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Review

Challenges facing food engineering ☆

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ABSTRACT

Food engineering (FE) was identified as a promising field in the mid-20th century. In the succeeding years, demand for food engineers in industry has continued unabated, but the field, in an academic sense, has not quite lived up to its potential. Yet, the coming challenges of the 21st century offer many opportunities for persons with FE training. This article is based on a plenary session held during the Conference of Food Engineering 2012, in Leesburg, Virginia, USA, and consists of a compilation of opinions of the authors. In order to develop further, FE needs to shed its historical mindset, and embrace a broader vision of its scope to include product, internal human and industrial processes, equipment, package and sensor/automation engineering. Training in FE could be vital to helping address issues such as water availability and quality, health and wellness, food safety, energy and sustainability. A number of 21st century developments will drive this change, including world population growth and aging; the digital universe, "big data" and informatics; personalization, food, health and wellness; food security, environment, sustainability and social responsibility; and the innovation ecosystem (open innovation and partnerships). Food engineering education will also have to change to keep pace with the extraordinary expansion of knowledge, the availability of virtual tools, diminishing funding and laboratory resources, and the possibility of creating partnerships between industry and academia. Studying inner transport phenomena, utilization of new techniques, such as micro processing for modeling and simulation of the digestion system, bioavailability, satiety, DNA predisposition, and nutrigenomics offer unique opportunities. The case of FE in UK and Europe are addressed, where consortia involving different industries have been able to partner to focus on problems with a common scientific theme to leverage their efforts. Finally, the experience of one food company in hiring food engineers as well as chemical engineers is highlighted, together with their interview processes and criteria. While this represents a collection of the opinions of the individual authors, it is hoped that the discussion stimulates a more wide-ranging conversation about FE to enable it to develop further into the 21st century.

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1. Introduction

For Food Engineering (FE) it is the best of times: it is the worst of times. We have seen much success in the past two decades with the major and continuing development of alternative processing methodologies, new technologies, novel discoveries, and food sources (Knorr et al., 2009). Yet, the FE profession is at a crossroads. Continuously diminishing government and other agencies' support, together with lack of critical mass among university faculty (specifically in the United States) has taken a heavy toll on research activity, attractiveness to new students, and new academic positions. Noteworthy proliferation and flourishing of many bio-disciplines has highlighted the immediate acute need for the FE profession to reassess its vision, strategy and mission to reinvigorate the domain and to sustain its future.

FE emerged in the 1950s and 1960s, under the influence of agricultural engineering, and later came under the influence of chemical engineering (CE; Karel, 1997). A number of programs emerged in Latin America in the 1960s and 1970s, involving a blend of European CE programs and US food science (FS) programs (Simpson, 2004). Within the US, most programs reside within land-grant institutions, and food engineers are often divided between various departments (e.g., FS, Biological and Agricultural Engineering). FEs have been represented in a number of professional societies worldwide (e.g., Institute of Food Technologists, IFT, American Institute of Chemical Engineers, AIChE, Institution of Chemical Engineers, IChemE, International Union of Food Science and Technology, IUFoST, American Society of Agricultural and Biological Engineers, ASABE, and The European Federation of Food Science and Technology, EFFoST).

In the late 20th and early 21st centuries, there have been a number of retrospectives (Goldblith, 1995) and views of the future (e.g., Karel, 1997; Bruin and Jongen, 2003; Aguilera, 2006), and a more general review (Floros et al., 2010) including other areas of FS and technology (FST), but involving a number of FEs. These works are all relevant in assessment of the current state and self-image of FEs.

The FE profession is at a crossroads. It faces tremendous challenges due to shrinking public and industrial research funding, intensified competition and proliferation of other bio-disciplines and other domains (e.g., bioengineering, biotechnology, CE, material science). The recent escalating global economic crisis and social pressure provide only a marginal explanation for the deteriorating support. More important is the observation that FE suffers from a lack of vision culminating in a drop in student enrollment, scarce academic positions, low attractiveness, to count only a few. The exponential growth in both knowledge and its complexity, intertwined with breakthroughs in science and technology progressing at a mindboggling speed, call for the reassessment of the roles of FE to meet future needs and significant challenges and mandate concentrated and multidisciplinary efforts.

Unabated and accelerating recent scientific progress into new areas focusing on biological science (e.g., personalization, DNA, nutrigenomics, gene expression and metabolic understating) are changing the curricula and "traditional" engineering topics are often reduced to allow other more current subjects to be introduced. This transition is even more severe as less research is allocated to FE due to lack of resources, cost and expertise that shifts to other more "sexy" and appealing topics. If this trend continues, it is likely that in the foreseeable future, "classical" FE topics will be mostly taught by faculty members with knowledge based only on textbooks with limited or no real experience.

To facilitate and/or provoke frank discussion within the community regarding the FE collective future, the following is an alternative approach. It is not intended to disparage any individuals or their point(s) of view, rather it is principally to provide a different view and to facilitate discussions and other contributions.

While it is clear that FE has accomplished much in its relatively short history, its lack of growth as a discipline, particularly within academia in the US, is cause for concern. Certainly, the drivers exist: the food industry has need for engineers, which it fills with a variety of hires, including chemical engineers (CEs), food engineers (FEs) and agricultural engineers. Opportunities and challenges for food engineering abound: the drive towards health and wellness, concerns about fresh produce safety, and the need, in an ever-competitive global environment, to deliver high quality at reasonable cost. These should be reasons for food engineering to thrive, yet there is a sense that the field is failing to live up to its early potential. For instance, in the US budget cuts at most US universities have left them with minimal faculty in this area. Additionally, the relative paucity of grants has driven many faculty members to more lucrative bio-based processing or nanotechnology areas. Without university faculty to drive the next generation of engineers, we may be faced with limited prospects in the years ahead.

"It was the best of times; it was the worst of times."
Charles Dickens: *A Tale of Two Cities*

In the spirit of Charles Dickens, we propose that FE could be depicted as a tale of two narratives: one suggesting that it is the worst of times, another that it is the best of times.

(a) The worst of times narrative and its consequences

Given the many different forces shaping the field, FEs (either currently active or entering the profession) hear a negative narrative that influences their collective thinking and has the following general themes:

FE is considered largely to be a subset of CE, which it should try to (but never will) successfully emulate. It is unclear how this thinking has evolved, but it may have its origins in the past leaders of our field profess strong CE connections and continue to look to it for inspiration (Bruin and Jongen, 2003). However, the prolonged lack of consensus on the definition of the field has led to a de facto stratification. Often, faculty without engineering backgrounds are hired into food science departments, and deemed "food engineers". In other departments, engineers are hired but are compelled to dequantify their coursework to meet the needs of mathematically challenged students.

The Golden Age of FE occurred in the middle of the 20th century (from around 1950 to 1975), with subsequent developments being less significant. This line of thinking has resulted in a culture in which the field looks fondly at its past glories, at the expense of its present and future. Scientists from the past regardless of their current activity or breadth of vision regarding the field often recommend that we look outside the field for inspiration. This approach gives scant attention to the many developments that have occurred in our own field in the recent past and relegates FE to being a derivative discipline.

The consequences of the worst of times narrative on the culture of FE are:

- *Elitism and Exclusivity* – The lack of a consensus definition of FE and the persistence of the status quo for many years has resulted in de facto stratification of the field into elites and the rest. Nowhere is this tendency towards elitism more apparent than in international organizations. Young FEs are faced with no unified supportive organization, with little guidance on professional societies with which to align themselves, and how they may get involved.
- *Unhealthy Competition within FE* – Lack of a cohesive organization and the intense competition for grants has resulted in unhealthy rivalry within the FE field. The unfortunate consequence is the tendency of FEs serving on grants review panels to be extremely critical of proposals in their own field. This tendency to over compete is also probably true in other fields (e.g., CE in the UK), however it is damaging in a field struggling for scarce resources in competition with other fields.

If the academic FE community in the United States is to thrive, we need to transform the current culture. There is a competing and more compelling narrative wherein FE can and should thrive in the future.

(b) The best of times narrative

In this narrative, FE is broadly defined as all engineering operations relative to the food system. The intent of this is to define FE broadly, ensuring a more inclusive umbrella. The community needs a greater number of invested members to flourish in the future.

Several main points of this narrative are listed below:

- *Engineering*. To be defined according to the commonly accepted definition of Accreditation Board for Engineering and Technology (ABET; http://www.abet.org/accreditation/; visited February 3, 2013).
- *Major developments have occurred in the past 25 years and the pace is accelerating*. For instance, major developments in nonthermal and advanced thermal preservation technologies (e.g., Knorr et al., 2009) have proceeded apace, and some technologies are either already commercial or on the verge of being so. Hence, it is too soon to conclude that the best developments in FE were in the 1970s, as described above. It is worth noting, however, that it is not advisable for FEs to assume that consumers perceive the value of the process. Most often, consumers buy products, not processes; that a process is fascinating and attractive to academics does not make it capable of producing products that improve their marketability or value through the consumers' eyes. Thus, consumers should be taken into consideration in order to avoid situations in which the process is perceived unacceptable (e.g., radiation).
- *Outside the field*. Some major engineering developments affecting the food industry have occurred outside the normal FE channels (e.g., equipment companies, sensors and automation developments, foodservice applications).
- *The 21st century is replete with potential opportunities for FEs to contribute.* Some of the major drivers are: the world population (soon to be >7 billion) creating endless challenges (e.g., food supply systems design, antibiotic resistant pathogens, food safety, improved microbial inactivation technologies, bioactive components, minimal processing, sustainability, environment). All these topics lie at the interface of biology and engineering; and in particular, FEs are in a prime position to bring their skills and creativity to bear on them. Viewed from this perspective, it is the Best of Times indeed. This, for example, is the approach taken in the UK, in which research funders have realized (or have been told) of the size and significance of the food industry – and the severity of the issues linking to water and energy shortage.

Desired Consequence of the Best of Times Narrative –

- *Broader definitions.* FE definition to include current and future challenges leading to increased membership base enhancing our place and roles.
- *Organization of FEs.* To be structured into an inclusive organization enabling young FEs to experience an environment within which mentoring can occur, and the probability of higher success.
- *Collaboration.* Should be among FEs to increase visibility and funding for the group. Increased representation for FEs on university faculties enabling us to influence university administrators to invest in our important field.

It is time to overthrow the outdated ways of thinking about FE and to move forward with a more inclusive and forward thinking paradigm that also calls for reinventing and re-innovating the FE profession. We will first highlight several major recent trends that will have a significant effect on FE. Then, the information provided is analyzed for outlining selected recommended changes.

2. Selected major trends that will affect FE

The major trends summarized below have been selected based on a personal assessment. Numerous other important developments were not included. This was done deliberately due to space limitation. However, the reader is encouraged to add his or her own choices for a more complete picture.

(a) World population growth and aging

UN "median-variant" scenario, often seen as "most likely," predicts a world with 9.2 billion people by 2050, up from nearly 6.8 billion today (Block, 2012). Most of the growth is expected in less developed regions and economies. Another significant trend was defined as the 'Silver Tsunami'. According to the Boston Consulting Group (BCG; Kuenen et al., 2011) the dependency ratio (the number of people aged 65 and older for every 100 people of workforce age), rose from about 8 to 11 from 1950 to 2000, respectively, and more alarmingly, it will further rise to an estimated 25 by 2050. In developed countries, the average life expectancy increased from about 66 to roughly 78 years in 1950 to 2010, respectively. Simultaneously, fertility rates (measured as children per female) fell from 2.8 to 1.7. These numbers highlight very important trends of overall significant population growth, increased life expectancy and older people. These trends will have a significant impact with far-reaching ramifications for global food production, a need to supply adequate food and health-care, and special consumers' needs and expectations.

Population aging exacerbates some of the present risks and will play even a higher role in the future. Global aging will put significant pressure not only on corporate growth and productivity, but also on national pension, health-care, and welfare programs—as well as overall economic stability. The difficulties it will present are fundamental, with far-reaching ramifications.

On the one hand, the change in demographic patterns could present sizable risks. On the other hand, it also offers unique opportunities that will be created across virtually all industries and regions. The first step is simply for FE to recognize that a major demographic shift is at our door steps and that we should to be prepared for it. Hence, the need for new technologies, biotechnology, better utilization of land and water resources, reduced waste, renewable and sustainable food resources are paramount.

(b) ‘‘Digital Universe’’, ‘‘big data’’ and informatics

The ‘‘digital universe’’ or ‘‘big data’’ stands for large pools of data that can be captured, communicated, aggregated, stored, and analyzed. Digital data has become a part of every sector and function of the global economy. For instance, every day, 2.5 quintillion bytes (equal to Exabyte or EB; 1 EB = 10^{18} bytes) of data are created. As much as 90% of the data in the world today has been created in the last two years alone. This data is the outcome of a plethora of various sources (e.g., sensors, social media sites, digital pictures and videos, purchase transaction records, cell phone GPS signals; IBM, 2012). According to an IDC report (IDC, 2011), the amount of information created and replicated surpassed 1.8 zettabytes (1.8 trillion gigabytes), and it has grown by a factor of 9 in just five years. This mind boggling data explosion is also manifested in the market for big data technology and services that grows at an annual rate of nearly 40% and will reach $16.9 billion by 2015.

Given the ever-growing, technology-driven data stream in today's scientific world, there is an increasing need for methods and tools to make sense of these complex data sets in diverse fields. The ability to examine all potentially interesting relationships in a data set, independent of their form, offers tremendous versatility in the search for meaningful insights (Reshef et al., 2011). Hence, the ramification of big data is in the way businesses manage and extract value from their most important asset – information, and finding answers where ‘there are yet to be questions’ (IDC, 2011).

The big data phenomenon is not new. A decade ago, we (as many others) predicted that ‘‘Biomics, comprised of genomics, proteomics and metabolomics, is taking up its position as a lead science for the 21st century. Its influence on nutrition and FS will generate a unified area of research where both nutritional benefit and traditional food values become parts of an extended life science driving towards enhanced quality of life. Future developments in biomics, bioinformatics and information technology based approaches to foods will truly change and revolutionize the way food industry will satisfy consumer needs and wants.’’ (Desiere et al., 2002).

What role FE will have in this evolution remains to be addressed. However, the tools and know-how so FEs will be able to interact, interpret and utilize the richness of the big data, and to be able to cope with the explosion of information and the exponential growth and complexity of science and technology.

(c) Personalization: Food, health and wellness

The astounding scientific progress in biological sciences, nanotechnology and biotechnology are incredible by any standard. The vast progress is also projected by the fact that several commercial companies are already offering some DNA sequencing for less than $299 (e.g., https://www.23andme.com/; visited June 9, 2012). Combining this information with the capability to test a large genealogical DNA database will provide the foundation for personalization of food, nutrition and health in the foreseeable future.

FE needs to play a proactive role in developing the scientific understanding, processes and technology to address food personalization and supply unique products for different consumers. Moving from mass production to target groups with unique health and wellness (H&W) needs requires a new mindset, skills and know-how. The integration with other domains (e.g., medicine, biochemistry, chemistry, health authorities, consumers) mandates partnerships, collaboration, and becoming a key player in this complex ecosystem. It is worth noting that personalization runs against the past approaches that were concentrating on production in larger and larger factories, farther and further apart. So to go into personalization means either (i) late customization at the point of sale, or (ii) lots of smaller plants. Topics such as energy, water and land depletion, carbon print, sustainability, and the economics of running 3000 mile supply chains already attract a lot of interest and will continue to evolve affecting FE's future.

Food processing is mainly targeted to a more efficient use of resources. It also provides one of the main opportunities for FE by focusing on product engineering (i.e., designing and controlling food microstructures). In other words, this means, ‘inside engineering of foods,’ that creates value recognizable and appreciated by the consumers. A significant counter trend focuses on more organic, locally grown foods. This trend considers the term ‘‘processed food’’ (i.e., opposite of ‘‘natural’’) to be a negative connotation, and lays the blame for obesity squarely on the industrial food supply system (Pollan, 2008). While it is easy for the scientifically minded to scoff at these viewpoints, the major growth of the organic food segment in supermarkets, and the legal battles over access to the fresh produce section of the supermarket, is evidence of its economic clout. The argument put forward by the proponents of this view is that the approach of reduction of food to its nutrient components has resulted in an overly simplistic view of food, termed as ‘‘nutritionism’’, wherein our limited scientific understanding of food components and their benefits results in development of products that are presumed to be beneficial, but which may in fact be contributing to a decline in overall health and wellness. Indeed, the common recommendations for health, the consumption of more whole grains, fresh fruits and vegetables, runs counter to the argument for more processing and formulated foods. While the scientific basis for such claims need verification, the approach may well dictate new directions and opportunities for FEs seeking to work in minimal processing and preservation technology.

(d) Food security, environment, sustainability and social responsibility

Even as the food supply expands every year, the number of hungry people has grown over the last decade. Today, nearly 1 billion people are undernourished and the world will almost certainly fail to reach the UN Millennium Development Goal of halving the proportion of people who suffer from hunger by 2015. This reality has severe consequences for the health and survival of countless individuals, as well as for the social and economic development of entire nations (Villis and Hajoui, 2012). With the world's population expected to reach 9 billion by 2050, the problem of undernourishment remains a priority—particularly in regions that lack widespread food security (i.e., food availability, food access, food use based on knowledge of basic nutrition and care, and adequate water and sanitation; WHO, 2012). Achieving food security requires addressing land and water scarcity. By 2030, demand for water is forecast to be 50% higher than today, and withdrawals could exceed natural renewal by over 60%, resulting in water scarcity. With more than two thirds of all water being withdrawn by agriculture, food security is also at stake if world's water crisis is not resolved (Nestlé, 2011). Developing low cost nutritious and healthy foods (e.g., costing less than $1 per portion) for the urban poor is another significant challenge.

These data highlight some of the major challenges (e.g., water management -clean fresh water, irrigation, recycling, renewable water resources; diminishing farmland; sustainable energy supply – storage, transport, renewable & alternative resources; low cost nutrition, food security). Hence, future processes should focus on promoting technology change and productivity growth, reducing waste, unique processes for less developed regions, sustainability, green technologies, lower water consumption, postharvest practices, as well as enhancing investment in sustainable agricultural production capacity, rural development and support to farmers.

To further highlight the above, a recent EU forecast for Food Drink Europe 2030 lists a need for a global increase of 50% in food supplies and energy, and 40% in water (FoodDrinkEurope, 2012). Food waste and losses are alarming and call for immediate actions (Gustavsson et al., 2011). Some 4-billion metric tons of food per annum is produced. Yet due to poor practices in harvesting, storage and transportation, as well as market and consumer wastage, it is estimated that 30–50% (or 1.2–2 billion tons) of all food produced never reaches a human stomach (Institute of Mechanical Engineers, 2013). These disturbing global food waste, challenges FE to play a proactive role in developing new concepts, technology, transportation, infrastructure and processing, as well as consumer policies for addressing the need to feed the world to ensure its sustainability and food security.

Sustainability is another topic that requires special consideration. Not too long ago, it was a "nice to have" word in all reports. Since then, leading companies across the globe have realized that sustainability is also good business. No longer just a matter of legal compliance or philanthropic generosity, enterprise sustainability today is a strategic business imperative (Butner, 2010). The European food and drink industry puts sustainable growth at the heart of its business model. Ensuring sustainability, therefore, not only helps safeguard the Earth's limited natural resources, but also secures long-term competitiveness and prosperity (FoodDrinkEurope, 2012).

(e) Innovation ecosystem (open Innovation and partnerships)

In the last decade, OI has become a core part of the innovation ecosystem. The mantra "innovate or die" is no longer sufficient. OI and innovation partnerships could be the leitmotif for today's companies (Traitler and Saguy, 2009; Traitler et al., 2011). OI has been defined as "a paradigm that assumes that firms can and should use external ideas as well as internal ideas, and internal and external paths to market, as the firms look to advance their technology" (Chesbrough, 2003). It refers to organization permeability (i.e., openness) to acquisition, of new ideas, patents, products, etc. from outside its boundaries, often via licensing protected intellectual property. Recent definition of OI is: "the use of purposive inflows and outflows of knowledge to accelerate internal innovation, and expand the markets for external use of innovation, respectively" (Chesbrough et al., 2006). This openness distinguishes it from a closed innovation where all inputs are generated internally. However, OI should not be confused with "true openness" mainly applied in open code software such as Mozilla's Firefox browser (Melese et al., 2009; Müller-Seitz and Reger, 2009).

OI is founded on the reality that, in a world of vastly distributed knowledge and accelerated rates of development, companies can no longer afford to rely only on their own research: they must utilize outside sources and partners, buy or license processes, technology, inventions and solutions (Traitler and Saguy, 2009). OI has seen a massive expansion in recent years (Gassmann et al., 2010; Lindegaard, 2010), having spread and mushroomed in many industries (e.g., pharmaceuticals, chemicals, biotechnology, drugs, software). The large food companies have followed suit (e.g., Erickson, 2008; Fortuin and Omta, 2009; Kuhn, 2008; Saguy, 2011b; Sarkar and Costa, 2008; Traitler, 2009; Traitler et al., 2011; Traitler and Saguy, 2009), as well as small and medium enterprises (SMEs; e.g., Kocher et al., 2011; van de Vrande et al., 2009).

Despite OI's widespread applications, only 10% of all companies are ready for it; of the rest, 30% (denoted as "contenders") have seen the light and are struggling to make it work, and the remaining 60% of companies (denoted as "pretenders") don't really know what it is and why or how it could be relevant to them (Lindegaard, 2010). SMEs and others firms operating in traditional sectors are struggling with its implementation due to their relatively low level of absorptive capacity, and management challenges which are perceived as unattainable (van de Vrande et al., 2009; Lindegaard, 2010). The untapped potential and full adaptation of OI is particularly relevant for FE future activities.

3. FE education – A brief history, current developments and future needs

Developments in education are the harbinger of new paradigms for a profession. In 1952, Parker et al. published a series of three volumes on *Elements of Food Engineering*. These books heralded a new field of study to address the growing needs of the food industry of that era. A series of articles appearing in *Food Engineering* magazine in the early 1950s noted that demand for FEs in that decade exceeded the supply (Lawler, 1953). These articles exhorted students to pursue FE, identifying "a large demand for technical people, good starting pay, limited technical competition, and a high degree of job stability in the emerging field of food engineering." Among the areas of work, needs were expressed in process development, equipment design and fabrication, plant design and construction, and engineering research. Kaufman (1952) argued that to feed an increasing population, there was an important need to find new processing methods along with increasing production of agricultural crops and emphasized the new role for FEs and food technologists in the expanding food industry.

Some of the early books published in FE provide a good understanding of how this field has changed since its inception. Parker et al.'s books were focused on the descriptive aspects of processing technologies employed in the food industry. In *Unit Operations in Food Processing*, Earle (1966) provided simple expressions useful in design and analysis of food processing. A major change in the content used for FE education occurred with a book written by Charm (1963). He introduced a more quantitative approach in presenting heat and mass transfer based on advanced mathematics. This approach, based on the author's lectures given at the Massachusetts Institute of Technology, became readily accepted in teaching food engineering. The emphasis in educational programs shifted to studying kinetics of reactions as well as heat and mass transfer to allow design of equipment and processes appropriate for the food industry.

A quantitative description of FE, based on rheology, mechanical operations, heat transfer, and mass transfer, with its applications to selected unit operations, was the basis of *Food Process Engineering* by Heldman (1975). Other books from the same vintage included Harper (1976) and Loncin and Merson (1979). In most cases, these books were written for students pursuing an engineering degree with application in food processing. These books contained mathematics and physics at a level commensurate with what engineering students studied in their typical degree program.

In 1984, Singh and Heldman (1984) wrote "*Introduction to Food Engineering*" as a textbook for students studying FE in the FS curriculum. Students pursuing a degree in FS normally do not take advanced subjects in mathematics or physics that are typical of engineering students. Therefore, the emphasis in this book was to provide algebraic solutions of various mathematical expressions that are useful in design and analysis of common food processing operations. Other books written more specifically for FS students included Toledo (1980), and Brennan et al. (1990). With the increasing use of computers in the food industry, the contents of these books reflected such developments. For example, in the most recent edition of *Introduction to Food Engineering*, Singh and Heldman (2013) included the use of spreadsheet-based solutions of engineering problems, use of MATLAB™, and web-based animations of food processing equipment. Future developments in the publishing arena will provide new opportunities to authors for including more multimedia resources in digital versions of textbooks appropriate for teaching food engineering. It is worth noting that even a MATLAB illiterate person can use the new user-friendly programs much more effectively so that problems that have been traditionally done by graphical method or by approximation can be addressed properly using a correct numerical approach (e.g., Barsa et al., 2012). Online calculators for various FE problems have been developed by Mark D. Normand, Micha Peleg and others (http://demonstrations.wolfram.com/index.html; visited September 8, 2012). Similar to the aforementioned developments in the printed resources for FE education, classroom teaching is undergoing dramatic changes. Methods used for teaching science and engineering courses continue to evolve with the increased availability of tools that show promise for improved learning and retention of subject matter by students. During the past five decades, the availability of these tools has occurred at a rapid pace. While a hand-held "slide rule" was the main device for solving numerical problems in the 1960s, today's engineering students are using advanced computational fluid dynamic solvers to visualize and comprehend underlying concepts of given problems. Largely, this change has occurred with the development and widespread availability of personal computers. A quick review of teaching tools developed in the recent past shows how the class room teaching of engineering subjects has embraced the use of spreadsheets for calculations, digital slides for textual content, animations of simple to complex engineering systems, and the use of various communication methods to allow more students to interact with the lecturer. The role of technology in education is now an active subject of scientific inquiry. In a series of articles published in *Science*, many authors demonstrated the widespread influence of technology in enhancing Science, Technology, Engineering and Mathematics (STEM) education (Dede, 2009; Greenfield, 2009; Mayo, 2009; Mayadas et al., 2009). The role of immersive interfaces for engagement and learning in the context of computer video games was discussed by Dede (2009). An example of an immersive game developed at Harvard university, called *River City*, was used to demonstrate that "a broader range of students gain substantial knowledge and skills in scientific inquiry through immersive simulations than through conventional instruction."

While hands-on laboratory experiments are most effective in learning new scientific concepts and testing novel hypotheses, many experiments in food processing are time consuming. Limited time available in a typical laboratory period does not permit thorough examination of process variables. These constraints force instructors to demonstrate a process with limited engagement of students in investigating various operating procedures and their effects. The heavy demands on faculty time and resources have forced many institutions to seriously curtail teaching such courses. Similarly, factory tours and field trips are now rarely undertaken. Yet it is undeniable that operation of food processing equipment in a pilot plant offers the most engaging environment for a student to learn the "why" and "how" of a process and its underlying mechanisms that impact the ultimate quality and safety of a food. Such experiential activities offer excellent opportunities to observe and analyze the connections between the process carried out with processing equipment and what is learnt in a basic science course such as physics, chemistry or microbiology. In a book on *Virtual Experiments in Food Processing*, Singh and Erdogdu (2009) used computer simulations of selected food processing operations for students to conduct virtual experiments. Vieira and Ho (2008) edited a book, "*Experiments in Unit Operations and Processing of Foods*," wherein experiments are described, experimental results supplied for student work, and videos can be visited at https://www.iseki-food.net/equipment/pilot_plant. Moreover, a database was created to help educational institutions to share their resources. In the future, more reliance on such approaches using digital technology is anticipated.

There is no denying that today's students are extremely computer savvy. According to a recent study from the Pew Internet and American Life project, more than one-half of all teens have created media content, and roughly one-third of teens who use the Internet have shared content they produced (Lenhardt et al., 2005). Electronic gadgets relying on the Internet are now being increasingly used in large-enrollment classrooms. During the past decade, computer games have become increasingly popular as a source of entertainment for the younger generation. In this rapidly changing environment, students now expect any educational product that relies on multi-media technologies to have the fidelity that is being provided by the entertainment industry. Production of high-end products for use in education has remained limited due to the high cost of software and related resources. Fortunately, many of the software programs used in producing animation movies for the screen are now being offered for educational purposes at heavy discounts. Furthermore, a large resource of animated graphic clip-art has been created by the Internet community and is now becoming easily available at an affordable cost. It is therefore timely to develop high fidelity, computer-based educational content that is highly engaging, yet effective in its delivery.

The FE curriculum in the future will require incorporating new topics that are now beginning to impact the food industry. The study of energy and water utilization in industrial operations will require increasing emphasis. The role of industrial operations on the environment, in both carbon and water foot print impact and in the selection of various options for delivering foods from the farm to the consumer, will need to be addressed in future course work. Similarly, the role of traceability in food safety is a topic that is ripe for developing new course material. With more consumer emphasis on links between food and health, courses at the interface between engineering, medicine and nutrition will need to be considered. Further automation in the industry will require courses on robotics, neural networks, and the use of advanced imaging techniques in food processing operations. The challenge for future educators will be how to provide appropriate coverage of these emerging topics in a typical degree program.

The benefits of industrial engagement during undergraduate education involving industrial internships are well documented. Such programs are expected to grow as an alternative to conducting experiments in pilot plants that are becoming too expensive to maintain at educational institutions. Innovative approaches in greater sharing of educational resources by institutions are expected in the future. The European Master's degree program is an excellent example of how collaborations between universities, with industrial support, can result in an effective educational experience for students. The ISEKI_Food network has developed several databases to help sharing resources (https://www.iseki-food.net).

The ISEKI_Food network is a remarkable network, initially supported by the European Union (www.isekifood.net). The most recent project is ISEKI-Food 4 (http://www.iseki-food4.eu/). It involves 86 partners from 27 European countries and 3 partners from non-European countries, with more than 40 associated partners from all over the world. Its key objectives include (1) to innovate the education and training of Food Science and Technology

(FS&T) students by the development of guidelines to update and modernize higher education courses and training programs and tools, including new scientific disciplines and teaching approaches to produce the FS&T professionals of the future and (2) to implement the role of the third level of education (PhD programs, in particular) in promoting the employability and entrepreneurship of the graduated FS&T and food professional, and (3) To create a framework offering lecturing qualifications for university teaching staff.

A recent editorial (Anon., 2012) highlights an additional important point concerning advanced studies, namely, ''it is prudent to ask whether the training that graduates receive allows them to make informed choices about whether to pursue a career in science, as well as how to succeed once that choice has been made.'' The recommended view of this editorial was: ''Importantly, the next generation must be given a realistic view of what it takes to succeed in science so that they can make an informed choice about their future career path. In this regard, waiting until graduate school may be too late, and we should consider delivering courses on 'how science works' as part of undergraduate science degrees. Such courses could provide training in science communication, experimental design, ethics, publication, funding, public engagement and science history, as well as introducing the wide range of academic and non-academic careers that are open to science graduates.''

The European Track_Fast project (www.trackfast.eu), coordinated by the ISEKI_Food network and recognizing this need, developed the website http://www.foodgalaxy.org/, with the aim to inform and attract a new generation of food science students and professionals. Moreover, employers are demanding non-specific skills and the above mentioned Track_Fast project is making an important contribution in Europe in this field. Such projects are aimed at addressing new challenges for educational institutions to ensure that the curricula help in the development of required skills.

4. A European (and especially a UK) perspective

The food industry is bigger than people think – for example, in the UK the food industry is the largest manufacturing sector, at 15%, and is responsible for 160 $MtCO_2$ emissions, and uses 367 TW·h annually, approximately 18% of total UK final energy use. The importance of the sector in manufacture is sometimes forgotten.

FE in Europe is widespread in academia, although there are few formal FE schools (e.g., Lund, Sweden; ENSIA, France). Excellent FE groups exist in most countries. However, in UK, there is little tradition of FE as a separate degree course, as training in most universities is based around classical disciplines. Over the last 20 years, most FS&T departments in the UK, as elsewhere, have tended to concentrate on biology and nutrition – largely because that is where they can get students and research funding. Although physical science is still important, and physical scientists still teach in these departments, the amount of material that could be classed as engineering is small – and the decrease in the mathematical skills of the students has not helped the teaching of what is sometimes technically difficult material. This has reduced the amount of engineering taught and researched in many food departments.

However, many CE departments have over the last 20 years developed an interest in food processing. This has happened for a number of reasons. In the UK, the major industries that had supported the discipline, largely petro chemically based, are now mature and have reduced their manufacturing and research base, and secondly, the number of CEs recruited into Fast Moving Consumer Goods (FMCG) companies, including food, has increased. Most of the UK CE departments now carry out research into foods, although Birmingham, with >25% food processing research, is the largest group.

(a) Industry and the EU: collaboration

Work on food processing in Europe has been driven by the large number of major food companies that have grown up and are based there. The large research centers of Nestlé in Switzerland and elsewhere, of Unilever at Colworth and Vlaardingen, and of companies such as Danone and Cadbury, have created an environment in which food research is important in the EU. Companies such as Kraft, which recently bought Cadbury, have invested significantly in research in the UK, for example into Bournville (chocolate) and Banbury (coffee). The companies have also provided a significant source of employment for highly qualified food scientists and engineers– as well as recruiting people from outside the field with degrees in other disciplines. The work in these research centers is often of very high quality, for example, integrating materials physics into food product characterization and design (such as Ubbink et al., 2008).

The success and size of these major companies means that they are able to influence policy. For example, Unilever has been able to influence the funding policies of the UK and Dutch government and to ensure that food research (such as nutrition and materials science) is supported. That has made the funding of food work easy. For example, in the UK, engineering research is funded by the EPSRC (Engineering and Physical Sciences Research Council) whilst biological and food research is funded by BBSRC (Biology and Biotechnology Research Council). Funding FE, therefore, can be tricky! The two councils have to work together to allow research across the interface, which can be difficult to organize.

Industry is also influential in the EU, which has established a 'Technology Platform' called 'Food For Life' (http://etp.ciaa.be/asp/index.asp) that acts to set the research agenda and to try to link industry and academia. The intention is to create a research agenda that is integrated across the EU. The creation of European research through the centralized Framework system has been highly successful – research programs have to be multi-center and multi-country, and also commonly involve 50% industry funding, usually in-kind. The drawback is, however, excessive complexity in application and administration: creation and management of a large consortium is often a full-time job that cannot be done by many groups. Large organizations, such as Wageningen, Campden BRI in the UK, and INRA in France, are well-suited to the management roles. However, this complexity also makes the structure inflexible – once consortia have been successful, they tend to stay together, and can be difficult to join. A number of these programs have involved food engineering, and have led to excellent research that would have been difficult to do any other way. For example,

- NOVEL Q – Links more than thirty industry and academic partners across the EU (and outside; including groups from South Africa and Argentina) to study high pressure processing (HPP), pulsed electric field processing (PEF), plasma decontamination, advanced heating technologies and packaging.
- MODSTEEL – Developing low-energy surface coating for reducing fouling in heat exchangers during treatment of milk products making food plants less prone to protein adsorption and easier to clean (Santos et al., 2004), linked groups from Portugal, Germany, the Netherlands, Greece and Sweden.

As well as research programs outputs, some of the EU schemes, such as 'Marie Curie' in which students from one EU country study for PhD degrees in other countries, have been very successful in creating skilled engineers and scientists who have a strong research background and experience of many countries. These people tend to be very employable – speaking multiple languages as well as being technically qualified. The EU programs have both created a pool of skilled graduates who understand food and FE, and linked disparate groups across the continent.

(b) Commonality with other industry sectors; formulation engineering

Classical process engineering is concerned with processing materials, such as petrochemicals, which can be described in thermodynamic terms. However, modern process engineering is increasingly concerned with production of materials whose structure (micro- to nano-scale) and chemistry is complex and a function of the processing it has received. For optimal performance, the process must be designed concurrently with the product, as extraction of commercial value requires reliable and rapid scale-up. As an example, if the thermal and shear history of chocolate is incorrect, the product does not solidify in the right crystal form (Stapley et al., 1999; Tewkesbury et al., 2000). Not only foods, but also pharmaceuticals, paints, catalysts and fuel cell electrodes, ceramics, thin films, cosmetics, detergents, and agrochemicals are structured products. In all of these, material formulation and microstructure controls the physical and chemical properties that are essential to its function. Wesselingh (2001) gives an excellent outline of the need for the shift from process to product engineering in both teaching and research, whilst Charpentier (2002) discusses the understanding across length-scales needed in product development as the '3rd paradigm' in CE.

One concept we have found especially useful from the product (or formulation) engineering approach is to group together problems in different industries that have essentially the same physics. The research issues that affect widely different industry sectors are common: the need is to understand the processing that results in optimal nano- to microstructure and thus optimal effect. Products are structured solids, soft solids or structured liquids, with properties that are highly process-dependent. To make these products efficiently requires combined understanding of their chemistry, processing and materials science. Much of the science within these sectors is common and built around designing processes to generate microstructure:

- To *optimize molecular delivery*: for example, there is commonality between food, personal care and pharmaceuticals; in all of these sectors, molecular delivery of actives is critical (in foods, to the stomach and GI tract, to the skin in personal care, throughout the body for the pharmaceutical industry);
- To *control structure in-process*: for example, fuel cell elements and catalysts require a structure which allows efficient passage of critical molecules over wide ranges of temperature and pressure; identical issues are faced in the manufacture of structured ceramics for investment casting, in chocolates and spreads, and in the controlled release of molecules in foods and pharma;
- Using processes with appropriate *scale and defined scale-up rules*: the need is to create processes which can efficiently manufacture these products with minimal waste and changeover losses.

Critical common drivers for research are:

- *Energy and sustainability:* For example; (i) personal products are increasingly using natural feedstock that are inherently unstable and variable and must be disposed of without environmental impact; (ii) ensuring food supplies for the world's population means that food manufacturing processes have to be much more efficient.
- *Health:* designing structures that deliver drugs or nutrients effectively to the body, such as (i) building foods that have high-fat taste but low-fat functionality (Norton et al., 2006), and (ii) creating delivery systems that enable biotherapeutics to be delivered where needed.
- *Scaling up nanotechnologies:* many of these materials could exploit new nano-scale understanding (for example, nanoemulsions and nanoencapsulates which can deliver nutritional or biotherapeutic actives) if efficient scale up routes for these materials were available.

Using this approach, it is possible to create partnerships between food and other product engineering companies – the Centre for Formulation Engineering in Birmingham has received significant support from food companies such as Kraft and PepsiCo, as well as FMCG companies such as P&G and Unilever, pharma companies such as GSK and Pfizer, as well as fine chemicals companies concerned with formulation, such as Johnson Matthey, Imerys and BASF. Work on FE is thus supported by a range of companies that have the same interests, but are not direct competitors. This linkage enables us to get larger and better funding support than if we go to food companies alone, as the funding bodies see that the interests are cross-sector and of value to more than one industry. Such linkages might be possible elsewhere.

5. FE paradigm shifts

FE needs to reassess its vision and strategy to meet future challenges and to continue to play a key role in food and wellness domains. Some significant paradigm shifts are highlighted to address the vast opportunities. It should be emphasised, however, that these shifts are quite limited by our personal views and assessments. To really move forward, consensus is needed and therefore open deliberations and further discussions are highly recommended.

(a) Academia and industry new roles

To effectively cope with the accelerating exponential and unprecedented development of science and technology, universities and industry need each other. This necessity is amplified by the quest for highly qualified human resources and the ever-increasing cost of research and equipment.

The 'old' characteristics of the professor should be redefined. In addition to all the known responsibilities and activities, he or she should also play a proactive role in industry as well, motivated by the synergistic power of collaboration and driven by the overall goal of becoming a full member of an industrial team. This could require devoting ample time to a particular industry and becoming an "organic" member of the industrial OI effort. The intimate presence of academicians in industry should create new possibilities, such as offering advanced industrial studies (PhD, MSc). This approach could lead to significant outcomes, such as opening the door to industrial internships, fellowships, advanced education, etc. (Saguy, 2011c; Saguy, 2013). For instance, the Royal Academy of Engineering in the UK has recognized this topic, and runs schemes not only to embed academics into industry, but also to move industrialists into academia. Thus, both sides learn the problems of the other – and the academics hopefully learn the problems that are both technically exciting and industrially relevant.

Basic research is the foremost objective of any leading academic institute, and excelling is paramount. However, the model of fundamental research carried out in isolation is probably not sustainable by itself anymore. A new mantra should be utilized, i.e., from invention and discovery to enhanced collaboration and relevance. We need to realize that applied research is also important, as it ameliorates research and teaching, enhances students' exposure, and increases resources and collaboration. One of its most important features is relevance.

Embracing people working in the industry should be favourably considered for teaching and other academic activities; moreover, they could be utilized to facilitate knowledge transfer, ultimately promoting innovation, collaboration and entrepreneurship. This new paradigm calls also for more intimate industrial involvement, mainly of its leadership and experts, transforming their role into a proactive one by teaching graduate courses, mentoring research, serving on university committees and boards, contributing to the strategic thinking of the universities, and enhancing their overall contributions to social responsibility. Industry, in addition, needs to take a proactive-role in shaping the vision and the curricula, committing to long-term support, and utilizing *'Sharing-is-Winning' principles* (Traitler and Saguy, 2009), namely; start a dialog, establish trust, build goodwill, and create value. Surprisingly, these simple and straightforward governing principles are not always practiced. Embracing industry should be extended also to collaborations with chefs, considered by some as 'most innovative individuals in the food industry' (Aguilera, 2009). This will start a new wave of scaling-up gastronomic engineering for a premium food industry market.

Academia's new roles also call for some additional significant modifications. A recent book described "the power of pull" (Hagel et al., 2010), which is based on three main elements: access (find, learn and connect with people, products, and knowledge to address unanticipated needs), attract (people and resources one did not even know existed but are most relevant and valuable), and achieve (pulling out personal and institutions' full potential with less time and greater impact). This offers a very plausible approach for creating value and rapidly driving performance to new levels. It calls for the creation of environments that effectively integrate teams within a broader learning ecology so that performance improvements accelerate as more participants join in. Adapting this approach would allow us to move away from the "old" way of "push" (e.g., being able to predict demand for goods, services, education needs) to the new way of "pull"; it requires the creation of innovation ecosystem(s) that will go beyond single university boundaries by transforming learning and teaching methods, encouraging the combined efforts and full participation of all of the diverse stakeholders, and most importantly, make use of passionate human resources. However, accomplishment of this paradigm requires a new mind-set that facilitates thoroughly revision and/or development of new curricula, teaching and learning methods, so that ultimately FS&T and FE academia will reinvent and re-innovate its domain. It also calls for promoting porous and interfacing boundaries, interdisciplinary and serendipitous connections, and entrepreneurship. All these ingredients should provide an engaging environment and stimulating ecosystem for students. Social networks should play an important part, and its vast economic potential for education specifically was recently highlighted (Chui et al., 2012). Last but not the least, both academia and industry need to play a very important role in mentoring the new generation, and in addition to science and technology, social responsibility, values, ethics, and soft skills should be also taken into consideration. Passion and love of the profession is also a part of this mentoring responsibility.

(b) Food and health '*Enginomics*'

Considering the vast scientific progress, FE needs to play a proactive role in the innovation ecosystem. Multidisciplinary knowledge base, health and food security are some key paramount ingredients that should be included. '*Enginomics*' (engineering + nomics) depicts some of the major topics FE should consider. '*Enginomics*' (e.g., internal human unit operations, gastric processes, targeting, bioavailability,+...) is comprised of these main pillars:

- Food (e.g., properties, composition, renewal food resources, + ...).
- Product engineering (structures and microstructure design, material science, packaging, modeling, + ...).
- Human internal processing (inner unit operations, gastric, digestibility, targeting, bioavailability, micro-processing, + ...).
- Manufacturing (e.g., processing, waste and water management, environment, compliance, regulations + ...).
- Health and Wellness (e.g., medicine, brain, biology, biota, pro and pre-biotic, nanotechnology, biotechnology, + ...).
- Nutrition (e.g., personalization, prevention, satiety, + ...).
- Consumers (e.g., safety, acceptability, special needs, emotions, pleasure, +...).
- Social responsibility (food security, feeding the world, ethics, values, sustainability + ...).

Enginomics is a term coined for highlighting the importance of the emerging trends of H&W and the need to focus on units operation inside the human body. It most probably will be changed and/or improved in the future. Yet, it is used to promote discussion on the exact term and/or how to optimally implement it considering the vast scientific knowledge and complexity of the future.

(c) Innovation partnership: from triple- to quadruple-helix

The "triple helix" (Etzkowitz, 2008) encompasses university, industry and government, and their interactions are a crucial element of innovation in increasingly knowledge-based societies. This triple helix intersection of relatively independent institutional spheres generates hybrid organizations such as Technology Transfer (TT) or Knowledge Transfer (KT) offices in universities, technology-based firms, and government research labs. Although this concept is very appealing as it integrates the key players in the innovation ecosystem, it lacks a very significant fourth player, namely the private sector, which includes small businesses, banks, private and venture capital (VC) funds and angels: these are extremely important in jump-starting the innovation process and providing the required and essential resources. This concept was termed the fourth helix (Saguy, 2011b) and it should be implemented for acceleration of innovation and crossing what is also known as the valley of death (Traitler et al., 2011).

To date, VC is very difficult in the food industry, as the return on capital is much less than can be found in pharma and in the software or electronics sectors. In addition, the time span required is much larger compared with software and similar industries. This issue calls for in depth assessment and development of good practices that should be applied to facilitate future VC funding and how to attract all the stakeholders.

(d) Social responsibility and metrics

For a business to create value for its shareholders, it must also consider how to bring value to society. Since the first emergence of corporate social responsibility (CSR) in the 1950s (De Bakker et al., 2005). CSR has moved from ideology to reality and represents an important dimension in contemporary business practices (Maon et al., 2009). CSR has also been implemented in Open Innovation (OI) to promote innovation (e.g., Jenkins, 2009; Rama et al., 2009; Saguy, 2011a). The contemporary term of Creating Shared Value (CSV) considers how to provide joint benefits to all stakeholders. It also recognizes that social harm or weaknesses frequently create internal costs for firms—such as wasted energy or raw materials, costly accidents, and the need for remedial training to compensate for inadequacies in education (Porter and Kramer, 2011).

This approach deserves additional consideration so that it can also be adopted by academia. Universities have an important social responsibility and therefore should play a major role in maximizing research impact, while simultaneously considering CSV. This should include scientific merit as well as overall contribution to society (e.g., job creation, standards of living). Metrics for quantifying scientific contributions have been developed over the years (e.g., journal quality, impact factor, number of citations), as have measures of financial success (e.g., patents, licensing, royalties). Academic social impacts associated with CSR and CSV are still vague concepts. The development of suitable metrics to assess and evaluate research's overall contribution lies at our doorstep, and it is our responsibility to address this complex topic. The new metrics should cover a spectrum of important dimensions: on the one hand, they should continue to promote the high quality of fundamental research and reward scientific breakthroughs, enhanced OI and partnerships. On the other, they should also facilitate and augment contributions to society. A genuine concern for society in all actions and decisions should become the norm and an integral part of the innovation process (Saguy, 2011a,b,c, 2013; Traitler et al., 2011).

The association of university technology managers (AUTM; http://www.autm.net/New_Metrics/4063.htm; visited April 2, 2012) suggested metrics for public research institution contributions to the economic health of their communities. Some of the metrics suggested are: institutional support for entrepreneurship & economic development, ecosystem of institution, human transfer activities, technology knowledge transfer activities, network creation activities, and value creation activities.

These are extremely important attributes and should be considered as a part of academia's social responsibility and for assessing the ability for a given research institution to make an impact on the community and economy.

6. Recommendations

The above highlights these main points: (i) FEs need to know is common to us all, and the skills are useful to industry and in research; (ii) there will have to be a multiplicity of solutions for different parts of the world as different countries have different industries and traditions; and (iii) challenges for the profession is to find new and innovative ways of ensuring that it continues to build within those traditions.

In a nutshell, these are selected main recommendations for chartering FE's future:

- Expanding academic focus beyond fundamental research, to embracing also applied research, building cohort mutual programs with industry for promoting collaboration, partnerships, open innovation, advanced theses and joint-research, long term support, resource-sharing and social responsibility.
- Broadening FE's role in leading the investigating on the effect of foods and structure on inner human mechanisms, processes, bioavailability and H&W.
- Developing new technology, processes, equipment, package, sensors and automation for both developed and less developed countries and addressing the challenges to ensure food security, population growth and aging, water and land scarcity, and sustainability.
- Fostering engaging novel teaching and learning methods utilizing recent computer technology, social media and big data to attract students and enhance science excellence.
- Enhancing visibility and adequate funding for the field and increasing in the number of FE faculty in academia.
- Proactive role in searching for optimal synergies and partnerships with other professional domains.

References

Aguilera, J.M., 2006. Seligman lecture 2005: food product engineering: building the right structures. Journal of the Science of Food and Agriculture 86, 1147–1155.

Aguilera, J.M., 2009. Gastronomic engineering. In: Moskowitz, H.R., Saguy, I.S., Straus, T. (Eds.), An Integrated Approach to New Food Product Development. CRC Press, Boca Raton, FL (Chapter 18).

Anonymous, 2012. Editorial: next-generation training. Nature Reviews, Microbiology 10 (July), 439.

Barsa, C.S., Normand, M.D., Peleg, M., 2012. On models of the temperature effect on the rate of chemical reactions and biological processes in foods. Food Engineering Reviews 4, 191–202.

Block, B., 2012. U.N. Raises "Low" Population Projection for 2050. Worldwatch Institute. <http://www.worldwatch.org/node/6038> (released 09.06.12).

Brennan, J.G., Butters, J.R., Cowell, N.D., Lilly, A.E.I., 1990. Food Engineering Operations. Elsevier Publication Co., Ltd., Essex, England.

Bruin, S., Jongen, T.R.G., 2003. Food process engineering: the last 25 years and challenges ahead. Comprehensive Reviews in Food Science and Food Safety 2, 42–81.

Butner, K., 2010. Driving performance through sustainability strategy, synergy and significance. IBM Institute for Business Value. <http://www.ibm.com/common/ssi/cgi-bin/ssialias?infotype=PM&subtype=XB&appname=GBSE_GB_TI_USEN&htmlfid=GBE03414USEN&attachment=GBE03414USEN.PDF) (visited 01.06.12).

Charm, S.E., 1963. The Fundamentals of Food Engineering. AVI Publishing, Westport, Conn..

Charpentier, J.-C., 2002. The triplet "molecular processes–product–process" engineering: the future of chemical engineering? Chemical Engineering Science 57, 4667–4690.

Chesbrough, H.W., 2003. Open Innovation: the New Imperative for Creating and Profiting from Technology. Harvard Business School Press, Boston, MA, USA.

Chesbrough, H., Vanhaverbeke, W., West, J., 2006. Open Innovation: Researching a New Paradigm. Oxford University Press, Oxford, UK.

Chui, M., Manyika, J., Bughin, J., Dobbs, R., Roxburghm, C., Sarrazin, H., Sands, G., Westergren, M., 2012. The Social Economy: Unlocking Value and Productivity Through Social Technologies. MaKinsey & Company. <http://MGI_The_social_economy_Full_report.pdf> (visited 20.07.12).

De Bakker, F.G.A., Groenewegen, P., Den Hond, F., 2005. A bibliometric analysis of 30 years of research and theory on corporate social responsibility and corporate social performance. Business and Society 44, 283–317.

Dede, C., 2009. Immersive interfaces for engagement and learning. Science 323 (5910), 66–69.

Desiere, F., German, B., Watzke, H., Pfeifer, A., Saguy, S., 2002. Bioinformatics and data knowledge: the new frontiers for nutrition and foods. Trends in Food Science and Technology 7, 215–229.

Earle, R., 1966. Unit Operations in Food Processing. Pergamon Press, Oxford, England.

Erickson, P., 2008. Partnering for innovation. Food Technology 62(1), 32–34, 37.

Etzkowitz, H., 2008. The Triple Helix: University–Industry–Government Innovation in Action. Rouledge, New York, NY, USA.

Floros, J.D., Newsome, R., Fisher, W., Barbosa-Canovas, G.V., Chen, H., Dunne, C.P., German, J.B., Hall, R.L., Heldman, D.R., Karwe, M.V., Knabel, S.J., Labuza, T.P., Lund, D.B., Newell-McGloughlin, M., Robinson, J.L., Sebranek, J.G., Shewfelt, R.L., Tracy, W.F., Weaver, C.M., Ziegler, G.R., 2010. Feeding the world today and tomorrow: the importance of food science and technology. An IFT Scientific Review. Comprehensive Reviews in Food Science and Food Safety 9, 572–599.

FoodDrinkEurope, 2012. Environmental Sustainability Vision Towards 2030 Achievements, Challenges and Opportunities. <http://www.fooddrinkeurope.eu/uploads/publications_documents/FDE_RALayoutFINAL.pdf> (visited 12.06.12).

Fortuin, F.T.J.M., Omta, S.W.F., 2009. Innovation drivers and barriers in food processing. British Food Journal 111 (8), 839–851.

Gassmann, O., Enkel, E., Chesbrough, H., 2010. The future of open innovation. R&D Management 40 (3), 213–221.

Goldblith, S.A., 1995. Of Microbes and Molecules: Food Technology, Nutrition and Applied Biology at M.I.T., 1873–1988. Food and Nutrition Press Inc., Trumbull, CT, USA.

Greenfield, P.M., 2009. Technology and informal education: what is taught, what is learned? Science 323 (5910), 69–71.

Gustavsson, J., Cederberg, C., Sonesson, U., van Otterdijk, R., Meybeck, A., 2011. Global Food Losses and Food Waste. <http://www.fao.org/docrep/014/mb060e/mb060e00.pdf> (visited 04.04.12).

Hagel, J.I., III, Brown, J.S., Davison, L., 2010. The Power of Pull. How Small Moves, Smartly Made, Can Set Big Things in Motion. Basic Books, New York, NY, USA.

Harper, J.M., 1976. Elements of Food Engineering. AVI Publishing, Westport, Conn..
Heldman. D.R., 1975. Food Process Engineering. AVI Publishing, Westport, Conn.
IBM, 2012. What is Big Data? <http://www-01.ibm.com/software/data/bigdata/> (visited 07.06.12).
IDC, 2011. Extracting Value from Chaos. <http://www.emc.com/collateral/demos/microsites/emc-digital-universe-2011/index.htm> (visited 08.06.12).
Institute of Mechanical Engineers, 2013. Global Food Waste Not, Want Not. <http://www.imeche.org/docs/default-source/news/Global_Food_Waste_Not_Want_Not.pdf?sfvrsn=0> (visited 30.01.13).
ISEKI-Food 4, 2012. <http://www.iseki-food4.eu/> (accessed 13.07.12).
Jenkins, H., 2009. A 'business opportunity' model of corporate social responsibility for small- and medium-sized enterprises. Business Ethics—A European Review 18, 21–36.
Karel, M., 1997. The history and future of food engineering. In: Fito, P., Ortega-Rodriguez, E., Barbosa-Canovas, G.V. (Eds.), Food Engineering 2000, pp. 3–19 (Chapter 1).
Kaufman, C.W., 1952. Food Engineer's Place in the Food Industry. Food Engineering, vol. 25. McGraw Hill, Albany, NY.
Knorr, D., Balasa, A., Boll, D., Jager, H., Mathys, A., 2009. Alternative processing methods for funbctional foods. In: Moskowitz, H.R., Saguy, I.S., Straus, T. (Eds.), An Integrated Approach to New Food Product Development. CRC Press, Boca Raton, FL (Chapter 24).
Kocher, P.-Y., Kaudela-Baum, S., Wolf, P., 2011. Enhancing organisational innovation capability through systemic action research: a case of a swiss SME in the food industry system practise. Action Research 24, 17–44.
Kuenen, J.W., van Osselaer, J., Berz, K., Kaye, C., Sander, A., Schouten, W.-J.& Tsusaka, M., 2011. Global Aging: How Companies Can Adapt to the New Reality. <http://www.bcg.com/documents/file93352.pdf> (visited 08.06.12).
Kuhn, M.E., 2008. Driving growth through open innovation. Food Technology 62 (6), 76–82.
Lawler, F.K., 1953. Rewarding careers await technical men in food industry. Food Engineering, vol. 25. McGraw Hill, Albany, NY.
Lenhardt, A., Hitin, P., Madden, M., 2005. Teens and Technology. Pew Internet.org. <http://www.pewinternet.org/Reports/2005/Teens-and-Technology.aspx> (accessed 20.02.11).
Lindegaard, S., 2010. The Open Innovation Revolution Essentials, Roadblocks, and Leadership Skills. John Wiley & Sons, Hoboken, NJ.
Loncin, M., Merson, R.L., 1979. Food Engineering, Principles and Selected Applications. Academic Press, San Diego.
Maon, F., Lindgreen, A., Swaen, V., 2009. Designing and implementing corporate social responsibility: an integrative framework grounded in theory and practice. Journal of Business Ethics 87, 71–89.
Mayadas, A.F., Bourne, J., Bacsich, P., 2009. Online education today. Science 323, 85.
Mayo, M., 2009. Video games: a route to large-scale STEM education? Science 323, 79.
Melese, T., Lin, S.M., Chang, J.L., Cohen, N.H., 2009. Open innovation networks between academia and industry: an imperative for breakthrough therapies. Nature Medicine 15, 502–507.
Müller-Seitz, G., Reger, G., 2009. Is open source software living up to its promises? Insights for open innovation management from two open source software-inspired projects. R&D Management 39 (4), 372–381.
Nestlé, 2011. Creating Shared Value Summary Report 2011. Meeting the Global Water Challenge. <http://www.nestle.com/Media_Center/Interactive_CSV_2011/index.html#/1/> (visited 12.06.12).
Norton, I.T., Fryer, P.J., Moore, S.R., 2006. Product/process integration in food manufacture – engineering sustained health. AIChE Journal 52 (5), 1632–1640.
Parker, M.E., Harvey, E.H., Stateler, E.S., 1952. Elements of Food Engineering, vols. 2 and 3. Reinhold Publishing Corporation, New York, NY.
Pollan, M., 2008. In Defense of Food: An Eater's Manifesto. Penguin Press, London, England.
Porter, M.E., Kramer, M.R., 2011. The big idea: creating shared value. Harvard Business Review 89 (1–2), 62–77.
Rama, D., Milano, B., Salas, S., Liu, C., 2009. CSR implementation: developing the capacity for collective action. Journal of Business Ethics 85 (2), 463–477.
Reshef, D.N., Reshef, Y.A., Finucane, H.K., Grossman, S.R., McVean, G., Turnbaugh, P.J., Lander, E.S., Mitzenmacher, M., Sabeti, P.C., 2011. Detecting novel associations in large data sets. Science 334, 1518–1524.
Saguy, I.S., 2011a. Academia and food industry paradigm shifts required for meeting innovation challenges. Trends in Food Science and Technology 22, 467–475.
Saguy, I.S., 2011b. Paradigm shifts in academia, food industry and government to accelerate innovation. In: Presented at "Innovation and Technological Linkage in Foods: Challenges and Opportunities for the Province of Córdoba" (October 27–28), Cordoba, Argentina.
Saguy, I.S., 2011c. Academia-industry innovation interaction: paradigm shifts and avenues for the future. In: Procedia Food Science (11th International Congress on Engineering and Food, ICEF11), pp. 1875–1882.
Saguy, I.S., 2013. Academia-industry innovation interaction: paradigm shifts and avenues for the future. In: Yanniotis, S., Taoukis, P., Stoforos, N.G., Karathanos, V.T. (Eds.), Advances in Food Process Engineering Research and Applications. Springer, New York (Chapter 32).
Santos, O., Nylanderm, T., Rosmaninho, R., Rizzo, G., Yiantsios, S., Andritsos, N., Karabelas, A., Müller-Steinhagen, H., Melo, L., Boulangé-Petermann, L., Gabet, C., Braem, A., Trägårdh, C., Paulsson, M., 2004. Modified stainless steel surfaces targeted to reduce fouling – surface characterization. Journal of Food Engineering 64, 63–79.
Sarkar, S., Costa, A.I.A., 2008. Dynamics of open innovation in the food industry. Trends in Food Science & Technology 19, 574–580.
Simpson, R., 2004. Teaching food engineering as a stand-alone degree. In: Presentation at 2004 IFT Annual Meeting.
Singh, R.P., Erdogdu, F., 2009. Virtual Experiments in Food Processing, second ed. RAR Press, Davis, CA.
Singh, R.P., Heldman, D.R., 1984. Introduction to Food Engineering. Academic Press, San Diego, CA.
Singh, R.P., Heldman, D.R., 2013. Introduction to Food Engineering, fifth ed. Elsevier Publishing, San Diego, CA.
Stapley, A.G.F., Tewkesbury, H., Fryer, P.J., 1999. The effects of shear and temperature history on the crystallisation of chocolate. JAOCS 76, 677–685.
Tewkesbury, H., Stapley, A.G.F., Fryer, P.J., 2000. Modelling temperature distributions in cooling chocolate moulds. Chemical Engineering Science 55, 3123–3132.
Toledo, R.T., 1980. Fundamentals of Food Engineering. AVI Publishing, Westport, Conn.
Traitler, H., 2009. Innovation partnerships as a vehicle towards open innovation and open business. In: Moskowitz, H.R., Saguy, I.S., Straus, T. (Eds.), An Integrated Approach to New Food Product Development. CRC Press, Boca Raton, FL (Chapter 5).
Traitler, H., Saguy, I.S., 2009. Creating successful innovation partnerships. Food Technology 63 (3), 22–35.
Traitler, H., Watzke, H.J., Saguy, I.S., 2011. Reinventing R&D in an open innovation ecosystem. Journal of Food Science 76(2), R62–R68, 3–35.
Ubbink, J., Burbidge, A., Mezzenga, R., 2008. Food structure and functionality: a soft matter perspective. Soft Matter 4, 1569–1581.
van de Vrande, V., de Jong, J.P.J., Vanhaverbeke, W., de Rochemont, M., 2009. Open innovation in SMEs: trends, motives and management challenges. Technovation 29 (6–7), 423–437.
Vieira, M., Ho, P. (Eds.), 2008. Experiments in Unit Operations and Processing of Foods. Springer Science+Business Media, LLC, New York, NY, USA.
Villis, U., Hajoui, M.E., 2012. Global Food Security How Businesses Can Increase Food Access for the Poor. <https://www.bcgperspectives.com/content/articles/poverty_hunger_corporate_social_responsibility_global_food_security/> (visited 10.06.12).
Wesselingh, J.A., 2001. Structuring of products and education of product engineers. Powder Technology 119, 2–8.
WHO, 2012. Food Security. <http://www.who.int/trade/glossary/story028/en/> (visited 12.06.12).