on actual food supply.

It is possible to use feeds to deliver biological and / or infectious agents to aquaculture organisms or resulting seafood products. Such agents could be present in imported components used to formulate feeds that would then be passed on to seafood products reared in the U.S. However, most commercially available aquaculture diets are manufactured in the U.S., and, as typical for aquaculture, are produced using "extrusion" technology. This indicates that a biological or infectious agent delivered through such a system would have to survive extremely high temperatures and pressures endured during the extrusion process, which for the most part sterilizes. Vitamins and other additives are sometimes applied post-extrusion (*e.g.,* sprayed on or coated) and thus may pose a potential for introduction in that manner. As such, concerns for adulteration of feed ingredients in aquaculture is typically chemical agents, as in the case of melamine, and not biological. Terrestrial animal diets that are manufactured without an extrusion process may be more vulnerable to introduction of biological agents. Additionally, proper biosecurity during storage of imported feed ingredients prior to feed manufacture is good management practice.

Appendix 6: *Aquaculture and Seafood Production*

Aquaculture is the farming of aquatic organisms, which primarily includes plants, finfishes, and shellfishes. This is a $150 billion per year global industry, yet the U.S. component of this market share is less than 1% and the country is the number one global importer of seafood in the world. This is despite access to the best infrastructure and both freshwater and marine resources of all countries. The United Nations (UN) Food and Agriculture organization (FAO) FAO considers the U.S. to be a country with one of the greatest unrealized potentials for aquaculture among all those in the world.[45,46]

America has grown complacent in regard to the current position of U.S. seafood over the last several years. This unfortunately has led to a national seafood trade deficit in excess of $16 billion annually—and this figure continues to grow each year. In the current U.S. marketplace, 9 out of 10 seafood products consumed by Americans originate from other countries and this proportion is trending closer to 19 out of 20 seafood products in the future. A concern here is based both on economics and public health. For example, since 90% or more of the seafood consumed in the U.S. is imported, this indicates that the country is mostly reliant on foreign countries to provide this commodity (*e.g.,* it is a matter of food security). The country has outsourced its dependence on this product and this is a vulnerability.

> **“The national seafood trade deficit in excess of $16 billion annually and 9 out of 10 seafood products consumed by Americans originate from other countries”**

Also considering the challenges of the USDA to meet the future demand for food supply in 2035, 2050, and beyond—the global future is seafood. Seafood is the dominant food animal protein consumed by humans throughout the world and fishes have the best feed conversion rate of all agricultural food animals;[63,64] the UN FAO predicts that 2/3 of all global seafood will be produced using aquaculture by the year 2030.[47] This is because all of the world fisheries are at maximum sustainable yield and / or are already overfished—there will be no additional seafood production from commercial fishing and this has been realized since the passing of the Magnuson–Stevens *Fishery Conservation and Management Act* of 1976).[48] In order to substantially increase domestic seafood production, the U.S. will need to recognize and promote its aquaculture industry as one of the key agriculture components of the future food supply.

Research Area: Aquaculture Production

The contention here of the U.S. position in the global seafood market, although impressively contributing to a substantial trade deficit, is aimed more at our insufficiency as a country to domestically secure our own food supply (*i.e.,* lack of independence; economic warfare to control the supply chain with sole source-type leverage by foreign powers).[101]

In May of 2020, Executive Order 13921 *Promoting American Seafood Competitiveness and Economic Growth* was released that detailed improving American competitiveness in the global seafood market to help detract from this massive economic impact of the trade deficit and to re-direct priorities toward securing the domestic U.S. seafood supply.[49] These priorities also align with Executive Order 14017 to secure *America's Supply Chains* (February 2021) and Executive Order 14036 on *Promoting Competition in the American Economy* (July 2021).[50,51] USDA announced in July 2021 that it intends to make significant investments to expand processing capacity and increase competition in meat and poultry industries to make agricultural markets more accessible, fair, competitive, and resilient for American farmers[52] and this also is an opportunity to address, in part, the deficit in domestic seafood production, including fostering U.S. aquaculture and seafood production capabilities. In many cases the technical feasibility of culturing aquatic organisms is known, however regulatory and permitting issues with federal, state, and local governments is the impediment. The future of food-animal farming is aquaculture.[102,103]

Appendix 7: *Seafood Safety*

As above, with economic and supply chain concerns for seafood also comes concerns with seafood product safety and health impacts to the American publics. As an example, many seafood products imported into the U.S. originate from Southeast Asia by volume and a considerable amount is sourced from China, which is the number one seafood producer in the world. The UN FAO shows that China produces about 2/3 of all seafood globally—to put things into perspective, this means that China produces about twice as much seafood as all of the other countries in the world combined.[46] China and other countries in Southeast Asia often raise or harvest seafood products using unsustainable practices (*e.g.,* concerns of CITES, environmental stewardship, and labor welfare) or husbandry conditions that are not in compliance with current USDA and FDA regulatory standards. It therefore becomes the duty of the federal government to regulate and identify these import cargos at all U.S. ports of entry to ensure that the imported products are safe, reliable, and adhere to minimum standards for consumption by the American publics.

At present there are 52 existing FDA alerts (*i.e.,* "Red List") on imported seafood products (FIGURE 1).[104] The two major global offenders of this are Thailand and China.[105] Better tracking of seafood shipments into the U.S. are required to ensure that the FDA can keep pace with these required measures such that disease outbreaks and other food safety concerns are not imminent threats. These outbreaks and / or threats may be intentional or unintentional in origin. For example, many of the seafood importation alerts are based on the following concerns by the FDA as described in the import alerts:

- Spoiled or decomposing product
- Bacterial contaminants, including foodborne pathogens
- Chemical / poisonous contaminants
- Treatment of product with chemicals and antibiotics that are prohibited and / or unapproved by either the FDA and / or USDA (*e.g.,* product residues)
- Mislabeled or counterfeited seafood products (*e.g.,* food fraud, violating country-of-origin labeling, or false labeling such as labeling *Pangasius* basa, also known as swai, as “channel catfish”, which is a domestic U.S. product)

Given the high volume of seafood imports into the U.S., this poses concern with being able to accurately screen the volume of products as well as then providing foreign actors with the opportunities to intentionally deliver agents into the U.S. food supply chain (*i.e.,* food terrorism; “slipping through the cracks”).[106,107] As many seafood products are often sold raw (*e.g.,* fresh, refrigerated, or frozen) or unprocessed, this poses a risk for using it as a vehicle to introduce both biochemicals as well as active biological agents into the country.

As of 8 February 2021, the FDA has rolled out Phase II of a pilot program designed to better track imported shipments of seafood using machine learning artificial intelligence in order to quickly and efficiently identify problematic or dangerous containers that may pose a threat to US public health (FDA *Artificial Intelligence Imported Seafood Pilot Program* as part of the FDA *New Era of Smarter Food Safety* initiative).[16] The results of this rollout will be collected from February 1, 2021-July 31, 2021, and success at targeting violative seafood shipments will be reported.[44]

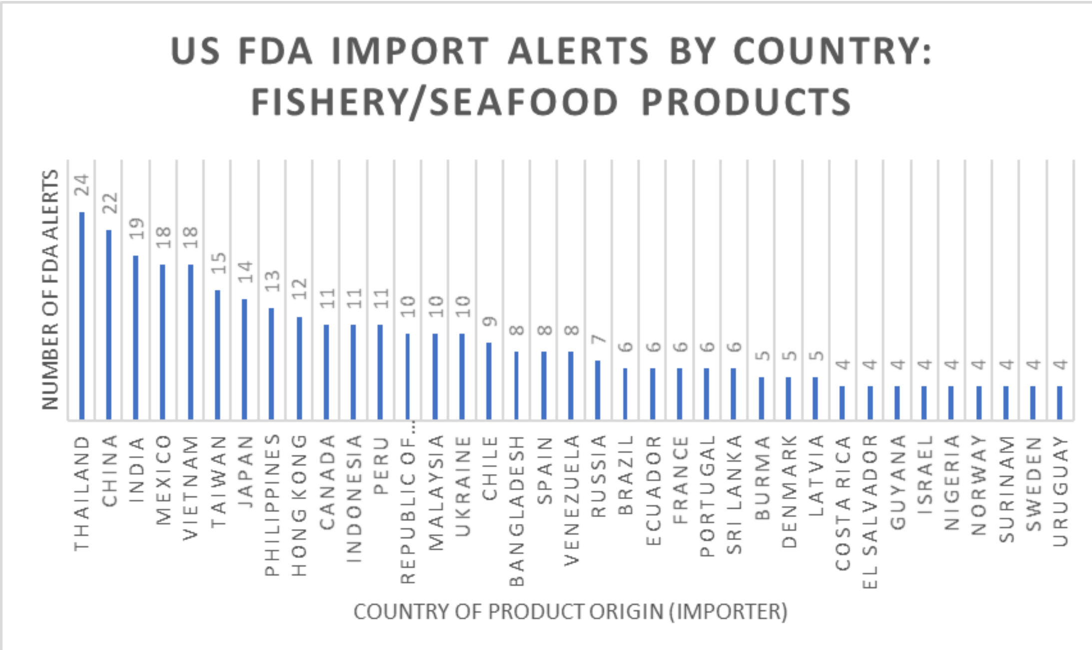

FIGURE 1. Countries with 4 or more current FDA Import Alerts (*i.e.,* "Red List") for Fishery and Seafood Products into the United States. Reasons for FDA Import Alerts issued for products include: decomposition/filth; presence of bacteria/noncompliance with HACCP; presence of unapproved drug or chemical residues; unsanitary canning, packing, or shipping conditions; misbranded labels; refusal to remit to FDA inspection(s); and failure to provide proper process information. There are 57 additional countries with 3 or less FDA Import Alerts (*not shown*). The data are current for January 2021 and compiled from the following FDA Import Alerts: 16-02, 16-04, 16-05, 16-07, 16-09, 16-100, 16-105, 16-114, 16-118, 16-119, 16-12, 16-120, 16-121, 16-124, 16-125, 16-127, 16-129, 16-13, 16-131, 16-133, 16-136, 16-137, 16-17, 16-18, 16-20, 16-22, 16-23, 16-25, 16-31, 16-35, 16-39, 16-50, 16-74, 16-81, 16-95, 45-02, 54-14, 54-16, 66-41, 71-04, 99-08, 99-12, 99-19, 99-21, 99-22, 99-32, 99-33, 99-35, 99-36, 99-37, 99-38, and 99-39.

Appendix 8: *Wildlife Resources Including Fisheries and Other Natural Aquatic Resources*

The North American Laurentian Great Lakes contain more than 20% of the world's surface freshwater and the U.S. is bounded by two expansive marine coastlines. Additionally, the importance of aquatic resources has been recognized by the U.S. Department of Interior for irrigation of farmland, provision of municipal water supplies, generating hydroelectric power, and providing control of flood plains. There are more than 90,000 dams in the U.S., impounding 600,000 miles (970,000 km) of river or about 17% of rivers in the nation and these dams also create hundreds of artificial freshwater impoundments or reservoirs.[108]

Thus, the U.S. has ample marine and freshwater resources to supply agriculture as well as other human needs.[54] However, given the geographic scale, it is quite difficult to protect and maintain all of this resource infrastructure simultaneously. For example, poisoning or sabotage of fresh drinking water may include cyberterrorism through the internet as well as physical acts such as introduction of chemical or biological agents into the water. However, physical damage to waterways, levees, dams or other infrastructures that may affect roadways, transportation, and flooding in developed urban or rural areas also are possibilities. Many of the municipal freshwater drinking and irrigation reservoirs are aging and failure of the infrastructure does not necessarily need to be directly due to sabotage as warning signs of impending failure (*i.e.,* neglect) of levees and other waterway infrastructures have been identified. It is estimated that more 15,000 dams in the U.S. are at risk of failure due to deterioration, which may lead to substantial economic and land use losses as well as the potential for human casualties.[55,56]

Results of the failure of such infrastructures can be seen in the aftermath of hurricane Katrina in New Orleans (2005, 1,800 deaths and $125 billion in damages) and Mississippi River flooding (1993, 32 deaths and $15 billion in damages). As a specific example of the importance of levees in floodplain control, the Mississippi River flood affected over 745 miles (1,199 km) in length and 435 miles (700 km) in width of the midwestern hydrographic basin, totaling about 320,000 square miles (830,000 square km). Within this zone, the inundated area totaled around 30,000 square miles (78,000 square km) and lasted hundreds of days; it displaced thousands of persons, destroyed agricultural crops and property, and released invasive species from controlled agricultural operations into the endemic wildlife (*e.g.,* Asian carps). In this regard the "$15 billion in damages" does not account for the aftereffects of the flood, some of which are still being combated decades later, such as the Asian carps migrating northward into the Great Lakes. During this flood, there also was active, intentional acts that contributed to the flood damages (see the case of *James Robert Scott 1994*, who is still imprisoned for tampering with Mississippi River levees during the time of the flood).

Overall, in regard to these infrastructures and resources there are two major considerations:

1) Many are ageing and require renovation or repair to remain effective in the future / avoid failure.
2) Geographical scale poses a challenge for surveillance.

Appendix 9: *Climate Change and Water Scarcity and Contamination*

Climate change threatens aging water utility infrastructure and land use through increasingly frequent and intense storms, risk of flooding, and sea level rise resulting from shifts in long-term climate patterns. Climate change effects on the aridization / desertification of U.S. regions is in the recent news.[109,110] The current Klamath River drought (2021) is an example of this problem and its impact to agriculture. The Klamath River runs from Upper Klamath Lake just north of Oregon-California south into California.[111] Restricted flow control on that river due to the most extreme drought in 127 years will affect agricultural irrigation and production in northern California (May 2021). The economic value of hay, alfalfa, potatoes, and grazed cattle agriculture from that region is estimated to be around $300 million.[112]

Domestic violent extremists (DVEs) also pose a threat to U.S. Food and Agriculture Production systems, especially in regard to environmental, animal rights, and anti-government activist groups. This has been recognized and reported by the FBI and U.S. Department of Homeland Security,[113] however these activities may be exacerbated by resource restrictions, climate change impacts, natural and unnatural disasters / phenomena, and during other times of psychological duress related to emergencies or crises.

Regarding water rights concerns, anti-government activists engaged in cattle grazing and federal property legal disputes with the U.S. Bureau of Reclamation, U.S. Department of Interior, U.S. Department of Homeland Security, and other agencies have lasted over 20 years (see the case of the *Bundy Standoff 2014*).[114,115] Considering the recent and extreme drought in the area of the Klamath River basin, activism is anticipated in this region again in 2021.

Adaptation strategies provided below are suggested from the U.S. Environmental Protection Agency (EPA) Resilient Strategies Guide for Water Utilities.[116] That report addresses anticipated current and future climate threats to contaminated water site management strategies as well as other topical areas including:

-Construct New Infrastructure
-Increase System Efficiency
-Model Climate Risk
-Modify Land Use
-Modify Water Demand
-Monitor Operational Capabilities
-Plan for Climate Change
-Repair and Retrofit Facilities

The U.S. Geological Survey (USGS) Water and Wastewater Infrastructure Science Team also:

> *"provides information on processes that affect contaminants as they move from naturally occurring and human-caused sources through aquifers, aquatic environments, and infrastructure. This comprehensive understanding of contaminant*

profiles from source to exposure is used to develop decision tools to economically, effectively, and efficiently reduce wildlife or human exposure and associated health risks."[117]

Overall, in regard to these infrastructures there are four major considerations:

1) Many are ageing and require renovation or repair to remain effective in the future/avoid failure;
2) Effective cybersecurity is lacking in water treatment facilities;
3) Extreme weather related to climate change potentially threatens utilities that produce drinking water and treat wastewater;
4) Federal technical and financial assistance to make such infrastructure more resilient to extreme weather; a network of technical advisors to assist coordination nationally.

Appendix 10: *Cyberthreats to Food and Agriculture*

With concerns being voiced about the need for critical infrastructure cybersecurity in electric, water (*e.g.,* Oldsmar Water Authority), energy (*e.g.,* Colonial Pipelines) and other businesses[118,119], this panel has seen little discussion about the Food and Agriculture Sector specifically, which has no cybersecurity requirements for control systems used in the food manufacturing process (see: *Food Safety Modernization Act 2015; FSMA*).[120] Consequently, on March 14, 2021 a blog was issued on the lack of control system cybersecurity in the food and agriculture industry, even though there have been control system cyber incidents since the late 1990s.[121] As a result of that blog, an interview was published "*Cyberattacks: What food processors won't talk about*" that can be found in the May 2021 issue of Food Engineering.[122] That interview detailed some key aspects of cyber threats and vulnerabilities.

Positioning, Navigation, and Timing (PNT) is necessary for the functioning of the Nation's critical infrastructure. Whether for civil, commercial, or military use, nearly all sectors rely on accurate PNT information to provide services. However, the ubiquitous use of the Global Positioning Navigation (GPS) as the primary source of PNT information makes these sectors vulnerable to adversaries seeking to cause harm by disrupting or manipulating the GPS signal.[75]

Other specific examples of cybersecurity threats to the Food and Agriculture Sector may include, involve, or relate to:

1) Impeding movement and supply of crops (both planting and harvesting) and meat, poultry, and seafood products (both production and harvest)
2) Delays in shipping of perishable items with concerns of food safety and spoilage
3) Management control of irrigation and fertilization efforts
4) Modern geopolitical disruptions that may affect:
   -Yields (*e.g.,* crop manipulation) creating shortages in fertilization, water, and pest control systems
   -Activism (*e.g.,* social concerns) that may affect pesticide, carbon / environmental impacts, Genetically Modified Organisms (GMOs), and PNT / GPS systems used to plant and harvest crops
5) Distribution including farmer to processor / processor to distributor that may affect:
   -Rerouting and delays of perishable items with concerns of food safety, spoilage, and food shortages
   -Theft
   -False invoices, bill of landing, and delivery / collection times
6) Processing, storage, and retail that may affect:
   -Refrigeration / freezing systems
   -Food shortages / delays impacting the domino effect of supply chains
   -Aging infrastructure / industrial computer programmable logic controllers (PLC) systems that need to upgraded, removed, or isolated to prevent cyberattacks

Case Studies of known cyberattacks related to industrial computer programmable logic controllers (PLCs) involving insider or outsider actors include:

Stuxnet[123] is a computer worm that was originally designed to target Iran's nuclear facilities and has since mutated and spread to other industrial and energy-producing facilities. The original Stuxnet malware attack targeted the PLCs used to automate machine processes.

NotPetya[124] is a Trojan horse cryptovirus-type malware that targets Microsoft Windows-based operating systems. Petya is a family of encrypting malware that was first discovered in 2016. The malware propagates via infected email attachments and attacks are believed to originated from the GRU Russian military intelligence organization.

Case Studies of other recent cyberattacks on U.S. food and agriculture companies involving insider or outsider actors include:

AmeriCold Logistics, LLC is a major temperature-controlled warehousing and transportation company with cold-storage capabilities that are integral to the U.S. food supply chains and also involved with COVID-19 vaccine distribution systems. This company was hit with a ransomware attack recently (2020).[125,126,127,128]

JBS USA Holdings, Inc. is an American food processing company that is a subsidiary of the largest meat processor in the world, which handles about 20% to 25% of the beef sold nationwide. A ransomware cyberattack forced nine U.S. beef plants to close and disrupted poultry and pork plant processing in 2021.[129,130,131,132,133,134]

McDonald's Corp. is a global restaurant chain that suffered unauthorized activity on an internal security system in 2021. The incident resulted in a data breach that lead to exposure of private information of restaurants, employees, and customers in the U.S., South Korea, and Taiwan.[135,136,137] Data that was reportedly accessed makes the company employees and franchisees more vulnerable to future phishing cyberattacks.

Cyberthreats to e-commerce of food and agricultural products includes the following concerns:

Web Skimming: Also known as e-skimming, card skimming or Magecart attacks, refers to cyberattacks in which hackers implant malicious computer code into websites and third-party supplies of digital systems to steal credit card and / or personal identification information. The COVID-19 pandemic has massively accelerated the growth of e-commerce, according to an Adobe report released June 12, 2021. Total online spending in May hit $82.5 billion, up 77% year-over-year. With each additional sale going online, and e-commerce becoming a major source of sale, it is easy for hackers to take advantage of this system. Malicious software code integrated into food websites and digital payment gateways to hack consumer credit card details is becoming a more frequent scenario. Such breaches can trigger a system failure and disrupt normal commerce operations. Hackers today are now trying to break into manufacturer digital systems and networks to look for customer credit card and personal data. Although not all manufacturers retain this type of data, that does not stop cybercriminals from breaking into digital systems looking for information to steal—These breaches can trigger systems to shut down and malfunction, thus impacting normal operations that can disrupt manufacturing and the flow of the supply chain.

Ransomware: Without cloud security, the food and agriculture industries are susceptible to ransomware attacks and these types of attacks have only been increasing in frequency over the years. These attacks can result in millions of compromised internal records and customer data, resulting in interruption and disconnection within the supply chain. Manufacturing operations are halted, resulting in lower earnings due to lost productivity and sales. Peripheral businesses and operations are impacted which could further lead to spoiled or expired foods, food wastage, and decreases in profit margins.

Malware: Malware is a type of hacking designed to break into industrial systems and data acquisition systems with the sole aim of bringing down the entire operations of factories and industries. Altering bill of materials, supply inventories / ordering, changing recipes, and creating toxic products that can all lead to contamination of the food supply chain are some examples.

Appendix 11: *Agricultural Energy Consumption, Fossil Fuels, and the Supply Chain*

Agricultural energy consumption is both direct and indirect.[83,84,138] In 2018, the U.S. consumed a total of 101.1 quadrillion Btu (British thermal units) of energy and roughly 10 percent of that energy was directly consumed by the Food and Agriculture System Sector (about 10.11 quadrillion Btu). Direct energy consumption includes the use of distilled fuels (*i.e.,* gasoline, diesel), electricity, propane, natural gas, and renewable fuels for activities on the farm. Additionally, approximately 4-5% of the energy used for bulk chemical and processing was indirectly consumed by the Food and Agriculture System Sector. Indirect energy consumption includes the use of fuel and feedstock (especially natural gas) in the manufacturing of agricultural chemicals such as fertilizers and pesticides.

Chemicals used by the agricultural industry are a subset of the bulk chemical industry (Chemical Sector) and includes fertilizers, pesticides, feed additives, packaging materials, and food preservatives, among many other compounds. Nitrogenous (ammonia-based) fertilizers require large amounts of natural gas as a feedstock and require heat and power for processing. The EIA 2010 Manufacturing Energy Consumption Survey estimates that the U.S. nitrogenous fertilizer industry consumed more than 200 trillion Btu of natural gas as feedstock in 2010 and another 152 trillion Btu for heat and power.[138] The production of livestock feed also consumes energy for milling, mixing, processing, and extrusion as examples.

Farm production: Agricultural energy consumption includes energy needed to grow and harvest crops and energy needed to rear livestock. Crop operations consume much more energy than livestock operations (about 40% more), and energy expenditures for crops account for a higher percentage of farm operating costs. The energy consumed in livestock operations is almost solely direct energy consumption and is relatively low compared with crop operations, as both a percentage of total operating expenditures and on a total energy basis. Livestock operations consume direct energy for ventilation systems, refrigeration, lighting, heating, watering, motors, and waste handling, whereas crop operations use energy to plant, harvest, irrigate, and dry crops. Distillate fuel (*e.g.,* gasoline, diesel) is the dominant fuel for direct energy consumption for both livestock and crop operations. Distillate fuel is used for crop tilling, harvesting, weed control, and other operations that require heavy machinery. Although some farms have access to public water supplies, most farms pump water from wells and groundwater sources. Most pumping is done with electricity, but pumps in remote locations may use diesel or propane.

Food processing and **Packaging**: Food processing includes conversion of raw ingredients into the finished food products. Some foods may only be processed by washing or cleaning, which requires water prior to packaging and distribution (*e.g.,* fresh produce, fruits and vegetables). Other foods require more intensive processing prior to packaging and distribution, such as meats, and processed foods (already cooked or value added). Crop drying is a fuel-intensive activity, and the amount of fuel used varies by the type of crop and its moisture content. High-temperature dryers are powered by either electricity or propane. Electricity is an important source of energy services such as running refrigeration or blast freezing equipment, especially for meat, poultry, and seafood that requires butchery and storage. Many processed foods require cooking (*e.g.,* baking, boiling, steaming) and cannery or freezing / refrigeration in some instances. Electrical energy also is required to power packaging and sorting conveyors, provide lighting and climate control, and other aspects of commercial warehouses and processing facilities. Together, processing and packaging consumes the most energy of the Food and Agriculture Sector (next to household meal preparation).

Transportation: Distillate fuel is also used to transport food and agricultural products.

An overall important consideration of the Energy Sector is cybersecurity.[85,86] Since disruption of the Energy Sector will indirectly disrupt the Food and Agriculture Sector due to critical structure interdependence, this also indicates that cybersecurity of the Energy Sector should be a concern for the Food and Agriculture Sector.

The recent Colonial Pipeline Cyber Attack (May 2021) reduced fuel availability during the spring planting season on some U.S. east coast farms, so the timing of that event had the potential to disrupt crop yields due to the time offset from sowing, especially if it had a longer duration—Agriculture is a timely process and missing a planting season can have dramatic effect on yields, especially for crops. This should be anticipated as a “warning shot” and the U.S. should be better prepared for the next occurrence as this is likely not the last of such events. Timing for such events would be unfortunate if they target planting (*e.g.,* spring) or harvest (*e.g.,* fall) as these timeframes are the most sensitive for row crops (*i.e.,* timely planting optimizes yields and timely harvest prevents spoilage in the fields). Cross communication between Energy and Food and Agriculture Sectors in this regard should be considered critical.

Appendix 12: *Transportation of Food and Agricultural Products*

As a result of the development of centralized industrial agricultural operations, many foods are shipped considerable distances from production sites to final consumers. According to the USDA, food and agricultural products are by far the single largest user of freight services in the United States by tonnage, comprising 24% of freight services across all modes by tonnage and 27% of all ton-miles.[139] In 2018, 4.5 billion tons of agricultural products worth $3.1 trillion were moved across all transportation modes. Trucks account for 83% of agricultural freight movements by tonnage and 88% by market value. Trucks account for 56% of agricultural freight ton-miles, primarily due to the key role of rail and waterway modes for transporting grains over longer distances. Thus, there is considerable interdependency between the Transportation Systems Sector and the Food and Agriculture Sectors.

From a policy perspective, there is a need for:[140]

-Proactive development of strategies to deal with employee absenteeism and other potential threats to the supply chain.

-Continued supply chain monitoring and industry engagement.

-Assessment and provision of additional public resources for greater access to pickup and delivery grocery services, including review of cyber threats to such economic activities.

Appendix 13: *Threats to Precision Agriculture* (as excerpted from the 2018 / AEP TFAR)

> *"Threats to Food & Animal Feed Processing and Manufacturing: This research did not examine threats to facilities and companies engaged in the processing and manufacturing of foods or animal feed. This area is likely susceptible to many of the same threats as precision agriculture in addition to threats more commonly seen in the critical manufacturing sector. This includes a lack of proper supply chain management for livestock feed products to ensure they are from approved sources. If computer systems are tracking these ingredients and system failures occur, feed ingredients from countries with high threat foreign animal diseases could be a potential risk for disease agents in contaminated feed and infect U.S. livestock. As with precision agriculture, these threats are only likely to increase as adoption of technologies and trade increases.*
>
> *• Impact of US Not Adopting Precision Agriculture: Countries including Brazil, Australia, European Union and China are quickly adopting precision agriculture technologies. US agriculture failing to adopt these technologies at similar rates could diminish the US role in the global agriculture market.*
>
> *• Cybersecurity of Commodities and Insurance Markets: Several of the key threats identified in this research concerned attempted market manipulation by threat actors. This research examined that threat from the side of the data producers, but data security of the markets themselves warrants further examination.*
>
> *• Threat Introduced by Limited Number of Precision Agriculture Technology Providers: Competition in certain aspects of the precision agriculture technology industry is low. This leaves farmers beholden to a few companies, regardless of their security practices. This is especially evident in UAS used in precision agriculture as most companies developing UAS for precision agriculture are Chinese firms."*[77]

Appendix 14: *Threats and Concerns from Food and Agriculture Sector Meeting* (November 2019)

Sector Threats and Concerns

Council members identified current and future threats to the sector including:

- ASF and other disease outbreaks, such as foot and mouth disease, remain a continuous a threat. The public and private sector should incentivize protection plans for livestock;
- Protecting intellectual properties;
- Mitigating unreliable information being presented to the public;
- Increasing use of aerial surveillance;
- Securing the U.S. bio-economy;
- Advisories accessing and collecting data;
- Climate change affecting crop yields;
- Insider threats and activities affecting agricultural products remotely with potential to trigger widespread panic;
- Lacking research on anti-microbial resistance, to emerging pest and diseases;
- Current laws are generally vague in their provisions for animals moving through both ends of the supply chain increasing potential for spread of disease;
- Lack of animal traceability and inadequate data management;
- Agroterrorism and potential use of emergent contaminants to spread panic and create disruptions of the supply chain;
- Lacking an updated national unified response to agricultural incidents;
- No standardized regulation for reimbursing crop and animal agricultural industries after an incident;
- Sharing classified information with the private industry; and
- Intentional adulteration and cooption of food manufacturing by adversarial actors.

Appendix 15: Global Food and Agriculture System Based Research Entities:

Several examples are provided below for opportunities where the U.S. government could interface within a global setting to help to afford line of sight clarity and information sharing pathways to augment intelligence pursuits that already exist in the spirit of protecting the food supply of the United States:

1.) Exploring opportunities within the ***Five Eyes Intelligence Oversight and Review Council*** (FIORC, "5 eyes" - including Australia, Canada, New Zealand) based network of intelligence and information sharing, could help to identify, address and mitigate potential threats to the global food supply and increase transparency and communication amongst collaborating countries.

2.) As shared in the final report from the most recent investigation from ***Operation OpSon IX***, 77 countries, including the U.S. [Food and Drug Administration], participated in this effort. "Operation Opson – which means 'food' in ancient Greek – is an annual law enforcement operation that aims to remove counterfeit and substandard food and drinks from the market and dismantle the organized crime groups involved."

    "In the light of the recent global health crisis, countries need to re-evaluate their approach in tackling the security of the food supply chain by looking into new strategies, increased controls, safer procedures, and preventative measures, while ensuring better protection for law enforcement personnel."[142]

3.) Similarly, there stands opportunity for the USG to realize collaborations to strengthen and bolster information sources as defined within the ***Global Alliance***[143]: The law enforcement community for the U.S. government has the opportunity to engage with global stakeholders in this endeavor that was established following the "horsemeat scandal" that ravaged the U.K. in 2013.[144]

Appendix 16: *Food and Agriculture* Centers of Excellence (COE)

Academic institutions, including those which maintain emeritus status or are currently funded by DHS Science and Technology (S&T) Office of University Program (OUP), as part of their Centers of Excellence (COE) initiative have significant homeland security science, research and development (R&D) technology, engineering, and mathematics capabilities, in addition to the food / ag / bio- subject matter expertise, and extensive applicable stakeholder networks.

Food and Agriculture Emeritus and Current COEs:

University of Minnesota's (FPDI) Food Protection and Defense Institute (Emeritus)

Kansas State (CEZAD) Center for Emerging Zoonotic Animal Diseases (Emeritus)

Texas A&M's (IIAD) Institute for Infectious Animal Diseases (Emeritus)

Texas A&M's (CBTS) Cross-Border Threat Screening and Supply Chain Defense (Current)

University of Illinois's (CIRI) Critical Infrastructure Resilience Institute (Current – not food and agriculture-focused, but has done some work in the area)

Rutgers (CCICADA) Command, Control, and Interoperability Center for Advanced Data Analysis (Emeritus)

Other Food and Agriculture Academic Centers:

Auburn University's Food Systems Institute

Kansas State University National Agricultural Biosecurity Center

University of Missouri's Food and Agricultural Research Policy Institute

Iowa State's Center for Food Security and Public Health

University of Nebraska's Institute of Agriculture and Natural Resources

Appendix 17: Recommendations to Improve Research Coordination (ASIPU)

Applied Solutions & Integration Promoting Understanding (Project ASIPU) within the Food and Agriculture Sector could be used to aid in the development of a coordinated research agenda by:

Contributing to the establishment of an annual (or biannual) conference. Project ASIPU research conference could be separate and aside from the Food and Agriculture Sector regular meetings. The outcomes of this AEP project could help focus the intent of the ASIPU research conference and aid in identifying a strategy to coordinate this activity.

Re-establishment of the Joint Committee on Research (JCR) within the Food and Agriculture Sector could help to increase visibility and aid in performing gap analysis while contributing to strategic planning moving forward.

1.) Prioritization of research needs:
    a. The ASIPU project could help to enable "future" research as described elsewhere in this document, where there is a need for disclosure / awareness of research gaps; provided that the JCR is aligned with the objectives, in partnership with government as well as academic stakeholders, there could be "examples" that are identified that can be used to demonstrate the vulnerability of the system due to its efficiency.
    b. Identify sole-sourced / single source suppliers:
        i. *e.g.,* commercially manufactured hard-boiled eggs and the *Listeria* outbreak 2020 / shortages due to one national manufacturer that was the primary supplier[145]
        ii. *e.g.,* vitamins / pre-treatment chemical production
2.) In partnership with other Sector stakeholders, private sector owners, and operators, academia, national laboratories, U.S. government, non-government organizations, the establishment of a coordinated national research plan for the next 5 years (*a new goal within the 2020 FAS Sector Specific Plan*) could help to:
        i. Aid with the development of the FSMA Section 108 National Agriculture and Food Defense Strategy;
        ii. To drive the need for a risk-based inspection program
        iii. To identify high risk food processing environments:
            1. *e.g.,* see the case of the *Peanut Corporation of America*
3.) The research strategy requires a communication pathway to ensure that the industry is aware of the outcomes or the status of the research being performed.[87]
            1. *For example, an Information Sharing and Analysis Center* (ISAC) where the industry would freely "exchange" insights on, among other items, research being performed
            2. Threats that have been identified within supply chains;

3. Forecasting or horizon scanning of threats that might not yet be visible to all stakeholders within the Sector

4.) Re-establishment of a *Food and Agriculture based Center of Excellence*
The former Center of Excellence at the University of Minnesota's Food Protection and Defense Institute (formerly known as the National Center for Food Protection and Defense) - among other activities – helped to serve as a non-attributable, centralized organization that would serve as a third party, with non-attributable data synthesis and analysis and information sharing for the private sector.

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One of the efforts that the NCFPD coordinated was the Food Defense Research Database – a centralized means of exploring and identifying what research has been completed or was in process; this effort contributed to situational awareness across the Food and Ag Sector. Other activities included criticality illumination within the Sector (FAS-CAT); Horizon scanning, anomaly deviation and tracking (CRISTAL).

While these recommendations could seem to be far-fetched, these are exactly the types of aspirational concepts and ideas that could help to drive next level thinking and the foster the development of collaboration opportunities, foster the creation of risk-reducing tools, resources and methods to protect the Food and Agriculture Sector critical infrastructure and ultimately the stability of the food supply of the United States.

Appendix 18: *Critical Inputs for U.S. Food Supply Chains*

In mid-2021, the owners and operators of the food and agriculture system's private sector, via several trade associations which have been engaging in high-level conversations with senior officials within the U.S. government, was tasked with identifying and asked to "submit" the top 20 – 30 inputs and ingredients in the food supply chain that are so critical that sustaining the food supply chain would be difficult if these inputs and ingredients were disrupted or otherwise not available. These are key resources to the Food and Agriculture Sector. Recognizing this, in the wake of the supply chain Executive Order, the Administration is aware of the challenges facing these strained inputs and ingredients to the food supply chain for the U.S. and wants to ensure the stability of the same: and this begins with the correct understanding of what needs to be protected, preserved and enhanced. So, there is a need for industry input on what is most critical — inputs, ingredients, tools of the trade, processing requirements, etc. – in order to protect the stability of the food supply chain.

The problem is that this list of inputs and ingredients does not exist. At least, not to the knowledge of those leaders within industry groups and trade associations driving supply chain resilience looking for this information. Outside of anti-trust "protected" meetings amongst members of various trade associations, the disparate and uncoordinated key resources that drive, sustain, and otherwise keep the food supply chain moving is currently invisible.

Within the last decade's worth of jointly coordinated [Government Coordinating Council (GCC) and Sector Coordinating Council (SCC)] Food and Agriculture Sector meetings, the participation of the private sector has waned to less than 10% of the once by invitation-only events that were filled with executives seeking to ensure that the food supply would not be disrupted via acts of terrorism or naturally occurring events that could devastate a segment, component, node of the food supply.

The challenge at present: how to increase interest and participation in these joint Food and Agriculture Sector meetings by representatives of the private sector to be able to engage in risk-based conversation with leading government officials and experts within academia to be able to discuss critical matters: What are the top 20-30 inputs and ingredients to the domestic food supply chain? By taking a proxy from what's happened to the automotive industry in 2021, and given the projections of the shortages of micro-chips into 2022 and beyond, what are the equivalent "micro-chips" of the Food and Agriculture Sector?[146]

What is critical to one firm might not even be on the radar of another firm. This is an example of a knowledge gap that a coordinated research agenda can help solve (or at least begin to take steps towards solving) or minimally, help address the information-sharing gap within the Food and Agriculture Sector. But, these conversations have to happen and have the right participants in the room for information to be exchanged, ideas to be considered, and relationships to be developed to protect, secure, and otherwise ensure the resilience of the food supply chain of the United States.