__The demand for agricultural products__ for nontraditional uses such as bioenergy or bio-based materials can potentially change agricultural production patterns, food availability, and food prices. Food Technologist Charles Onwulata uses an injection molder to modify whey protein structures for food and nonfood product development. Photo courtesy of Peggy Greb, USDA, ARS

BY CHARLES ONWULATA, L. FRANK FLORA & WENDY KRAMER

GLOBAL OPPORTUNITIES in Agri-food Science & Technology

Innovation and R&D—critical to the complex agri-food industry—enhance economic competitiveness and foster new food technologies, food safety, and value-added, healthful foods.

As fundamental as food is to life, so are research and development (R&D) and innovation vital to the food sector in order to meet food safety, health, environmental, and economic challenges. The food and agriculture sector is the world's biggest industry and its true value is difficult to measure. The World Bank estimates the food and agriculture sector at 10% of global gross domestic product, approximately $4.8 trillion (Murray, 2007). Food can be a commodity, a product, an ingredient, or a meal, with different values at each stage. The agri-food industry in the United States provides abundant food and fiber for the global market and thrives in an extremely competitive, highly integrated worldwide economy.

The level of farm output in 2004 in the U.S. was 167% above its level in 1948 for an average annual rate of growth of 1.74% (USDA, Economic Research Service, 2008).

Agricultural research has been successful in generating massive increases in total output, higher volume throughput, and cheaper products by using modern practices such as irrigation, fertilizers, and new processing technologies (Figure 1). The demand for bioenergy—renewable energy from biologically derived materials—can potentially change agricultural production patterns, food availability, and food prices. The increasing demand on agriculture to deliver high quality foods, animal feeds, fibers, bioproducts, and bioenergy, using environmentally sustainable practices, highlights the need for both public and private R&D in the creation and adoption of new products and technologies.

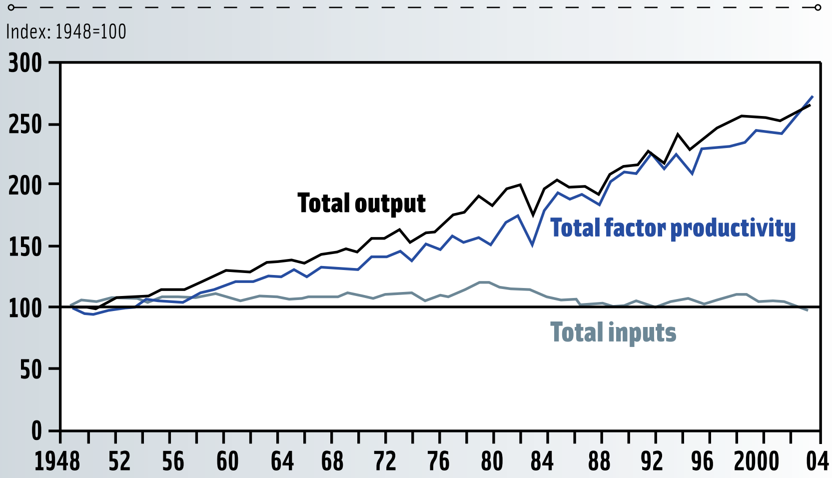
The decades before the surge in bioenergy growth (i.e., 1985–2004) represented an era of growing commodity surpluses and declining prices. The current economic outlook for most agricultural commodities predicts prolonged fluctuations between marginal supplies and shortages due to the global bioeconomy (Abbott et al., 2008). The merging of agricultural commodity prices and the bioenergy and crude oil markets may result in endemic food scarcity and rising prices. The Food and Agriculture Organization (FAO) foresees agriculture and food as a key issue facing humanity. The *OECD-FAO Agricultural Outlook 2006–2015 Highlights* forecasts increasing trade and an intensification of competition from growing markets in Brazil, China, and India, and rising worldwide per capita food consumption.

Value of Agricultural Research

The U.S. retail food market is over $500 billion; total food sales are more than double that figure (Plunkett Research, Ltd., 2008). From economic studies in the U.S., there is considerable evidence that agricultural research has made major contributions to the improvement in overall economic productivity. Thus, it is clear that there has been a high return of investment from agricultural research. Moreover, spillovers of agricultural research, across many boundaries, benefit industries, nations, and economic sectors (Fuglie et al., 2007).

An analysis of relevant market trends, science and technology needs of agricultural research, and agri-food industries worldwide reveals a future bright with possibilities that can be realized through innovative research. In the food industry, slight or marginal changes are evident. For example, the food industry introduced a record 20,031 food and beverage products in 2006, according to Datamonitor. Datamonitor typically classifies over 90% of new food and beverage products introduced as "not innovative." Instead, these products may involve variations of existing products, such as new flavors, package sizes, or brand names. This

Figure 1. Changes in U.S. agricultural output, inputs, and total factor productivity[1] since 1948.



[1]*Total factor productivity measures total output per total inputs, or the overall efficiency of agricultural production.*

practice suggests that food firms use new-product introductions as a differentiation strategy to present a fresh image to consumers, rather than providing truly novel products (Martinez, 2007).

A future scenario for agricultural research will need to integrate many attributes, for example, using modern tools to improve process and product development and delivering nutrition and health by providing probiotics and prebiotics, phytonutrients, and antioxidants (Mellentin, 2008). Consumers will demand enhanced-value foods that contain added health-promoting components—minimally processed, multi-functional foods, and organic products produced using environmentally benign practices. Delivering these enhanced-value foods will require new and improved food technologies.

The organic agriculture paradigm views the production of healthful foods and the sustenance and health of the environment, soils, plants, animals, and humans as one indivisible system. Organic agriculture encompasses the entire food supply chain, from production and handling, through quality control and certification, and to marketing and trade (Scialabba, 2007). High consumer demands for safe, healthful foods, efficient and productive organic farming, preservative-free processing, and development of "smart" and healthful packaging pose huge scientific and technological challenges.

Other challenges include food security, that is, do we have enough high quality, nutritious food for everyone? Can we deliver nutrient-rich foods to avoid hidden hunger—foods with missing micronutrients? These are a few of the challenges that food science and technology must solve in the 21st century.

Innovation and R&D Investments

The food and beverage market is competitive and complex. Innovation is crucial to meet new challenges. Major areas of food research will include food composition and quality; health, wellbeing and nutrition; biomaterials research; processing and production; and packaging innovation. Many food processing technologies in use today are 40–60 years old or more. New technologies need to deliver enhanced value and maintain good manufacturing practices, which include enhancing nutritional qualities. Worldwide, consumers are demanding healthy, green, organic, or wholesome, quality products. Research should emphasize value-added, high quality foods; health promoting, minimally processed, and multi-functional foods; organic processes and products; and delivery of quality and safety through new technologies.

In 2008, the global food economy witnessed supply scarcities, rising food prices, global food insecurities, and political unrest. The World Bank projects that to account for bioenergy demands, cereal and meat supplies would have to increase by 50% and 80%, respectively, to meet projected demands in the next five years. The World Bank recommends increased investments in science, technology, research, and development to spur innovation. The World Bank recognizes that low investment in R&D goes hand in hand with low technology transfers.

Besides declining investments in agricultural research, other factors such as a possible global economic slowdown, a declining number of trained personnel, and an increase in specific applications research (short-term intellectual property (IP) driven research) that weakens the link between basic research and technology development contribute to less productivity, lack of new products, and limited innovation for economic growth. Outside of government-funded research for public good, the embrace of patents and profits means that the basic infrastructures that sustain developing technologies are lacking (Farm Foundation, 2006). Strong evidence shows that pharmaceutical research and public basic and clinical research stimulates economic benefits (Toole, 2007). For example, a $1.00 increase in public basic research generated an $8.38 increase in private pharmaceutical R&D investment after 8 years. A $1.00 increase in public clinical research generated a $2.35 increase in private R&D investment after 3 years.

Yet, agricultural research, despite more than 20 years of slacking reinvestments, has provided successes in innovations and productivity. According to IMF (International Monetary Fund) data, world food prices declined by 75% in real terms between 1975 and 2005 (Heaney, 2008). "In constant 2001 dollars, annual spending on food and agricultural research in the United States increased from about $4.6 billion to $8.8 billion between 1970 and the late 1990s, with the private sector accounting for most of this growth. Public spending for agricultural research was mostly flat (after adjusting for inflation) between 1978 and 1998 but showed some renewed growth during 1998–2004."

Public spending on agricultural research includes productivity-oriented research and research on natural resources, food nutrition and safety, rural development, and economics. Enhancing productivity accounts for about 60% of public agricultural research. "About 70% of private research in the late 1990s was oriented to farm production and about 30% went to food manufacturing" (Fuglie and Heisey, 2007).

Global Food Challenges

The challenges facing global food supplies include a trend toward a biomass-based bioeconomy (bioenergy), food quality (health enhancement), food energy management (obesity/starvation), rising food costs, and global food safety (supply/traceability).

Energy and agricultural markets are integrated (Tyner and Taheripour, 2008). Energy prices have always affected agricultural prices, mostly on the input—fertilizer, pesticides, or diesel; higher input resulted in lower production. Today, higher energy costs are affecting output prices as well. The greatest pressure on sustainable and profitable agricultural production systems is this shifting paradigm of bioenergy, which creates new scarcities and threatens food supplies worldwide, resulting in food insecurity.

Food security exists when all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life. *Biofuels: An Emerging Threat to Europe's Food Security* discusses the impact of an increased biomass use on agricultural markets, prices, and food security. The choice of biofuels is a gamble for agriculture both in terms of earnings and the risks; in the short term—increased earnings for farmers, but in the long term—global food insecurity resulting from hitching agriculture to biofuels (Schmidhuber, 2007).

Food Quality

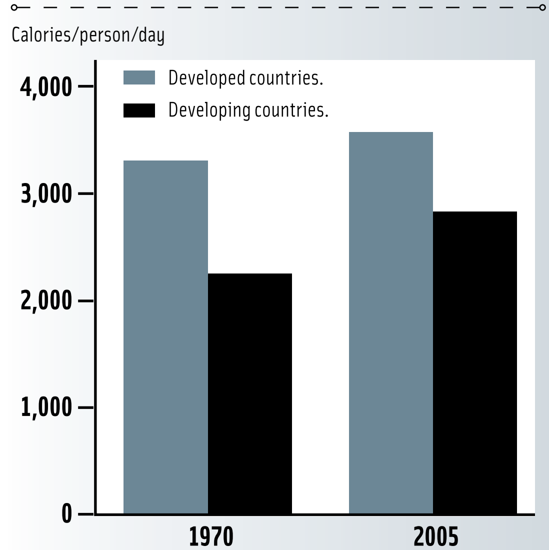
Food may be available, but not necessarily in desirable, aesthetic, cultural, functional, or cost conditions. Customers purchase fresh agricultural produce based on external attributes of color, firmness, and aroma, and internal qualities of taste and texture. Likewise, food quality is a major issue for processed foods, both in terms of nutrient availability and delivery. Fresh produce and processed foods, like other globally sourced products, without uniform production or international manufacturing standards/regulations, have the potential for increased quality and safety risks. Labeling foods with the country of origin provides information for tracing the source of a product, in case of contamination. Beginning September 30, 2008, in the U.S., all perishable agricultural commodities must bear country-of-origin labeling; the USDA Agricultural Marketing Service monitors compliance for all covered commodities. Labeling will benefit food security investigations in case of contamination or deliberate compromise of food integrity.

Food Energy Management

Globally, food consumption patterns are changing as the income of more consumers has risen in the last decade, and they demand more high-value products (Frazao et al., 2008). Income affects food choices. Growth in per capita income in developing countries has provided a powerful and sustained stimulus for agricultural products (Trostle, 2008). Consumers in developing countries not only increased per capita consumption of their staple foods, but also increased consumption of meats, dairy products, and vegetable oils. With greater overall per capita consumption, per capita caloric energy increased (Figures 2 and 3); between 1970 and 2005, and the consumption of grains decreased (Rosen and Shapouri, 2008).

Adult obesity in the U.S. has doubled since 1980, from 15% to 30%, as defined by body mass index (Levi et al., 2008). Obesity is a global health concern. Donnelly et al. (2008) supports the role food technology plays in developing food innovation to reduce obesity. Opportunities exist in new functional foods and technologically innovative ingredients to target obesity. The U.S. market for fortified and functional foods and beverages is the largest in the

Figure 2. Calorie availability is increasing in developing countries.



Source: Food and Agriculture Organization of the United Nations world. In 2008, combined value sales are expected to reach $33.3 billion, accounting for one-third of total global sales. In terms of size, growth, and innovation, the dairy sector tops the global fortified and functional packaged-food market (Baroke, 2008).

Not everyone's income is increasing, however. There is unyielding food insecurity in developing countries (Rosen and Shapouri, 2008). Food contamination—either accidentally or by adulteration—has presented challenges in the food/feed supply chain. Examples are the melamine incidences in baby formula, dairy and pet foods, and dioxin in the European Union (EU). According to the Levin Institute, globalization has made low-cost production and processing of foods possible, in regions within countries with cheap labor, to create low-cost ingredients.

Addressing food supply/scarcity can aid economic viability and competitiveness. For example, by maintaining the quality of harvested agricultural commodities to prevent losses, estimated at over 25%, supply could be increased using available land and technological resources (Kader, 2005). Loss of acceptability, edibility, and freshness leads to loss of nutritive and caloric values. Food marketability must be maintained during storage, adding market values to commodities. Food security entails ensuring that safe, nutritious foods for all are guaranteed through the availability of sufficient, wholesome foods and the knowledge of adequate food handling and preparation practices to ensure food safety.

Global Food Safety

Providing wholesome foods from farm to table is a challenge. Foodborne contamination can occur at any stage in the chain. The USDA Economic Research Service estimates that each year 76 million U.S. consumers contract foodborne illnesses, resulting in 325,000 hospitalizations, 5,000 deaths, and many other complications (Kuchler, 2007). Globalization of fresh produce and processed foods, through varied production and handling systems, has increased the potential for contamination. Worldwide, the trend will continue, as more and more supply chains are linked. In 1997, The World Health Organization (1998) saw that food safety risks due to globalization posed a challenge to public health. Several incidences, within the last year in the U.S., have demonstrated that increased reliance on food sources from countries with less stringent standards or monitoring capacities has led to outbreaks of foodborne illnesses. This presents significant challenges to develop food handling processes to minimize safety risks, if not, "Foodborne infections may increase in the coming years as a consequence of increased globalization of our food supply" (Volansky, 2008).

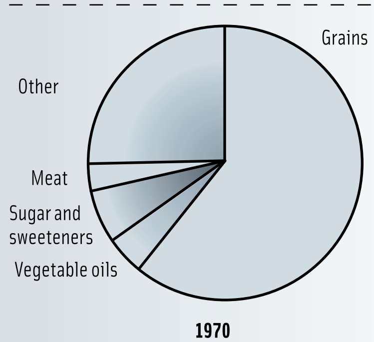
The World Is Mobilizing

The USDA Agricultural Research Service (ARS) Strategic Plan for FY 2006–2011 (published February 2007) emphasizes four strategic goals: (1) to ensure high-quality, safe food and other agricultural products, (2) to sustain a competitive agricultural economy, (3) to enhance the natural resource base and the environment, and (4) to provide economic opportunities for rural citizens, communities, and society as a whole. The National Research Initiative of the USDA Cooperative State Research, Education, and Extension Service (CSREES) supports and funds research in human nutrition, development of new products, improvement in national food security, development of new and sustainable feedstock, and development of bioconversion products through innovative and cutting edge technologies.

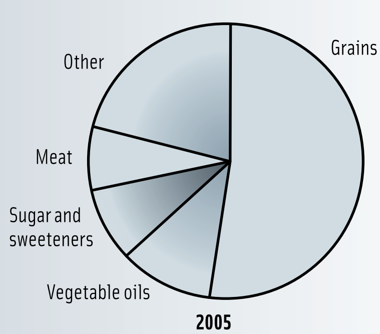
Canada's Science and Technology Framework seeks to mobilize science and technology to increase productivity, sustain growth, and strengthen a knowledge base that can translate scientific research outcomes into commercial applications. The leading areas are developments that generate health, environmental, and societal benefits supporting basic research. The Canadian government funds industrial research through direct funding and the Scientific Research and Experimental Development tax credit. "The increased potential for agricultural research is taking place at a time of growing international recognition of innovation as a source of economic growth." The challenges include how to create an economic and funding environment for agricultural research in ways that will increase innovation (Gray, 2008).

Similarly, in 2007, the

Figure 3. Grain share of developing country diet shrinks...



...as meat and vegetable oil share rises



Source: Food and Agriculture Organization of the United Nations

European Union Standing Committee on Agricultural Research identified long-term research projects to address the challenges to agriculture and support the developing European Knowledge-based Bioeconomy. This information was used in a model to predict possible future scenarios for European agriculture with a 20-year perspective and to formulate policies. The model parameters were climate shock, energy crisis, food crisis, cooperation with nature (environmental awareness), food security, and social health problems. The outcome or researchable issues identified were food sustainability, food security, and competitiveness. Particular recommendations were for the European Union to transition its research agenda to address immediate sustainability concerns and to develop a long-term, high technology research agenda to insure investment needed to generate research development and economic growth (European Commission, 2007a). The Swedish Government and European Commission Workshop in their "Foresight to Set Long-Term European Agricultural Research Priorities" sees the need to redefine agriculture as moving toward a knowledge-based agri-business and the need to think and act along a whole chain (i.e., food, feed, fuel, and fiber); thus, setting priorities for tomorrow.

Food Industry Research Interests

Industry research needs are varied. One major need is discovering enhanced-value, structure-function nutrient advantages, such as phytonutrients for health. The industry needs research to develop new technologies for fractionation, isolation, extraction, reduction (e.g., low salt), concentration, and delivery of health-enhancing ingredients. In addition, food industry research should address food security and quality for an increasingly sophisticated world market demand for enhanced quality and nutrient value. More resources are needed to support end-use quality evaluations. Research objectives for the food industry can target enhanced value processing and product quality as well as developing new, rapid, and objective methods to evaluate quality and functionality.

The food industry can increase food, feed, and fiber volumes by reducing food processing wastes and co-products recovery schemes. Opportunity exists to develop new processes for produce with high-value components, the so-called "super produce". Super produce are colorful, flavorful, high nutrient specialty fruits, nuts, and vegetables rich in anthocyanins, polyphenols, and protective heart-healthy compounds. These nutrients must be preserved through harvesting and processing. Specifically, the research needs are:

• Structure-function/nutrition of health-promoting wholesome foods with multi health benefits and new processing technologies to protect and concentrate nutrients such as phytonutrients and folic acid and flavor/aroma phenols.

• Enhance quality and new uses (product innovations). Develop and implement methods to improve processing and end-product quality and develop rapid measurements for functionality and nutrient prediction.

• Develop healthy and flavorful, value-added products (e.g., bran, oil, protein) to maximize health benefits through processing and address health/obesity.

• Develop new delivery techniques for nutrients (e.g., delivery of probiotics) and develop new processing technologies for nutrient identification, characterization, stabilization, and delivery.

• Develop knowledge and understanding of bio-metabolism—nutrient/food interaction.

• Improve quality. Conduct enhanced value-added research for food and feed, improving quality of harvested and processed produce, quality of produce in controlled atmosphere, and reducing quality loss in storage. Develop postharvest practices for optimizing quality through improved monitoring.

• New technologies for processing streams. Develop processes to recover more feed and fiber from waste by the removal of harmful substances such as allergens, gossypol, or acrylamide, and through process enhancement and recovery of food-based byproducts.

• Food security. Provide more quality food through new technologies and enhanced nutrient retention.

Also, nanotechnology has the potential to generate new products for the food industries with numerous benefits in smart packaging, nanosensors for food safety, food nutrient delivery systems, nanoemulsions, etc. (Siegrist et al., 2008; Daniells, 2008).

Status of R&D in the Food Industry

In the U.S., the total value of agri-food industry shipments exceeded $660 billion in 2006. Market forces and globalization are driving industry toward more innovation. However, R&D expenditures in the food industry are low compared to other industries. From OECD figures, investment in R&D as a percentage of value of production in the food sector for Europe was 0.32% in 2003 (Europe Innova) and for the United States was 0.39% in 2002 (European Commission, 2007b), compared to the chemical, rubber, plastics, and fuel products in OECD countries of 2.72% in 2001 (European Commission, 2007b). The European Technology Platform Food for Life (2008) outlines a plan to boost the competitiveness of the European food and drink sector, which is the largest manufacturing sector in Europe, employing about 3.8 million people. Table 1 from *Monitoring Industrial Research: The*

Table 1. Ranking of industrial sectors by aggregate R&D from the world top 1,400 companies in the 2007 Scoreboard.

Rank	Sector	R&D Investment (€ m)	Change from previous year (%)	Share in R&D Investment (%)	R&D Intensity (%)
1	Pharmaceuticals & Biotechnology	70,523.5	15.7	19.3	15.9
2	Technology Hardware & Equipment	64,531.5	13.1	17.6	8.6
3	Automobile & Parts	60,807.1	1.5	16.6	4.1
4	Electronic & Electrical Equipment	27,138.9	4.9	7.4	4.4
5	Software & Computer Services	26,522.8	13.2	7.3	9.8
6	Chemicals	17,186.0	9.6	4.7	3.1
7	Aerospace & Defense	15,991.3	12.4	4.4	4.8
8	Leisure Goods	14,208.6	-1.0	3.9	6.5
9	Industrial Engineering	9,319.3	11.5	2.5	2.7
10	General Industrials	8,867.6	8.0	2.4	2.1
11	Fixed Line Telecommunications	7,283.1	12.9	2.0	1.6
12	Health Care Equipment & Services	6,446.1	17.3	1.8	6.8
13	Oil & Gas Producers	4,923.7	20.5	1.3	0.3
14	**Food Producers**	**3,918.5**	**7.6**	**1.1**	**2.2**
15	Household Goods	3,911.9	7.2	1.1	1.6
	Top 15 Sectors	341,580.0	9.7	93.4	4.2
	Rest of 22 Sectors	24,243.9	13.9	6.6	0.9
	Grand Total	365,823.9	10.0	100.0	3.4

Source: The 2007 EU Industrial R&D Investment Scoreboard. European Commission, JRC/DG RTD.

2007 EU Industrial R&D Investment Scoreboard show industrial research in innovation in a variety of industries including food (European Commission, 2007c).

Agricultural Research Funding and Impact Assessment

Return on investment of the broad benefits derived from agricultural research provides tangible measurement of the substantial value of agricultural R&D. Agricultural research has created and will continue to create many economic gains and technological advancements (Scanes, 2007). The Consultative Group on International Agricultural Research (CGIAR) documented that agricultural research generates many aggregate outputs including technologies, tools and practices, information, and improved human resources, but that individual impact estimates remain uncommon partly due to difficulties of assessing benefits from different types of research (Raitzer and Kelley, 2008).

Agricultural priorities linked to performance permit measurable assessment at the end of project cycles. The USDA assures relevance, quality, and performance of its Agricultural Research Service (ARS) through a 5-year program cycle, which begins with development of a strategic plan. The National Programs Leaders develop plans to ensure that research is relevant to either immediate or long-term goals. In brief, the cycle includes program planning and priority setting to ensure relevance; scientific peer review to ensure quality of plan and merit; project implementation; program coordination to ensure performance; and retrospective program assessment to quantify quality outcomes (Knipling and Rexroad, Jr., 2007).

Public funding of agricultural research conducted by ARS and the land-grant university system has been a high-yield investment. It has benefited every man, woman, and child in the United States and much of the world. A USDA, Economic Research Service publication *Economic Returns to Public Agricultural Research* presents a positive overview indicating that for each public dollar spent on agricultural research, on average, $10 worth of benefits return to the economy (Fuglie and Heisey, 2007).

Agricultural research has to meet a wide range of challenges, such as innovative food processing and enhancement; food security and sustainability; climate change; environmental impacts; pressure on natural resources; and globalization. Advances in all scientific areas, through multi- and inter-disciplinary knowledge and technologies, will influence new research directions in food science and technology, plus new product development. Convergence of new ideas from different disciplines will help us to better understand and solve complex and interlinked agricultural, postharvest, and food processing issues. **FT**

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