Food Research

Call to Action on Funding and Priorities

feeding the minds
that feed the world

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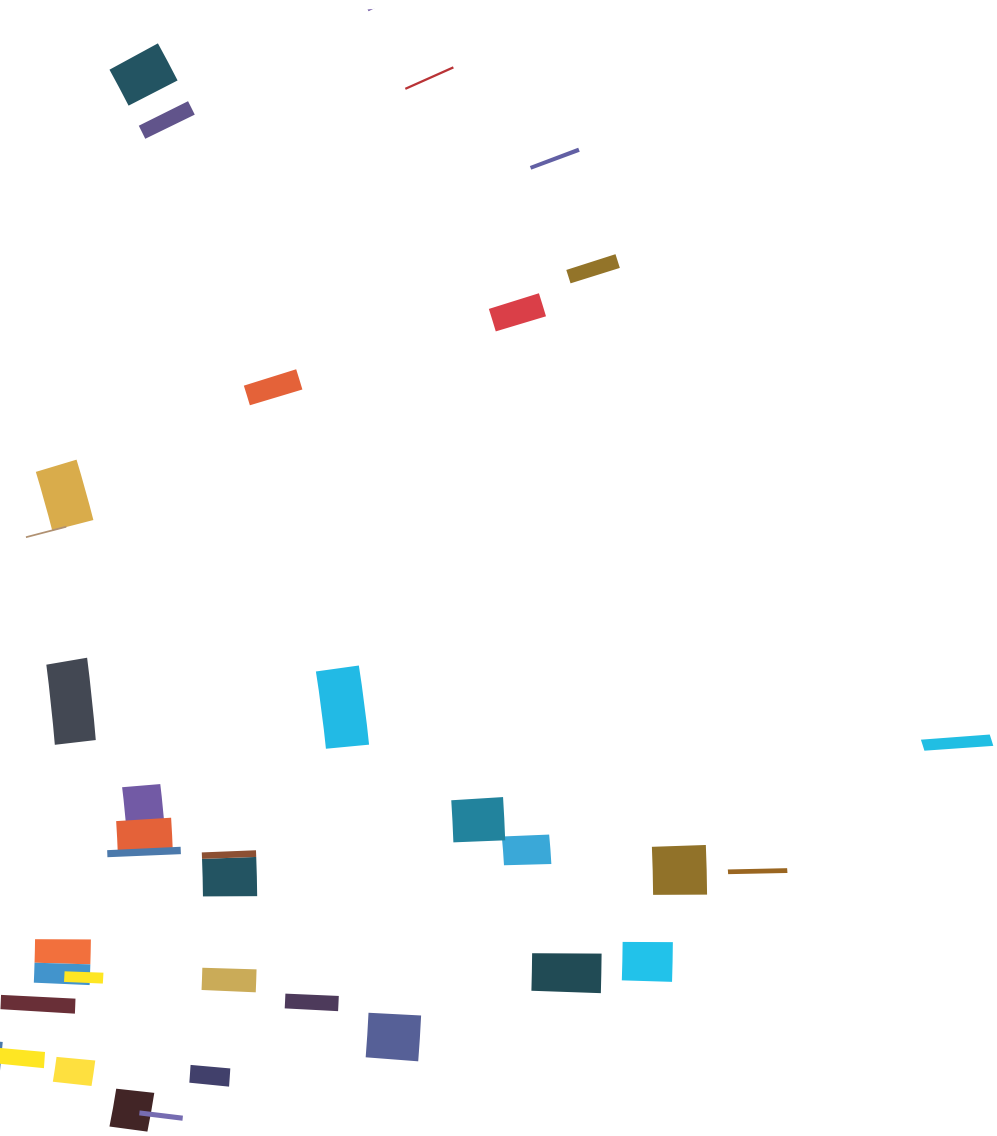

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Glossary

- **AgriFood**—Agriculture and Food
  - Agriculture—Farming, livestock, crops, harvesting, storage, transportation, distribution
  - Food—Processing, manufacturing, distribution, retail, food service, and delivery of food and beverage products
- **Combined gross domestic product**—Direct and Indirect contributions to gross domestic product (GDP)
  - Direct—Direct contribution includes the number of jobs in food– and agriculture–related industries; the wages paid to employees; the value added; and total output, for example
  - Indirect—Indirect contribution includes the economic impact of the suppliers that support the food and agriculture industries
- **Food Science**—The discipline of food science and technology which integrates basic and applied sciences including biology, biotechnology, cell biology, chemistry, computer science, data informatics, engineering, genomics, materials science, microbiology, nutrition, packaging, physics, sensory science, toxicology, etc.
- **Research**—Basic, fundamental, translational, applied

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I Executive Summary

Following years of stagnant public funding, Food Science research faces mounting and urgent challenges. During this time, private funding increased, but it has not been a direct substitute due to shorter-term focus. Our food system faces generational disruption and complexity driven by socio-economic, environmental, and market forces. AgriFood and the environment are inextricably linked with production and supply of food for a growing global population. ***This white paper explains the disproportion of funding for Food research relative to its economic contribution as well as the rationale for funding increase.***

Contributions to the Economy: After healthcare and housing, AgriFood is the third-largest Direct contributor to the U.S. gross domestic product (GDP). In 2018, U.S. AgriFood contributed $5.08 trillion (T) (24.8%) of Combined GDP, accounted for 22.8 million (M) jobs (14.2%), with Food contributing 20.7 M, and it delivered $137 billion (B) (5.4%) in exports and $146.5 B (4.7%) in imports. Food is a net exporter, while Agriculture is a net importer.

State of Research Funding: Considering the scale of the contribution of U.S. AgriFood to the national economy, the investment in AgriFood Research & Development (R&D)—both public (federal) and private has been low. In 2018, private investment (including venture capital) in AgriFood was $21.6 B, of which Food accounted for $9.9 B, which was higher than public investment at $0.1 B in Food and $0.9 B in Agriculture. As a percentage of GDP, public investment in 2018 in AgriFood R&D (4.2%) and Food R&D (1%) were lower than for pharmaceutical (4.9%).

Research Priorities in Food Science: An Institute of Food Technologists (IFT) 2019 survey of members found three priority areas for increased funding:

1. Public Health: to improve the nutritional quality, palatability, and accessibility of food.
2. Food Safety and Quality: to protect integrity of globalized food chains and digitize food safety and traceability to prevent, manage, and rapidly address critical issues.
3. Food Security and Sustainability: to increase the quantity and quality of food available, drawing on technology breakthroughs, while reducing food loss and waste.

Continued underfunding will likely risk public health, food safety, food security, and erode the U.S. talent pipeline and global competitiveness.

Call to Action:

Policymakers must recognize and address the significant risk associated with chronically underfunded research in Food. This is a call to action for a paradigm shift to drive innovation and value creation, feed the talent pipeline, and maintain global competitiveness. We have identified the need for:

- Increasing and prioritizing USDA's funding for AgriFood research, with a primary focus on Food
- Authorizing additional federal agencies to fund interdisciplinary research in Food
- Enhancing public-private partnerships for AgriFood research, with a focus on research in Food

II Introduction

In 2020, our food system is facing serious global challenges and experiencing transformative changes. Several factors are disrupting market forces and adding new dimensions to the food sector. Population growth increases demands on global food and trade. Consumer needs and changing dietary patterns add increasing variability to the food economy. Food regulations and protection policies are imbalanced. Climatic and environmental changes rise in step with geopolitical tensions. While economic and political factors remain uncertain, science and technology continue to advance. The food industry is also undergoing structural changes affecting the established business models of innovation in the consumer packaged goods (CPG) sector and business-to-business (B2B) and business-to-consumer (B2C) channels. Furthermore, consumers and policy decision-makers are demanding a greater emphasis on health and wellness due to the association of chronic diseases and illnesses with diet and lifestyle (KPMG, 2018).

The challenge of ensuring safe and nutritious food calls for achieving greater efficiencies across the entire food system. Supporting efforts for viable solutions will come from three main strategies: innovation, research, and social awareness. The first will include an increase in food production using innovative technologies, protecting natural resources and environments, and reducing food loss, contamination, and waste. Correspondingly, research into identifying optimum dietary patterns for maintaining health across the lifespan will continue. Finally, increasing consumer awareness about food and nutrition and increasing access and affordability to safe and nutritious food products by underserved populations are essential. Our food system has evolved over the centuries along with society into a global network of immense size and complexity. As noted by Professor Emeritus at Purdue University and World Food Prize Laureate Philip E. Nelson, committed food scientists and technologists in a profession at the crossroads of scientific and technological developments have been integral to this evolution (Floros et al., 2010). Success in the modern food system is allowed with the integration of many disciplines, including biology, chemistry, physics, engineering, materials science, microbiology, nutrition, toxicology, biotechnology, genomics, computer science, and many other disciplines, to solve difficult problems (Floros et al., 2010). Sufficient public investment in interdisciplinary research and technological advancement in the food system will be essential to effectively address the current challenges we face.

Several scientific groups have described current U.S. food and agriculture challenges and identified opportunities to address them relative to specific government agency priorities or the potential contributions of particular disciplines (National Academies of Sciences Engineering and Medicine [NASEM], 2018).

This white paper presents (1) the contributions of AgriFood and Food to the U.S. economy, (2) the state of funding for research in AgriFood and Food, specifically for Food Science, and (3) the findings of IFT's member survey related to research gaps, impact of insufficient funding, and current sources of public funding in Food Science, and (4) the case for increasing federal funding and public-private partnerships for research in AgriFood and Food.

A paradigm shift is needed to drive innovation to address the challenges across the food system, feed the talent pipeline, and maintain global competitiveness. IFT's call to action is for:

- Increasing and prioritizing USDA's funding for AgriFood research, with a primary focus on Food
- Authorizing additional federal agencies to fund interdisciplinary research in Food
- Enhancing public-private partnerships for AgriFood research, with a focus on research in Food

III Current Food System Challenges

The world population is currently 7.7 B. The population is expected to grow to 8.5 B by 2030 (10% increase). Projecting further, the population will increase to 9.7 B (26% increase) by 2050 and 10.9 B (42% increase) by 2100 (United Nations Department of Economic and Social Affairs, 2019). This population growth will require at least 60% more food compared to 2006 (Food and Agriculture Organization of the United Nations [FAO], 2016). The FAO estimates that 1.3 B tons of food are wasted or lost each year in both developed and developing countries (FAO, 2011). In developed countries, food loss is generally low in the early to middle stages of the supply chain, but there is substantial waste at the retail and consumption stages. The opposite tends to be true in developing countries due to poor infrastructure from farm to market. Interestingly, food loss and waste are roughly U.S. $680 B in industrialized countries and U.S. $310 B in developing countries (FAO, 2020).

Malnutrition: Malnutrition results from insufficient or unbalanced consumption of nutrients essential for health and leads to staggering health-care costs (FAO, 2019). Throughout the world, malnutrition occurs in three forms simultaneously. These include undernutrition (insufficient food), micronutrient deficiency (insufficiency of nutrients in the diet), and overnutrition (excess calories in the diet). Public health crises are associated with the quality and quantity of the food supply. Malnutrition ranging from intermittent food insecurity to prolonged starvation affects billions of people worldwide. Famines related to natural disasters, political disputes, and wars are frequent. According to the FAO, 820 M people were hungry in 2018 across the globe. The FAO estimated that more than 2 B people (including people suffering from hunger and those affected by moderate levels of food insecurity) do not have access to sufficient, safe, and nutritious food. Of the 2 B, 8% reside in North America and Europe (FAO, 2019). Although the economy in the United States is strong, the United States Department of Agriculture (USDA) estimated that as of 2017, 40 M people, including 12 M children, were food insecure (Feeding America, 2019). A growing population will exacerbate hunger and food insecurity. Although micronutrient deficiency is declining globally, it remains prevalent in the developing world (Foundation for Food and Agriculture Research [FFAR], 2019).

Overweight and obesity continue to increase in all regions of the world, particularly among school-age children and adults. Globally, an estimated 40 M children < 5 years of age were overweight in 2018. In 2016, 131 M children 5–9 years of age, 207 M adolescents, and 2 B adults were overweight. In the United States, in 2015 and 2016, the prevalence of obesity was 18.5% in children and adolescents and 39.8% in adults (FAO, 2019). Obesity increases the risk of heart disease, stroke, type II diabetes, and some types of cancer, which are the leading causes of preventable premature deaths. The estimated annual medical cost associated with obesity was $147 B in 2008. According to the Centers for Disease Control and Prevention (CDC), chronic diseases such as heart disease, cancer, and diabetes are the leading causes of death and disability, accounting for $3.3 T in health care costs (CDC, 2019a, 2019b).

Domestically and globally, nutrition science and consumer food preferences continue to evolve. Increasingly, consumers are concerned about the impact of food choices on their health and the environment. Additionally, consumers expect food products in the marketplace to address their values related to sustainability, animal welfare, and the treatment of labor forces (NASEM, 2018).

Environment: Food system challenges are compounded further by environment and climate change issues. More frequent extreme weather events such as floods, droughts, wildfires, and hurricanes have devastating effects on food production. Additionally, natural resources such as land, water, and fertile soil are diminishing worldwide, thus limiting the ability to improve food and agriculture productivity with current production methods (NASEM, 2018).

From the 1960s through 2000, a combination of scientific and technological breakthroughs, business investment in innovation and delivery systems, and government policy and institutional interventions met the demand for abundant and affordable food (Cole, Augustin, Robertson, & Manners, 2018). During this time, the quest for

convenient consumer-packaged foods led to a 20-fold growth of plastic packaging materials, due to its versatility and cost-effectiveness. The capacity to recycle or reuse these packaging materials has been insufficient, however, with only 14% of packaging materials being recyclable. The overwhelming amount of plastic packaging materials in landfills, rivers, and oceans has led to negative environmental consequences and highlight the drawbacks of using plastics in the current food system and value chains (World Economic Forum [WEF], 2018).

Consumer: In the United States, there has been a noticeable and growing disparity of income and access to food. Affluent consumers place value on attributes such as organically produced food with short and "clean" ingredient lines for perceived health and wellness outcomes. In contrast, lower socio-economic consumers experience persistent food insecurity and limited access to affordable, nutritious food, with detrimental effects on health and wellness.

As the world population continues to increase, the rise in global food demand will drive the dependence on global food trade from 17% today to 50% by 2050 (High Level Panel of Experts [HLPE], 2017). Megatrends, such as diminishing natural resources, development of megacities, evolving consumer lifestyles, shifting dietary patterns, and smarter food chains (e.g., use of sensors) will be challenged by population growth during the next 30 years (Cole et al., 2018). To feed the global population and increase food security, we will need to increase the production of safe and affordable foods. At the same time, the food produced must be of high quality and nutritional value, with lower environmental impact. Production practices must also be changed to dramatically reduce food loss.

These global trends will have a significant impact on the preparedness of the entire food system for the next 20–30 years, both in future-proofing the industry and dramatically evolving its operations to shape the future. Key drivers are scientific and technological advances, new business models, and regulatory frameworks. Food CPG incumbents, with rich legacies that shaped global consumption during the past 100+ years, are seeking new approaches to meet consumer demands. Since the 2008 recession, CPG performance has diverged from the S&P 500 by 72%. Innovation models—startups, incubators, and accelerators—in conjunction with corporate venture funds and strategic mergers and acquisitions are disrupting the industry and building new scaled infrastructure (Kapacinskas, 2019). Venture capital comprised more than 25% of private R&D expenditure in the U.S. food industry in 2018 (Olson, 2018; Watrous, 2018). At the same time, new partnership models are emerging from technology intellectual property and R&D, to sourcing and market routes (Kapacinskas, 2019).

In the second half of the 20th century, a rise in food production matched exponential population growth. Today's challenges require similar outcomes. Solutions require a collaborative approach and investment by government, industry, and academia.

Foundational to this are:

- A total food system approach with sustained investments in research in Agriculture, Food, nutrition, and technology
- Interdisciplinary research and transdisciplinary teams, without historical silos
- Robust standards and regulatory convergence across jurisdictions

Cutting-edge research in Food Science is a prerequisite to the multitude of necessary solutions for the challenges faced among nations and within the global food system (Foegeding & Sathe, 2015). ***Sustained funding for research and education and training is necessary for a safe, affordable, high quality, nutritious, and environmentally sustainable food supply.***

IV Economic Contributions of Food

A. Contribution of Food to the U.S. GDP[1]

The AgriFood sector contributes both Direct and Indirect impacts on the economy. Take a moment to consider how wheat is transformed from the farm to the consumer. The value of wheat increases at every step as it moves along the entire food supply chain. Initially, wheat moves from the farm to storage, and then is transported to a processing facility and converted to wheat flour. Next, the flour is incorporated into the production of foods such as bakery products for retail or food service consumption and related packaging. These wheat-containing foods are then distributed and finally consumed either at home or in a food service setting (Figure 1). Direct impacts come from the value addition of crop, food, or beverage as it moves through the supply chain. Indirect economic impact comes from the value added by the providers of materials (e.g., wheat seed and fertilizers), equipment (e.g., harvesting), transportation, storage, and labor to produce these materials, for example.

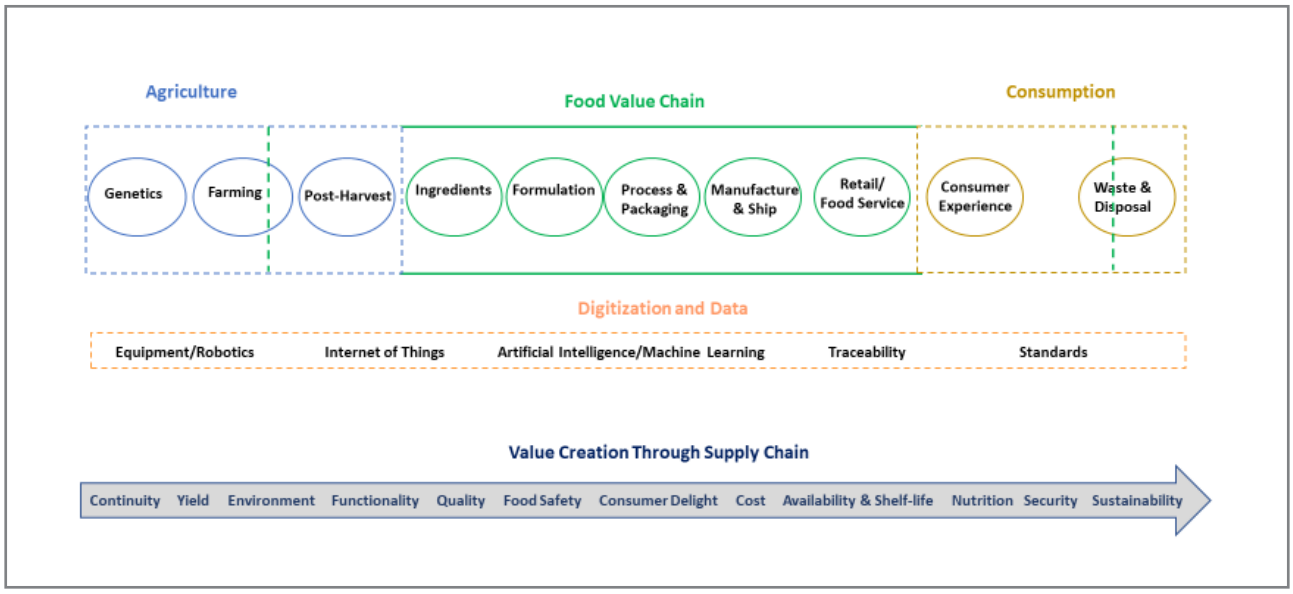


Figure 1: Food value chain supply and demand in the era of convergence

There are four core components of the AgriFood that contribute to the U.S. GDP. These include (1) agricultural raw materials, (2) processing and manufacturing industries, (3) retail food and beverage product sales, and (4) food service product sales (Figure 2).

[1] Gross domestic product (GDP) was used in place of NAICS Codes. NAICS codes do not align directly with Europe due to anomalies in the structure for capturing food and agriculture data and also include some non-Food subcomponents.

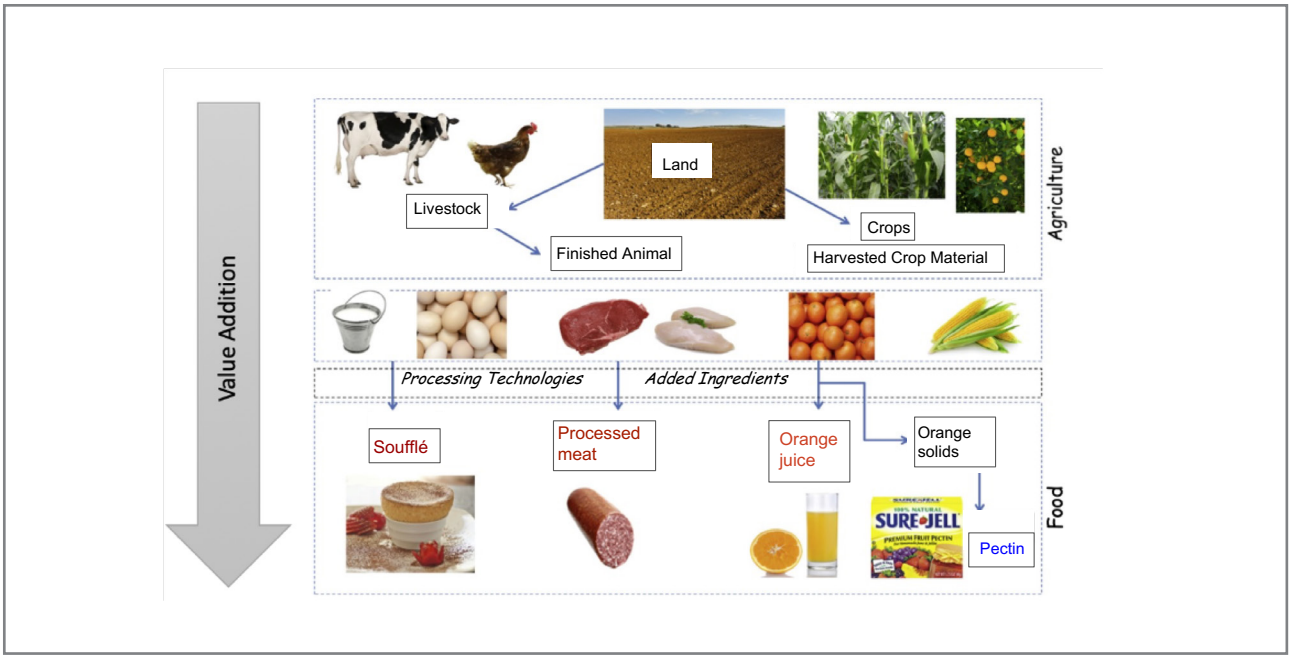


Figure 2: Value addition points in the food system

For Food, the economic contribution from processing and manufacturing industries is embedded within the economic value of retail and food service sales. In 2018, the estimated combined contributions to the U.S. economy from these four sub-sectors of the AgriFood sector was conservatively $5.08 T or 24.8% of GDP as shown in Figure 3 (Feeding the Economy, 2019; Schouten, 2018).

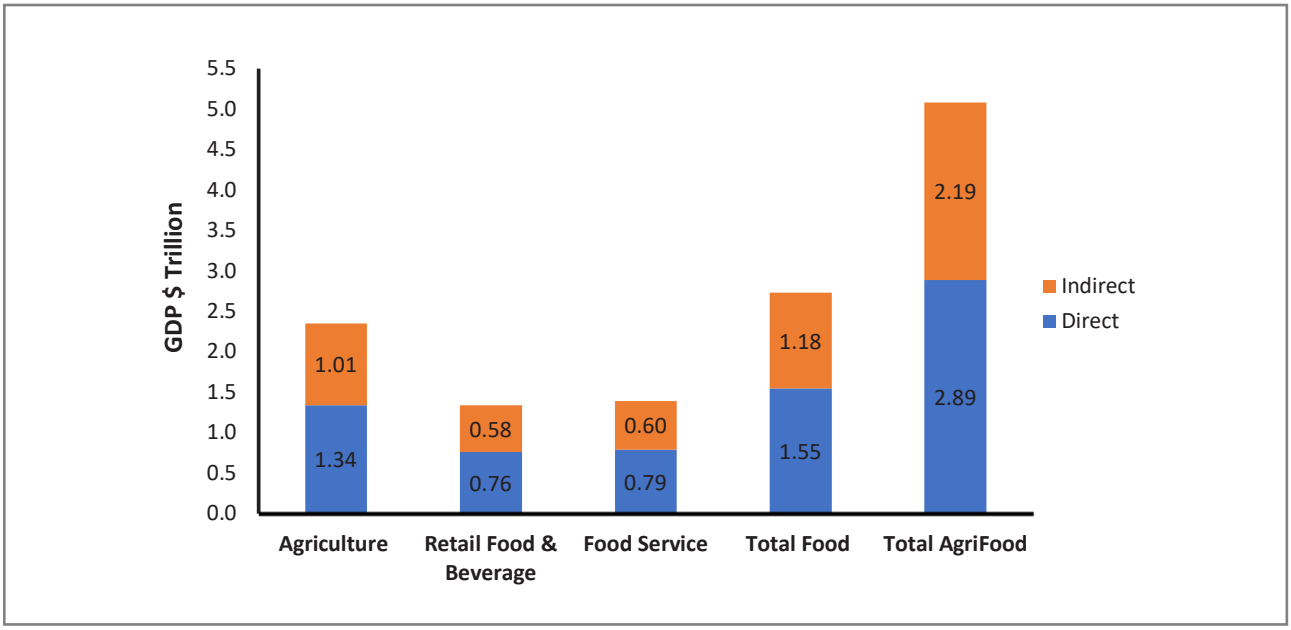


Figure 3: Contribution of AgriFood to the U.S. GDP in 2018 (Feeding the Economy, 2019; Schouten, 2018)

In 2018, contribution of AgriFood to Direct U.S. GDP was 14.1% (Agriculture 6.5% + Food 7.6%). Within AgriFood, the Food component itself was the third-largest contributor (Figure 4), at 7.6% of Direct GDP (Feeding the Economy, 2019; National Association of Home Builders [NAHB], 2019; Schouten, 2018; Statista, 2019a; Tradingeconomics, 2020a; USDA/Economic Research Service [ERS], 2019a).

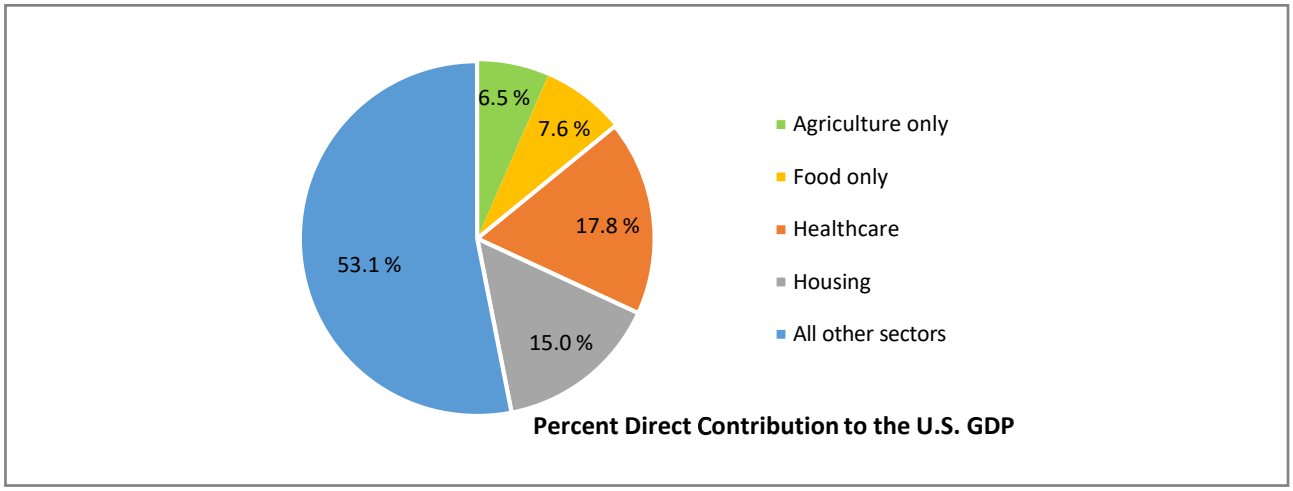


Figure 4: Percent Direct contribution by the largest sectors to the U.S. GDP in 2018 (Feeding the Economy, 2019; NAHB, 2019; Statista, 2019a; Schouten, 2018; Tradingeconomics, 2020a; USDA/ERS, 2019a)

Since the pharmaceutical sector is also a major contributor to U.S. health and longevity, evaluating its economic contribution, as well as the funding received against that of AgriFood offers a contextual framework. In comparison, the economic contribution of the pharmaceutical sector to the U.S. economy is less than the contributions from Agriculture and Food (Figure 5), demonstrating the importance of AgriFood to the U.S. GDP (Feeding the Economy, 2019; Peterson Center on Healthcare/Kaiser Family Foundation [Peterson-KFF], 2019; Schouten, 2018; Statista, 2019b).

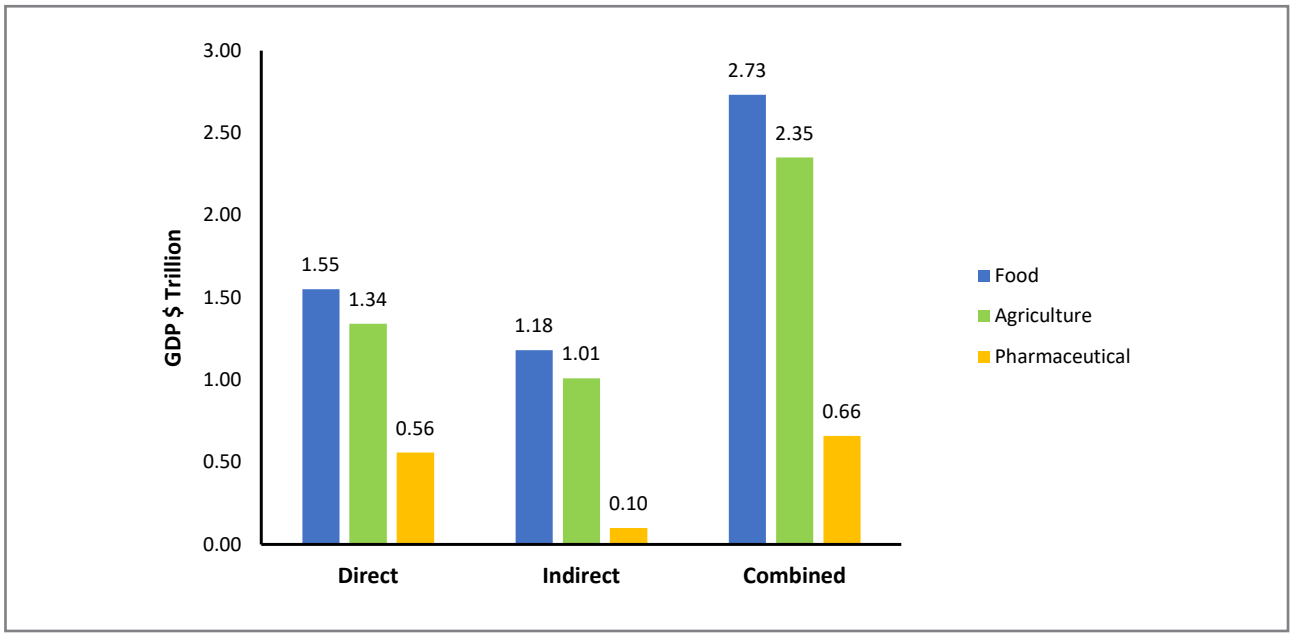


Figure 5: Comparison of the economic contributions of Agriculture, Food, and pharmaceutical sectors to the U.S. economy in 2018 (Feeding the Economy, 2019; Peterson-KFF, 2019; Schouten, 2018; Statista, 2019b)

Comparing the U.S. with a similarly developed economy, such as the European Union (EU), the respective AgriFood contributions to GDP are of similar absolute value. However, the economic value per capita is higher in the U.S. (Figure 6), because the U.S. population is 64% (328 M) of the EU population (511 M) (International Monetary Fund [IMF], 2019). The Eastern European countries drive the difference between the two economies within the EU. These countries have significant populations, but lower economic value contribution compared with Western Europe (European Commission [EC], 2019a, 2019b; Feeding the Economy, 2019; FoodDrink Europe, 2019; Schouten, 2018).

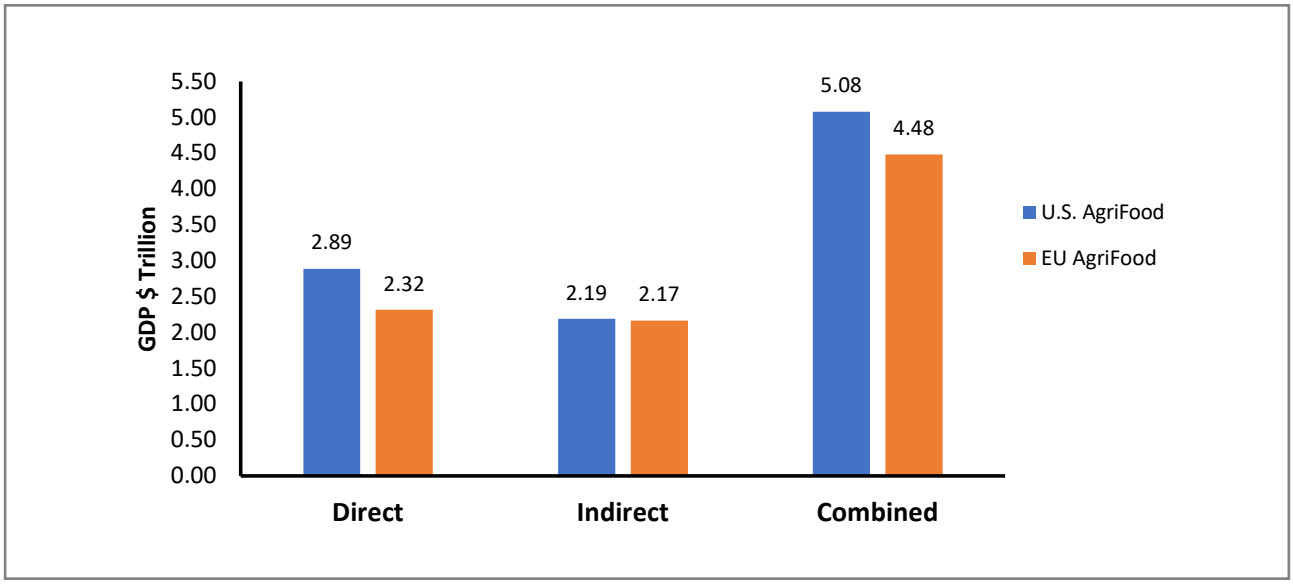


Figure 6: Impact of Food on the U.S. and EU economies in 2018 (EC, 2019a, 2019b; Feeding the Economy, 2019; FoodDrink Europe, 2019; Schouten, 2018)

In summary, AgriFood's Direct contribution to the U.S. GDP is 14.1%, with just over half the contribution from Food. Comparatively, AgriFood's Direct contribution is more than five times the size of the respective contribution of the Pharmaceutical sector. Further, in 2018, the estimated annual AgriFood contribution to federal, state, and local taxes (not including the state and local sales taxes or excise taxes that may apply for specific retail services) was more than $913 B (Feeding the Economy, 2019).

B. Contribution of Food to U.S. employment

In 2018, AgriFood contributed 14.2% (22.8 M jobs) of total U.S. employment, of which Food contributed the majority: 20.7 M at 12.9% of total U.S. employment (Table 1). Similarly, in the EU, the Food sector employed more people than the Agriculture sector. However, in the EU (Table 1), food service employed fewer people, 6.2 M (2.8%) compared with 11.9 M (7.4%) in the United States of the total employment (United States Department of Labor [DOL], 2019; EuroStat, 2019a; Feeding the Economy, 2019; FoodDrink Europe, 2019).

Table 1: Employment in Food in the United States and European Union in 2018 (DOL, 2019; EuroStat, 2019a; Feeding the Economy, 2019; FoodDrink Europe, 2019)

AgriFood sector	United States employment in million (% of total employment)	European Union employment in million (% of total employment)
Total employment	161.0 (100%)	223.8 (100%)
AgriFood*	22.8 (14.2%)	23.0 (10.3%)
Agriculture	2.1 (1.3%)	9.2 (4.1%)
*Food***	20.7 (12.9%)	13.8 (6.2%)
• Food service	11.9 (7.4%)	6.2 (2.8%)
• Food processing & retail	8.8 (5.5%)	7.6 (3.4%)
*AgriFood = Agriculture and Food **Food = Food service and food processing & retail		

In 2016, the U.S. food manufacturing sector employed more than 1.5 M people or 14% of all U.S. manufacturing employees. These employees were engaged in transforming raw agricultural materials into value-added products for intermediate or final consumption, directly contributing to the U.S. GDP (USDA/ERS, 2019a).

C. Contribution of Food to U.S. trade

Both Agriculture and Food contribute to U.S. trade (Table 2). The amount of total exports of U.S. AgriFood is lower than the total imported. In 2018, the U.S. AgriFood total exports were $137 B, at 5.4%, while the total imports were $146.5 B, at 4.7%. The difference is driven by higher Agriculture imports ($80.1 B, 2.6%) than exports ($64.4 B, 2.5%). In contrast, Food exports exceeded imports, as the value of the Food sector's exports was $72.6 B (2.8% of the total exports), and imports was $66.4 B (2.1% of the total imports). The value of EU AgriFood exports ($137 B, 5.9% of the total exports) was lower than the imports ($138 B, 5.9% of the total imports). However, the value of imports was marginally higher than that of exports, unlike the U.S. The trade data shows that both the United States and the European Union are less dependent on Food imports compared with Agriculture imports (Amadeo, 2019; EuroStat, 2019b; Statista, 2019c; Tradingeconomics, 2020b, 2020c).

Table 2: Contribution of Food to U.S. and EU trade (Amadeo, 2019; EuroStat, 2019b; Statista, 2019c; Tradingeconomics, 2020b, 2020c)

AgriFood sector	United States		European Union	
	Exports in $ billion (% of total exports)	Imports in $ billion (% of total imports)	Exports in $ billion (% of total exports)	Imports in $ billion (% of total imports)
Total	$2,550 (100%)	$3,100 (100%)	$2,308 (100%)	$2,336 (100%)
AgriFood	$137 (5.4%)	$146.5 (4.7%)	$137 (5.9%)	$138 (5.9%)
Agriculture	$64.4 (2.5%)	$80.1 (2.6%)	$ 58.9 (2.6%)	$93.8 (4.0%)
Food	$72.6 (2.8%)	$66.4 (2.1%)	$78.1 (3.4%)	$44.2 (1.9%)

AgriFood is an essential part of the U.S. economy. And, Food is a particularly significant contributor in terms of GDP, taxes, employment, and trade. ***Considering the economic benefits from the U.S. AgriFood sector, substantial research investment must be made by both public and private sectors to ensure long-term success and sustained economic contributions.***

V Research Funding in Food

Investment in R&D by public (federal) and private sectors is relatively low as a percentage of the economic contribution of U.S. Food. In 2018, the total Food R&D investment from public and private sources was approximately $10.0 B (Figure 7) compared to the Direct U.S. GDP of $1.55 T (Figure 5), resulting in an investment rate of 0.65% (Clancy, Fuglie, & Heisey, 2016; National Science Foundation [NSF], 2019; Schouten, 2018). Most of this investment was from industry and skewed toward *development*, thus leading to a minimal amount of funding for *basic to applied* research. In contrast, the 2018 Agricultural R&D investment from public and private sources was higher at $11.6 B or 0.86% of Direct GDP contribution, with public funding seven times higher compared with Food (Figure 7). The total U.S. AgriFood R&D was $21.6 B or 0.75% of the Direct GDP contribution. The spending for pharmaceutical (Table 3a) R&D was much higher, at 16.3% of the Direct GDP compared with AgriFood at 0.75% (American Association for the Advancement of Science [AAAS], 2019a; European Institute of Innovation and Technology [EIT], 2017; EIT Food, 2018; EuroStat, 2019c; Feeding the Economy, 2019; FoodDrink Europe, 2019; NSF, 2019; Schouten, 2018; Statista, 2019a; Tradingeconomics, 2020; USDA/ERS, 2019a, 2019b, 2019c).

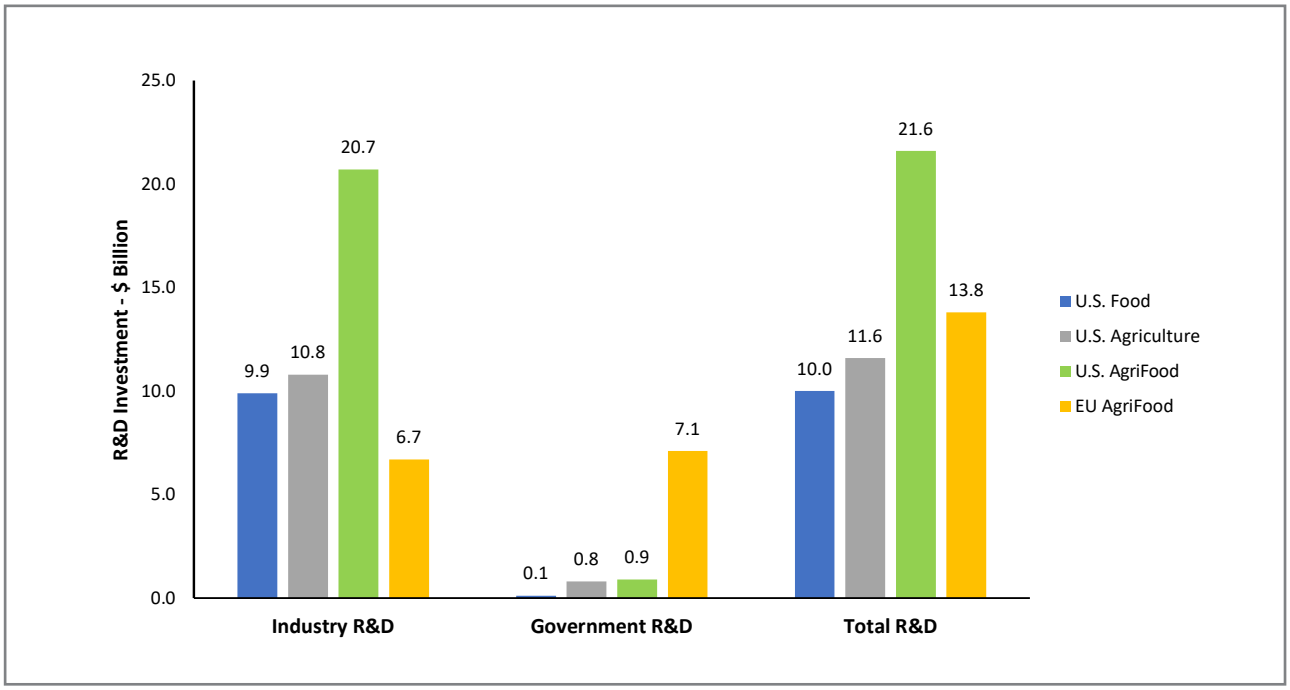


Figure 7: Public and private funding for R&D in AgriFood in the United States and European Union in 2018
(EIT, 2017; EIT Food, 2018; EuroStat, 2019c; FoodDrink Europe, 2019; NSF, 2019; USDA/ERS, 2019b, 2019c)

Table 3a: Comparison of the U.S. R&D spending in AgriFood with pharmaceutical as percentage of the Direct GDP and sources of R&D funding in 2018 (AAAS, 2019a; Feeding the Economy, 2019; EIT, 2017; EIT Food, 2018; NSF, 2019; Schouten, 2018; Statista, 2019a; Tradingeconomics, 2020a; USDA/ERS, 2019a)

Business sector	United States		
	Total R&D % of Direct GDP	Public R&D % of Total	Private R&D % of Total
AgriFood	0.75	4.2	95.8
Agriculture[*]	0.86	6.9	93.1
Food	0.65	1.0	99.0
Pharmaceutical	16.3	4.9	95.1
[*]Edible agriculture as opposed to non-edible agriculture			

In comparison, total 2018 EU funding for AgriFood was $13.8 B, approximately two-thirds that of the United States. However, public funding in the European Union for AgriFood, at $7.1 B, was higher than that of the United States, at $0.9 B, despite the smaller impact of AgriFood on the EU economy (0.59% of the GDP) (Figure 7 and Table 3b). More importantly, EU public R&D funding, at 51.4%, was a much greater contributor to AgriFood, than the U.S., at 4.2% (Table 3b) (AAAS, 2019a; EIT, 2017; EIT Food, 2018; EuroStat, 2019c; Feeding the Economy, 2019; FoodDrink Europe, 2019; NSF, 2019; Schouten, 2018; Statista, 2019a; Tradingeconomics, 2020a; USDA/ERS, 2019a).

Table 3b: Comparison of the U.S. and EU R&D spending in AgriFood as percentage of the Direct GDP and sources of R&D funding in 2018 (AAAS, 2019a; EIT, 2017; EIT Food, 2018; EuroStat, 2019c; Feeding the Economy, 2019; FoodDrink Europe, 2019; NSF, 2019; Schouten, 2018; Statista, 2019a; Tradingeconomics, 2020a; USDA/ERS 2019a)

Business sector	United States			European Union		
	Total R&D % of Direct GDP	Public R&D % of Total	Private R&D % of Total	Total R&D % of Direct GDP	Public R&D % of Total	Private R&D % of Total
AgriFood	0.75	4.2	95.8	0.59	51.4	48.6

A. Current public (federal) funding landscape in Food in the United States

Research in AgriFood is funded by a few U.S. federal agencies. The USDA is the major contributor for funding research in AgriFood, while the NSF, National Institutes of Health (NIH), and the Food and Drug Administration (FDA) allocate substantially smaller amounts, in total, by a factor of 4 to 5. The Farm Bill, which is renegotiated every five years, defines the amount of the USDA's funding for research in Food and Agriculture (Clancy, Fuglie, & Heisey, 2016).

The U.S. Congress Hatch Act of 1887 is a significant component of the USDA's research funding. Broadly, the Hatch Act supports research activities at land-grant universities for agriculture, including: crops, livestock, forestry, aquaculture, nutrition, home economics and family life, and rural community development. A substantial portion of AgriFood research supporting crops, livestock, and food production is sourced directly from Hatch funding (USDA/ National Institute of Food and Agriculture [NIFA], n.d.-a).

The USDA's research funding flows through three intramural research agencies and one extramural agency. The three intramural agencies are the Agricultural Research Service (ARS), Economic Research Service (ERS), and National Agricultural Statistics Service (NASS).

The USDA's extramural research agency, the National Institute of Food and Agriculture (NIFA), funds research through land-grant universities, state agricultural experiment stations, and other institutions at the state and local levels (Clancy, Fuglie, & Heisey, 2016). NIFA funds extramural competitive grants through the Agriculture and Food Research Initiative (AFRI) in support of the country's science and technology innovation to meet demands for safe, nutritious, convenient, and globally competitive food. In addition, NIFA takes part in training the next generation of the food and agriculture workforce. AFRI was established by Congress in the 2008 Farm Bill to advance science in food and agriculture. AFRI grants support research, education, and extension activities in six Farm Bill priority areas. The Farm Bill, however, does not mandate a defined amount for each priority area (NIFA/AFRI, n.d.-a).

Although the authorized funds awarded to AFRI have increased steadily (Figure 8), they are not sufficient to address either the range or complexity of the established Farm Bill priorities. This outpacing has resulted in insufficient support for all proposals/requests that are recommended for funding and rated as outstanding, high priority, and/or medium priority by agency review panels. For example, in 2016, AFRI received a total of 2,719 competitive grant applications, requesting approximately $1.9 B. Of these, only 664 applications were awarded totaling approximately $307 M, whereas an additional 757 proposals were recommended for funding by the review panels. If a further $682 M had been available, the latter could have been supported. With regard to Food Science and technology, in 2016, only 17 out of 93 applications related to food quality improvement were funded (NIFA/AFRI, n.d.-a, b).

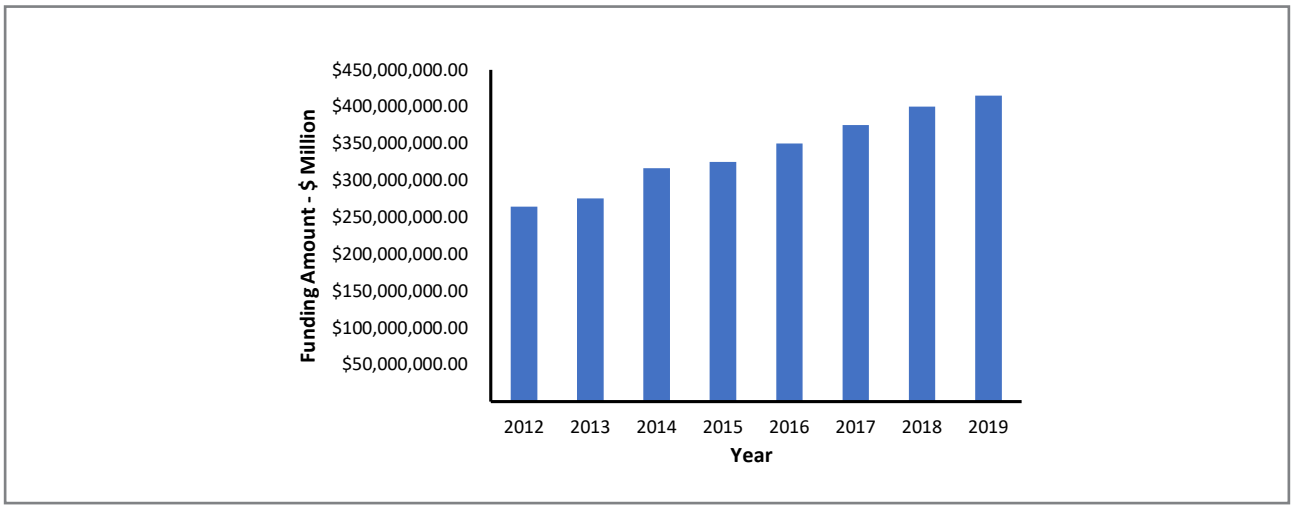
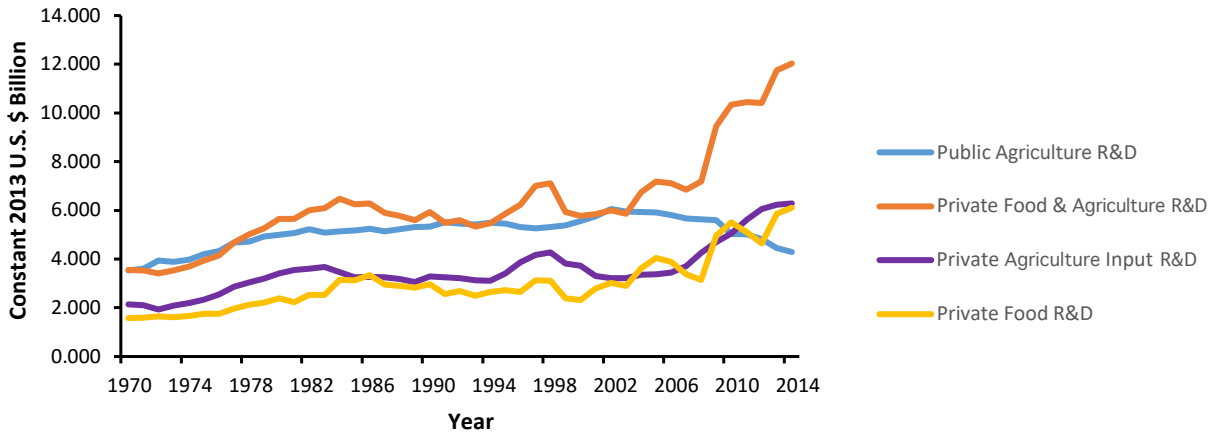


Figure 8: AFRI funding between 2012–2019 (NIFA/AFRI, n.d.-a, b)

B. Historical perspective on research funding in AgriFood

Historically, the U.S. federal government played a prominent role in producing new innovations and technologies for Agriculture. However, over time, agricultural input industries grew large enough to make considerable investments in R&D. Industry R&D is focused primarily on the *development* of commercially useful applications. The public sector is left as the primary source for much of the *basic to applied* research that creates the building blocks for major innovations in Food and Agriculture (Clancy, Fuglie, & Heisey, 2016).

In the past decade, the dominance of U.S. federal funding in support of AgriFood R&D has changed dramatically. Between 1970 and 2008 (Figure 9), the share of total AgriFood R&D conducted by the public sector remained at around 50%, yet by 2013 it dropped to under 30%. The decline in public R&D is attributed to decreased government spending as well as a rise in private R&D spending. Between 2008–2013, private sector R&D grew from $3.2 B to $5.7 B, a 56% increase. Even though the public and private R&D investments were quite similar from 1971 to the early 2000s, the public sector invested largely in agriculture R&D with little allocation to Food R&D. By contrast, the private sector funded both Agriculture and Food R&D nearly equally. However, in 2003, the two sectors began to diverge. From 2003–2013, private R&D investment in AgriFood increased steadily from $6.0 B to $11.8 B, while public Agriculture R&D fell from $6.0 B to around $4.5 B (Clancy, Fuglie, & Heisey, 2016).



Annual spending on research is adjusted for inflation by a research price index constructed by the Economic Research Service

Figure 9: Trends in public and private sector funding in Food and Agriculture (adapted from Clancy, Fuglie, & Heisey, 2016)

While the rise in private funding may offset the decline in federal funding, it is not a perfect substitute because the expenditures fall in different research areas. Economic studies have shown that an additional dollar spent by the public sector on Agriculture R&D stimulates an additional $0.70 in private R&D spending (Clancy, Fuglie, & Heisey, 2016).

The public and private sectors mostly invest in different areas of research. The private sector invests heavily in *development* within the USDA classifications of *food and feed manufacturing* and *farm machinery and engineering* leading to improved production processes and yield/profitability. Public R&D investments tend to drive outcomes in *environment and natural resources, human nutrition and food safety, economics, statistics, and policy, and social and community development* (Figure 10). Therefore, private funding is complementary and not a substitute for federally funded research in AgriFood (Clancy, Fuglie, & Heisey, 2016).

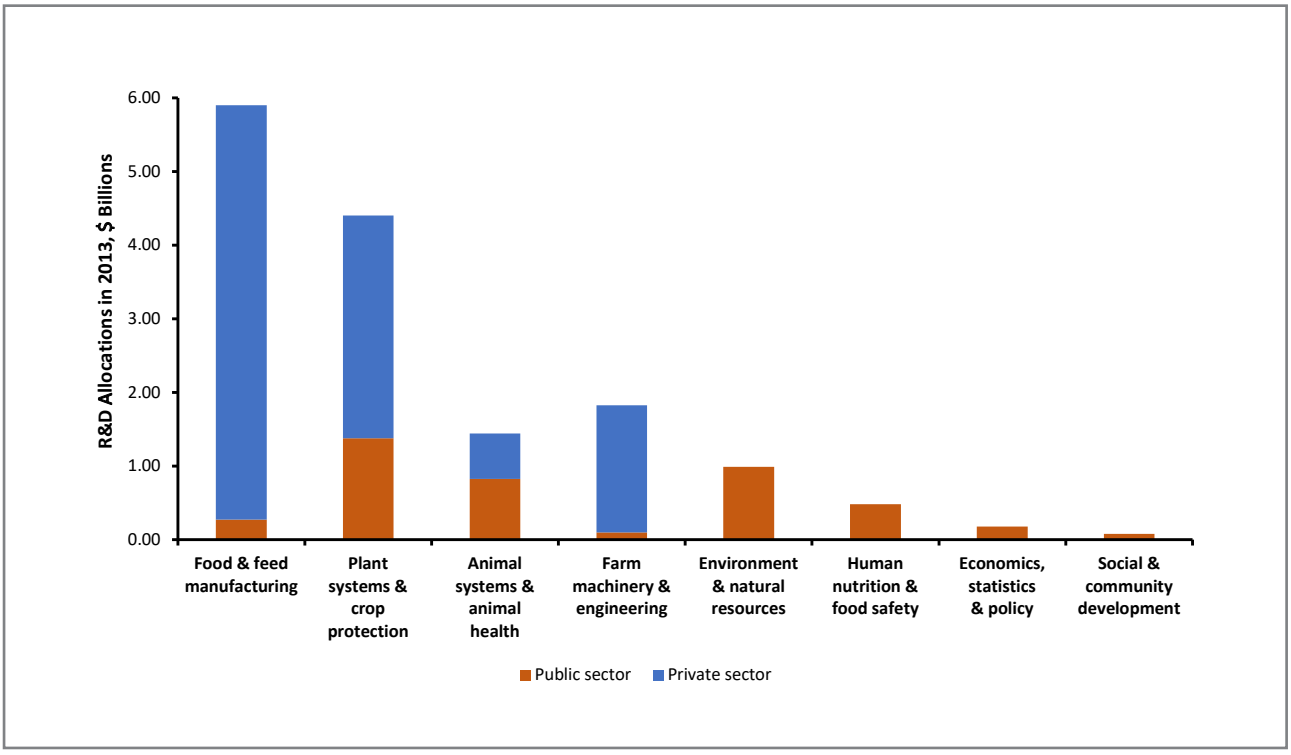


Figure 10: Public and private Food & Agriculture R&D allocations in 2013 (adapted from Clancy, Fuglie, & Heisey, 2016)

C. Comparison of federal funding for research across agencies

Academic research in AgriFood is dependent on federal funding defined by the Farm Bill. Fluctuations in federal funding priorities have a tremendous impact on the availability of funding for research. Funding for R&D in AgriFood has trended upward from private sources, while federal funding has declined (Figure 9). USDA's research budget is dramatically lower (Figure 11) as a percentage of the U.S. GDP than the budget for NIH and NSF (AAAS, 2019b).

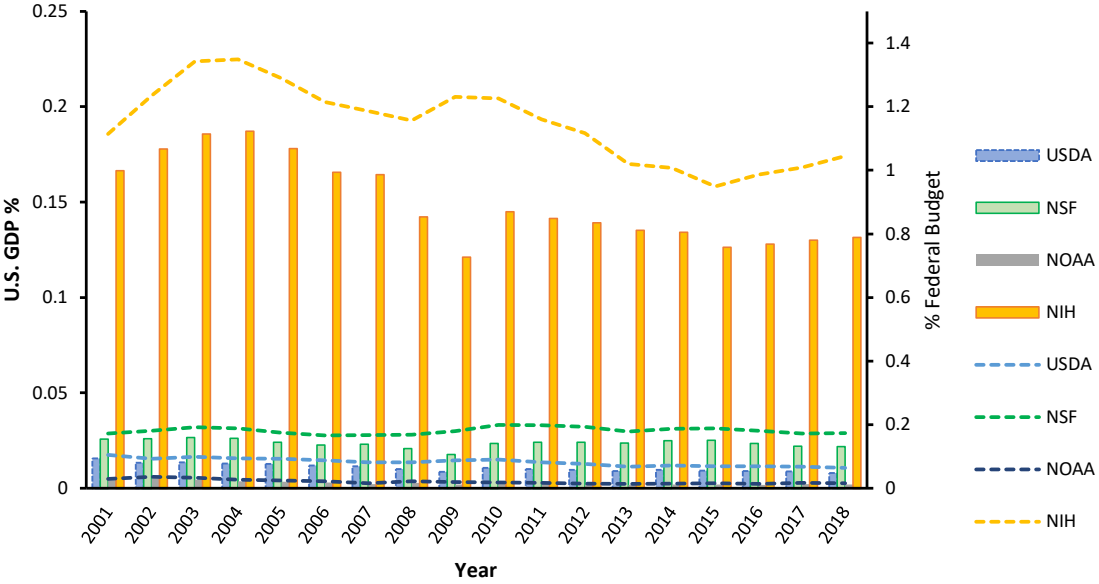


Figure 11: Federal R&D as a share of the U.S. budget and economy (adapted from AAAS, 2019b)j19

A detailed analysis of recent (2018) federal spending reveals large differences in overall R&D funding between USDA, NIH, National Aeronautics and Space Administration (NASA), and NSF (AAAS, 2019b) (Table 4).

Table 4: U.S. federal agency R&D budget, as percentage of total 2018 budget (AAAS, 2019b)

U.S. federal agency	Total agency budget in billions	% of total budget spent on R&D
Department of Health and Human Services	1,112.8	3.38 (NIH only)
United States Department of Agriculture	139.7	1.91
National Aeronautics and Space Administration	20.7	54.6
National Science Foundation	6.7	89.5

In 2018, the Department of Health and Human Services (DHHS) had the largest budget for conducting research, followed by USDA (Table 4). However, approximately 98% ($137.0 B) of USDA's total budget was devoted to a variety of programs, primarily supplemental nutrition assistance, with only about 1.91% ($2.7 B) designated to research, broadly defined. Further, the AgriFood focused portion of the USDA R&D budget comprises less than 60% of the total budget ($1.55 B) with the exclusion of areas like forestry, biofuels, and non-food agricultural crops. The benefitting sectors/industries of the USDA AgriFood R&D effort contributed 14.1% of the U.S. GDP in 2018. In comparison, DHHS research, predominantly through NIH, was 3.38% of the DHHS budget. The primary beneficiary sectors/industries (medical, dental, pharmaceutical, etc.) contributed 17.8% to the U.S. GDP. These differences are indicative of a fundamental issue of disproportional funding for research for AgriFood in comparison to the impact the sector has on the U.S. economy as measured by percent GDP.

A detailed analysis (Figure 12) of more than 2,100 research grants funded by the USDA in 2018, worth $1.5 B, raises additional concerns. Only 4% of grants were for direct Food research, such as food safety, nutrition, health, and food processing, as compared with 36.6% for Agriculture research, and 59.4% for all other research, including forestry, biofuels, education and extension activities, such as rural community support (Grants.gov, 2019). While some education and extension funding were connected to edible Agriculture and Food, it was not included in grant allocation for Agriculture and Food because it was not basic or applied science research. The federal share of research funding for food science, including food processing, preservation, and other food-related technologies, declined from 10% to 4% of the total funding for nutrition research between 1985–2009 (NASEM, 2018).

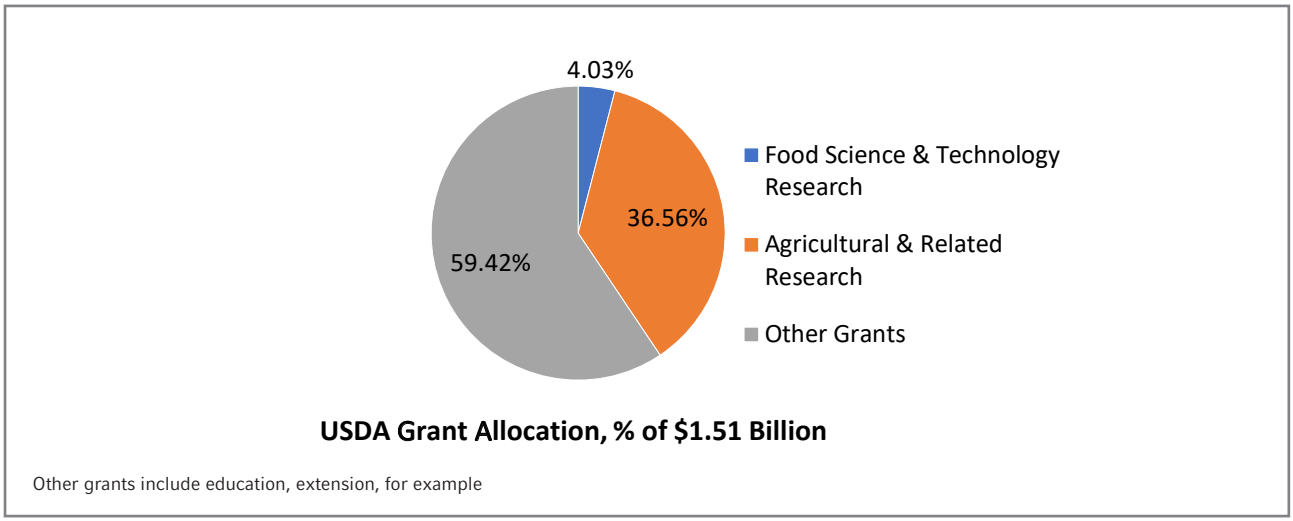


Figure 12: Percent of USDA research grant budget allocated to Food Science and Agriculture and related research in 2018 (Grants.gov, 2019)

With the decline in USDA funding for Food, innovative research on food safety, food processing, and preservation technologies has stagnated. In contrast, federal public funding for research in obesity, anorexia, and appetite control grew from 3.6% to 13.1% between 1985 and 2009, with the fastest growth in the research portfolios of both DHHS and USDA (Clancy, Fuglie, & Heisey, 2016; NASEM, 2018; Toole and Kuchler, 2015).

D. Comparison of the U.S. public funding for research in Agriculture with other countries

The U.S. public funding for Agriculture research has declined since 2008 (Figure 13). By 2013, funding dropped to levels approximately equal to 1990. In stark contrast, during this 1990–2013 period, developing countries such as China and India, steadily increased their funding, and since 2010, China's funding has surpassed all countries (Clancy, Fuglie, & Heisey, 2016). The decline in U.S. public funding for Agriculture risks national competitiveness, long-term cutting-edge scientific discovery, and the next generation talent pipeline.

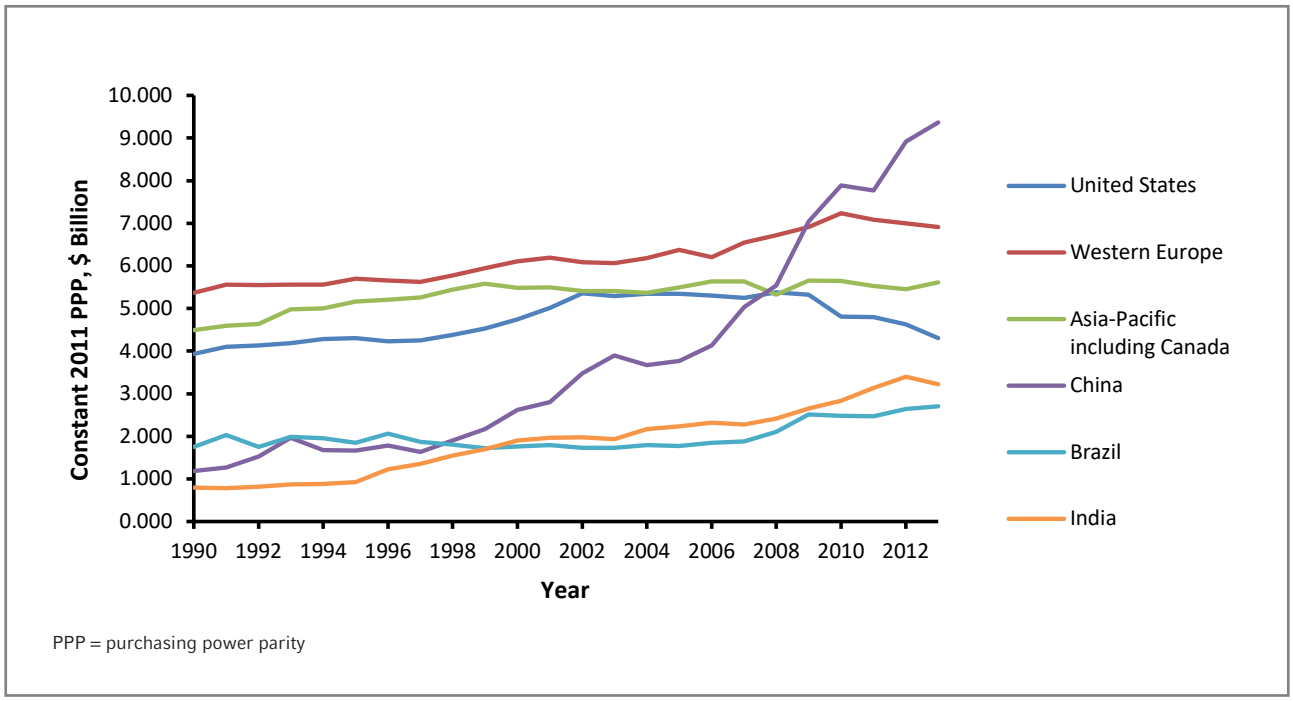


Figure 13: Trends in public funding for Agriculture R&D in selected countries (adapted from Clancy, Fuglie, & Heisey, 2016)

The above analysis shows that U.S. research funding in Food and Agriculture has been decreasing, while it has been impressively increasing in China and steadily increasing in India. In 2013, U.S. investment was half that of China and comparable with the 1990 U.S. investment, which was at that time four times that of China.

VI Contribution of Food Science to the Food System

Research is a critical component of sustaining and growing the value of the AgriFood industry in the United States, with additional contributions to public health, environmental, and global solutions. Numerous examples of both publicly and privately-funded research efforts demonstrate the value derived from such research. Usually, such efforts build upon prior research foundations and interconnect academic and private efforts that fuel innovation. This section highlights a few illustrative examples of research in Food Science (USDA/NIFA, n.d.-b). Many of the following examples led to breakthrough technologies and relied heavily on collaboration between public and private entities, suggesting that any one entity may not be able to fully fund the research needed to address current challenges.

A. Publicly (federally) funded research in Food Science

Food and Nutrition

The Food Composition Database is a great example of an output from multidecade fundamental research led by the USDA. Leveraging both internal, academic, and industry-based research, USDA compiled and continues to enhance the food composition database. The database serves as a comprehensive source of nutrient information for innumerable applications, such as use in product development, food and nutrition-related research, and development of dietary patterns.

Food Safety

Although tremendous scientific and technological advances have been made in food safety, we continue to experience food safety challenges. Fresh produce is a particularly challenging area, as evidenced by numerous recalls during the past decade, often associated with *Salmonella* and *Escherichia coli* contamination. A multi-year project funded by the USDA and led by Auburn University was launched to develop rapid, inexpensive, and easy-to-use biosensors for the detection of *Salmonella* on fresh produce, such as tomatoes, cantaloupes, and melons. A phage-based, magnetoelastic, nanotechnology-enabled biosensor was shown to bind selectively to all pathogenic *Salmonella,* without false positives caused by the presence of other microorganisms. The findings from this fundamental research led to the development of a prototype in-field device that strongly demonstrated the success of the application when compared with quantitative lab testing. Additionally, this research provides a foundation for expanding the technology to other microorganisms of concern (USDA/NIFA, 2017a).

Foodborne illness caused by norovirus, often known as the stomach flu, is estimated to cause over 20 M cases and 800 deaths each year. A multidisciplinary team of 25 institutions—NoroCore, led by North Carolina State University—undertook the challenge of reducing contamination and understanding the mechanisms by which the virus causes illness. The researchers discovered how noroviruses contaminate fresh produce, such as lettuce and kale, and developed surface sanitizers that reduce the virus on food service workers' gloves and food processing surfaces (USDA/NIFA, 2016a). Next, the researchers were able to culture the norovirus in human intestinal cells, a goal that had eluded researchers for 50 years. This foundational research can enable potential development of vaccines, therapeutics, and other measures to control the virus in humans and affect the management of norovirus transmission (USDA/NIFA, 2017b).

Preservation

USDA's investment in new food processing technologies based on microwave energy improved the safety of ready-to-eat meals for convenience-oriented consumers and soldiers. The USDA provided additional grants to accelerate the technology transfer to mainstream commercial markets. Further, the Australian government collaborated with Washington State University and invested $7.2 M to adopt the new technologies. This example shows that research conducted in the United States has global application and could generate additional funds (USDA/NIFA, 2016b).

Food Waste

Reducing food waste is a challenge undertaken by agencies such as USDA, EPA, and FDA and many players in the AgriFood sector. Supported by a USDA grant, researchers at Tuskegee University are utilizing biomass waste to create food packaging systems with advanced antimicrobial properties. The researchers isolated cellulose from sugarcane and stevia and incorporated polymers to develop bio-plastic packaging film, proving the potential of cellulose-based composite films for high-end applications. The research provides a foundation for further new green packaging systems for a variety of high-demand sustainable packaging products (USDA/NIFA, 2018).

Multistate benefit

USDA's Multistate Research Project W-2002, coordinated across multiple academic institutions in the United States, examined the impact of plant-based nutrients and components on health outcomes. These components include preventing or reducing the risk of heart disease, cancer, obesity, and age-related macular degeneration. The discoveries have inspired nutrition-based cost-advantaged solutions as viable alternatives to drug therapies and surgery. Moreover, farmers are using these findings to grow more nutritious crops, and food manufacturers are developing new healthy food products (Multistate Research Project, n.d.).

Further examples of multistate research are found within the NC-1023 project, an initiative supported by a USDA grant that is funding research on a variety of topics (Multistate Research Fund Impact, n.d.), including:

- Shelf-life and preservation
  - Development of food products with a five-year shelf life for NASA's Mars mission
  - Use of high-voltage atmospheric cold plasma technology to sterilize foods without the use of heat, chemicals, or water
  - Development of new edible films to reduce microbial growth and retain moisture on perishable foods
- Food safety
  - Use of high-pressure processing to kill bacteria and extend shelf life without sacrificing taste, texture, flavor, or nutrient content
  - Use of UV and nanoparticle technology to inactivate allergens in foods, such as in peanuts and shrimp to address contamination arising via processing lines
- Nutrition and health
  - Reduction in the particle size of salt such that the salt transfers to the taste buds more efficiently, without affecting the taste, allowing reduction of the amount of salt used in the food product.

B. Industry and public-private funded research in AgriFood

Privately funded research has led to major advances in technologies that continue to drive innovation and value creation. One such area is value-added ingredients with multiple benefits spanning economic growth, consumer benefits, and sustainability.

A game-changer is the scaled application of membrane separation technologies to address the challenge of disposing of whey, a by-product of cheesemaking that increases the biological oxygen demand in effluent streams. The advent of food-grade membrane made from plastic fibers and tubules that can be designed to deliver various pore sizes across a broad spectrum provided a necessary tool to help solve the issue for the growing dairy industry (Kumar et al., 2013). Basic research in protein science and membrane separation technology provided an economical solution to separate large amounts of valuable proteins from the cheese whey stream, allowing creation of value-added ingredients. These ingredients have given rise to product innovations, such as sports and bodybuilding nutrition beverages and infant milk.

Another example is the advent of naturally-occurring non-caloric sugar substitutes. Although artificial sweeteners are still widely used, consumer trends have led food scientists to develop naturally-occurring non-caloric sweeteners such as Stevia. This breakthrough included basic research on the Stevia rebaudiana plant, techniques to derive optimal sweetness from extracts, and an understanding of sensory perception in a variety of food systems (Carakostas, Curry, Boileau, & Brusick, 2008). Basic research efforts around naturally-occurring sweeteners provide consumers with options to help decrease sugar consumption and calorie intake, without sacrificing taste ("Stevia herb shakes," 2010).

The intersection of publicly and privately funded research enables the development of novel ingredients and food products that provide consumers with multiple benefits and value. An example of such research efforts is the formulation of plant-based protein products, e.g., plant-based patty and plant-based cheddar "cheeze" as alternatives to meat-based products (Nunes, 2019). The USDA/ARS has funded basic research on various high-protein terrestrial- and marine-crops, while the ingredient and food industries are focusing on potential viable paths to market. This is an area of heightened focus for startups and venture capital across the value chain. Research and development efforts include establishing economical production of concentrated plant-based proteins, developing processing techniques such as extrusion, and catalyzing regulatory standards. The introduction of plant-based protein products provides options for consumers who choose to consume plant-based foods as part of their values, lifestyles, or cultural preferences, in addition to meeting their nutritional needs (Nunes, 2019).

Despite the extensive research conducted, continued investment in Food and Agriculture research is needed. Evolving food system challenges and education of the next generation of scientists is critical, and policymakers must address the need for adequate funding. The next section reports on the research gaps articulated by U.S.-based professionals in Food Science from across academia, industry, and government.

VII IFT's Survey on Research Shortcomings within Food Science

Attaining a reliable and nutritious food supply that is safe, nutritious, affordable, and accessible to all is a joint responsibility of AgriFood, government (federal, state, and local), academia, non-profit organizations, and consumers.

In the past 50 years, advances in Food Science have helped create a reliable food supply of safe, abundant, affordable, accessible, and overall nutritious food options to meet the needs of consumers. Today, with a formidable AgriFood sector and faced with generational challenges in the food system, food scientists and technologists have been central in multidisciplinary ecosystems. These ecosystems include disciplines such as microbiology, chemistry, engineering, packaging, nutrition, sensory science, toxicology, biotechnology, material science, physics, economics, digital and data science, socio-behavioral science, and others. The ultimate goal is to grow and transform raw agricultural commodities into safe, nutritious, and environmentally sustainable foods that offer value to consumers. This is accomplished through varied scientific and engineering approaches from basic research to scalable and sustainable applications (Floros et al., 2010; NASEM, 2018).

The Institute of Food Technologists and the Council of Food Science Administrators (CFSA), recognized the urgency to substantiate research priorities to advance Food Science in response to national and global imperatives. The urgency was addressed by inviting IFT members to help identify key research needs and gaps, particularly in the post-harvest part of the value chain, recognizing some research needs also occur in other parts of the value chain.

A. Survey purpose and methodology

A survey was conducted in the first quarter of 2019. The purpose of the survey was to: (1) identify key research gaps in advancing Food Science, and (2) determine the impact of insufficient public funding in Food Science. The survey included a question related to each purpose, where survey participants could check one or more research area(s), research gap(s), or impact(s), as appropriate. Further, survey participants could also provide additional information, if desired. The survey was administered through an online portal to more than 6,500 current and former IFT members from academia (excluding CFSA members), industry (those primarily engaged in R&D), and government. The CFSA members (41) received a separate survey, which included questions regarding funding sources for research in Food Science, in addition to questions related to research gaps and the impact of insufficient funding. More than 400 members completed the survey.

B. Survey findings

Key research gaps in Food Science

The key research gaps were framed in the context of increasing/improving food production and efficiencies that benefit the economy and the public. The research gaps focus on Food Science and its integration with scientific developments in allied fields such as nutrition, genomics, behavioral and cognitive science, computing, and machine learning. The approach exemplifies the need for overarching solutions to the complexity of the food system. The key research gaps identified were clustered under three major current challenges:

- Public Health
- Food Safety and Quality
- Food Security and Sustainability

One or more research gaps identified herein have also been reported by others (Campden BRI, 2018; NASEM, 2018). However, a unique aspect is that the research gaps identified in the survey relate to the application of Food Science and other disciplines (in some cases) in the post-harvest production of food. Food scientists and

technologists are well suited to address these research gaps and can provide significant solutions to these challenges. Even though the reported key research gaps primarily focus on Food Science, to fully address them a transdisciplinary approach and collaboration with other disciplines is needed.

Public Health

Research gaps pertaining to public health-related issues are listed in Table 5. Consumers are increasingly interested in food products that are palatable, affordable, convenient, and which help maintain/improve their health and wellness (International Food Information Council [IFIC], 2019). Further, with the advances in genomics and technology, consumers are interested in managing specific health conditions through diet. Research is needed to combine nutritional needs and sensory expectations, such as taste and texture, across all life-stages and demographics, both at a population and individual level. Improving and enhancing the nutritional quality of foods could help reduce the risk of diet-related chronic diseases, improve public health, and decrease escalating health care costs.

Acceptance of science and technology in food production and product development is important for the adoption of innovations that address consumer needs and desires. Consumer values and perceptions impact food choices and trust. Consumer education is critical in increasing engagement, ability to make judicious choices, and building trust.

Table 5: Key research gaps related to public health

Public Health

Sensory and Nutrition

- Conduct innovative research on crops, ingredients, formulation, and processing technologies to:
  - deliver to various age cohorts affordable and accessible foods with palatable attributes and superior nutrition. These could complement existing initiatives in mitigating childhood obesity or could be new initiatives.
  - achieve desirable sensory properties and enhance nutritional profiles by reducing the food components/nutrients to limit—saturated fat, sodium, and added sugars
- Scale technologies to increase nutrient density and bioavailability of nutrients
- Understand effects of food matrix on micronutrient bioavailability

Personalization

- Develop food and beverage products that have the potential to benefit the host through the gut microbiota
- Apply "foodomics" (e.g., metabolomics, genomics, proteomics) and related technologies, and computational biology for personalized nutrition

Consumer and Customer Awareness

- Develop educational tools to:
  - enhance consumer awareness and understanding of traditional and innovative technologies used in food production and processing
  - enhance consumer awareness and understanding of healthy eating, such as portion size/control and use of nutrient claims and nutrition facts labels
  - train and educate food handlers and consumers about food safety through motivational learning methods about food preservation, food-borne illness, and personal hygiene

Food Safety and Quality

Research gaps pertaining to Food Safety and Quality[2] are listed in Table 6. Globalization of the food supply poses challenges related to protecting food from intentional and unintentional contamination and tampering—microbial, chemical, and physical and digital. Although regulatory and surveillance systems have improved, current systems can be further enhanced, including improvements for traceability and digitization, and use of artificial intelligence (AI) and machine learning (ML), to prevent, manage, and rapidly address critical issues related to the safety and quality of food products (Vanderroost et al., 2017)

Research utilizing rapid detection and analytical methods could help food producers swiftly detect foodborne outbreaks, allowing manufacturers to prevent, reduce, or rapidly manage outbreak incidents and stop the distribution of food products in the supply chain. The use of sensors to determine the freshness of food products could also result in reduced food waste both at the retail and consumer level. Integration and management of data collected using advanced technologies, such as blockchain, from farm to fork would help trace the product at each step in the supply chain and reduce the impact of foodborne outbreaks on public health. However, it is important that these technologies are affordable and accessible to producers and manufacturers of all sizes. Better understanding of the ecology of microorganisms throughout the food system will help enhance strategies to further improve food safety.

Table 6: Key research gaps related to food safety and quality

Food Safety and Quality
Interdisciplinary Food Safety
• Study of interactions between the gut microbiota and foodborne pathogens and virulence factors
• Evaluation of the impact of "greener" packaging on food safety
• Research on food safety training and associated behavioral outcomes
Contamination Prevention and Control
• Pursuit of processing and ingredient technologies to control microbial growth and contamination that contributes to spoilage and foodborne illness
• Development of phages as biocontrol agents in food safety applications
• Expansion of detection methods for rapidity, sensitivity/specificity, and analytical capability
• Advancement of chemical and physical hazard detection and mitigation
Data Analytics, Internet of Things (IoT), and Robotics for Prediction and Prevention
• Use of diverse data sources and big data modeling (e.g., Whole Genome Sequencing) to improve prevention of food borne outbreaks
• Understanding patterns of transmission of food pathogens in complex AgriFood systems in relation to outbreaks
• Research on the use of robotics/automation and artificial intelligence and machine learning in the food chain
Integrated Food Safety Systems
• Research on state-of-the-art E2E (End-to-End) traceability systems to enable chain of custody, food safety, product quality, and provenance authentication
• Advancements for rapid outbreak management
• Strengthening of food defense/protection

[2] Quality is in the context of quality assurance and control.

Food Security and Sustainability

Food security, both quantitative and qualitative, is a fundamental human requirement. The report by Capone, Bilali, Debs, Cardone, and Driouech (2014) stated the following:

> "Food security is built on four pillars (i) food availability: sufficient quantities of food available on a consistent basis; (ii) food access: sufficient resources to obtain appropriate foods for a nutritious diet; (iii) food use: appropriate use based on knowledge of basic nutrition and care; and (iv) stability in food availability, access, and utilization."

Increase in food demand is primarily due to population growth, but also because of changing food consumption patterns. The aim of the AgriFood is to provide enough food—both in quantity and quality, to meet the nutritional, lifestyle, and cultural needs of the growing population, in a manner that is environmentally, economically, and societally sustainable. Changes in both food consumption and food production are essential to ensure sustainable food and nutrition security. These changes will require systematic approaches to address food production and consumption and reduce food loss and waste (Capone et al., 2014).

The security of our food supply is of paramount concern to the U.S. federal and state governments. In 1985, the Congress passed legislation supporting federal efforts, including fundamental research, to ensure the security of the U.S. food supply. In 2016, the Congress enhanced the original effort to reflect the importance of a global perspective. The Global Food Security Act of 2016 articulated that:

> "It is in the national security interest of the United States to promote global food security, resilience, and nutrition, consistent with national food security investment plans, which is reinforced through programs, activities, and initiatives."

This legislation also includes the following:

- Accelerate inclusive, agricultural-led economic growth that reduces global poverty, hunger, and malnutrition;
- Increase the productivity, incomes, and livelihoods of small-scale producers;
- Build resilience to food shocks among vulnerable populations and households while reducing reliance upon emergency food assistance;
- Create an environment for agricultural growth and investment;
- Improve the nutritional status of women and children;
- Align with and leverage U.S strategies and investments in trade, economic growth, science and technology, agricultural research and extension, maternal and child health, nutrition, and water, sanitation, and hygiene;
- Strengthen partnerships between U.S. and foreign universities that build agricultural capacity; and
- Ensure the effective use of taxpayer dollars in achieving these objectives (H.R. 1567, 2016).

Since the passage of the Farm Bill, the USDA has redirected research funding to address food security. However, more emphasis is given on production agriculture with little attention to post-harvest production of food (including improving food quality, nutritional value, processing, packaging, and other critical aspects of the supply chain). The survey (Table 7) showed that research in Food Science could help address the four pillars of food security and improve the sustainability of food production. In addition to redirecting funding for research in Food Science, a significant increase in USDA's research budget is needed to meet the congressional mandate of improving national food security and sustainably. Long-term sustainability of our food supply, in light of climate change, natural disasters, bioterrorism, and global population growth will continue to be a challenge.

Table 7: Key research gaps related to food security and sustainability

Food Security and Sustainability

Security and Accessibility

- Foster interdisciplinary research and integrated practices to address food and nutrition security through:
  - innovative research on crops, ingredients, formulation, processing, and go-to-market technologies
  - innovative research on animal breeding and scaled aquaculture
  - innovative research on consumer preferred delivery of nutritious, affordable and accessible foods to various age sub-cohorts and demographics
- Develop integrated and efficient food supply models

Technology Breakthroughs to Reduce Food System Inefficiencies

- Develop and scale additional measures to address:
  - post-harvest food loss
  - food waste
- Conduct research into cloud-based sensors for bulk and packaged goods to predict food spoilage and shelf life, detect pathogens, and reduce loss/waste

Sustainability

- Develop technologies to provide convenience and portability without compromising quality and reduce the environmental impact of the food system
- Develop breakthrough preservation technologies to enable replacement of plastic packaging at scale and affordable cost

A highlight of the survey is that increasing crop yield and food production are not enough to address the complex, multidimensional, and multidisciplinary challenges. Rather, all aspects of the food system—including agriculture, food processing and packaging, distribution, food safety, nutrition, data science, innovative technologies, and consumer education need to be considered when addressing the challenges.

Impact of insufficient public funding in Food Science

The survey findings on impact of insufficient public funding for research in Food Science are summarized in Table 8.

Table 8: Impact of insufficient research funding in Food Science

Impact of insufficient funding in Food Science

Economy

- Decreased and/or diminishing returns in agriculture production efficiencies
- Reduced ability to scale innovative technologies and ingredients, and reduce food loss and waste
- Increased burden on natural resources (land, air, water)
- Decrease in global competitiveness of farming and the food industry
- Increased risk to national security—"food as weapon"

Public Health

- Continued escalation of public health and related health care costs
- Decrease in scientific/technological advances and leadership in food safety, quality, and nutrition

Talent and Research Pipeline

- Decline in student enrollment in Food Science and related fields
- Decrease in the talent pipeline across industry, academia, and government
- Decrease in the number of job opportunities in Food Science
- Decline in breakthrough and interdisciplinary research

It is apparent that the competitiveness of the U.S. AgriFood industry, which represents more than 14% of U.S. GDP is at risk due to the continued federal underfunding of research. This can be exacerbated in the face of limited natural resources, growing population, and growing consumer demands requiring rapid and sustainable solutions.

Further, diminished research in Food Science will likely escalate public health challenges, driven by growing food insecurity, reduced food safety, and increased risk of diet-related preventable chronic diseases. National security is affected both from an economic perspective, increasing the health care burden and uncompetitive labor costs, and military preparedness, where overweight soldiers are unable to perform normal activities and functions required of them (Popkin, 2011).

The U.S. leadership in scientific and technological advancement in AgriFood will continue to decline, putting the United States behind developed and developing countries who are investing more substantially and consistently. ***The lack of research funding for Food and Agriculture will impact student enrollment, training of scientists, research capabilities of U.S. institutions, and will affect the viability of U.S. AgriFood as a global leader. Further, it will reduce economic contributions to the GDP, with impacts at national, state, and local levels.***

Current public funding sources for research in Food Science

IFT also surveyed the CFSA members to better understand the current public and private funding landscape in Food Science. Fourteen CFSA members responded to the survey. All participants indicated that the USDA currently funds research in Food Science. The USDA was ranked as the topmost funding agency followed by NIH and FDA. Responses showed that USDA awards more funds, followed by NIH and other agencies, such as USAID, NSF, and FDA.

More than 90% of the respondents indicated that their state provided funding in food, primarily through USDA. Some respondents also indicated receiving funding from other state government agencies, such as the Department of Health and check-off programs. Seventy percent of the respondents received more public than private funding for research in Food Science. Private funding sources mentioned included commodity boards, other nonprofit organizations, and industry.

Survey participants expressed a strong need for both public and private funding and public-private partnerships, such as FFAR and EIT for research in Food Science. Private funding is important for many reasons, including leveraging the impact of public funds, addressing targeted areas of research typically not addressed through publicly-funded research, undertaking short-term and applied projects, promoting scientifically-driven innovations at a faster pace, providing practical training opportunities for students and young professionals, and ensuring that the U.S. scientists are at the forefront of cutting-edge research in Food Science.

VIII A Call to Action—Food Science Funding

Currently, the decline in public funding for Food, most pronounced since 2008, is of great concern and cannot be substituted by private funding. Public and private funding, however, can be complementary. This "call to action" includes a paradigm change in public, private, and public-private investments for research in Food to unlock scientific and technology solutions, build a robust talent pipeline, and maintain our global competitiveness. In addition to the USDA, we urge other federal agencies, such as the NIH, NSF, and Department of Defense to prioritize research in Food and Agriculture as part of their research agenda.

There is urgency for policymakers to recognize the significant contributions of the Food sector to the U.S. economy and the risk that is associated with chronically underfunded research in Food. IFT's call to action is for a paradigm shift to drive innovation and value creation, feed the talent pipeline, and maintain global competitiveness. We have identified the need for:

- Increasing and prioritizing USDA's funding for AgriFood research, with a primary focus on Food
- Authorizing additional federal agencies to fund interdisciplinary research in Food
- Enhancing public-private partnerships for AgriFood research, with a focus on research in Food

IX Conclusion

Historically, both publicly and privately funded research has produced tremendous benefits throughout the food system, from agricultural production to food manufacturing, retail and food service, and consumption at home and away from home. AgriFood plays an invaluable role in the economy and public health, with Food ahead of Agriculture in terms of GDP contribution, employment, and exports. To continue to create value and maintain global competitiveness, advancements in food science and technology and pursuit of innovation are critical. Investment in Food research will not only help to ensure a secure food supply but also reduce foodborne disease outbreaks and assist with efforts to protect the environment and national security. However, public investment in AgriFood research, and particularly Food, is critically low during a time of mounting challenges and does not reflect the sector's contribution to the economy and long-term competitiveness. It is vital to economic, national, and societal interests that the global food system ensures safe, nutritious, affordable, accessible, and environmentally sustainable food supply for the growing population, health, and the environment. Substantial and sustained increase in research investment behind AgriFood, and most importantly Food, are urgent to address these complex challenges at national and global levels. ***This paper calls for a paradigm shift to increase investment in Food research by the public and private sectors as well as public-private consortia.***

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