Heeding Malthus and Feeding the World: The Role of Chemical Technology

Introduction

"I think I may fairly make two postulata. First, That food is necessary to the existence of man. Second, That the passion between the sexes is necessary and will remain nearly in its present state," states economist Thomas Malthus (1766-1834) in his notable "An Essay on the Principle of Population"[1]. According to his knowledge of mankind, these postulates have always held over human history. Because an unrestricted human population will grow exponentially with time, it cannot be supported by food that grows linearly. Malthus consequently concludes that if man's need for food confronts insufficient supply, calamity will occur as nature attempts to balance the discrepancy between the food that is needed and the amount available.

Although the development and use of agrochemicals have helped to prevent Malthus' gloomy prediction, his 1798 warning still holds today. Recent surges in global food prices, perhaps due to natural disasters in Pakistan, Australia, and Russia, have re-introduced fears of food insecurity for members of industrialized nations and have exacerbated the problem of famine in emerging countries. Concern over rising food prices in the Middle East may have been partially responsible for fueling dissent in Tunisia, Egypt, Somalia, Libya, Syria, and Yemen. Therefore, avoiding famine and ensuring that all people have access to a dependable food supply will be important for promoting peace. Can existing technology sustainably feed a growing population? What further scientific or engineering advances, especially in chemical technology, are necessary to attain this goal?

The world population is expected to expand from 7 billion in late 2011 to 10.1 billion by 2100[2], up from 2.5 billion in 1950[3]. Major growth is projected for less-developed countries,

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[1] http://www.econlib.org/library/Malthus/malPop3.html#Chapter%20VII
[2] http://www.unfpa.org/pds/trends.htm
[3] Emsley, John. A Healthy, Wealthy, Sustainable World

predominately among the poorest populations in urbanized regions[4]. More mouths to feed requires that **more food must be produced**.

Climate change will raise global temperatures and provoke changes in wind and insect migratory patterns that may adversely affect crop yield. Farmers will need to choose crops and agricultural practices that minimize required resources per unit of land dedicated to agriculture. Once the food is harvested**,** it must be distributed and delivered to the hungry in a fast and efficient manner to prevent spoilage and waste.

Also, it is necessary to pay attention to the sustainability of meat and fish. Meat-based diets require more land, energy, and water resources than do comparable lacto-ovo-vegetarian diets; therefore, they may not be practical if resources are scarce.

The relevance of "organic" agriculture must also be examined. If its demand for resources exceeds those available, or if output cannot keep pace with an increased demand for food, growing organic food may not be sustainable.

A. Ensure sufficient water supply

Creating more food will require more nutrients and water for agriculture. John Emsley, the author of A Healthy, Wealthy, Sustainable World reminds us that agriculture is the biggest consumer of fresh water. As the availability of fresh water becomes threatened by global warming and by increased water needs for industry, efficient water becomes a paramount concern. This need can be addressed either by choosing genetically-modified (GM) or non-GM crops that are more drought-resistant, by recycling municipal or agricultural wastewater, by preventing rainwater run-off in the fields, or by desalinating saltwater from the ocean.

1. Develop and grow drought-resistant crops

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[4] See 2.

Drought-resistant crops thrive in a dry environment. Such crops will be more important as global warming increases the frequency of droughts. These hardy crops, particularly those that form staple foods, will be particularly important in the arid sub-Saharan region of Africa where particularly large population growth is expected. Stanford researchers predict that corn yields in southern Africa will drop by 25 percent by 2030 because of climate change[5].

Many international agricultural research centers and philanthropic foundations have focused on breeding drought-improved staple crops, using tools from molecular biology that enable more efficient selection of drought-resistant traits or from plant breeding to develop iterations of seeds based on feedback from farmers[6]. In the former method, researchers identify a plant's response to drought, dependent on a complex interplay of factors ranging from when in the lifecycle a drought strikes the plant, to its access to nutrients, to thousands of genes on the chromosome. The goal here is to select for preferred genes using conventional breeding practices[7]. The resulting hybrids could yield drought-tolerant varieties of crops required for cereal or protein, such as millet and sorghum, grain legumes, barley, and maize.

An alternative strategy is to use genetic engineering to supplement the genomic fingerprint of a plant with extra genes that confer drought tolerance. Researchers are investigating the transfer of foreign genes or inserting a copy of an existing gene into a plant. Different genes can be targeted. Several under consideration may cause the plant to begin preserving water as soon as it senses drought, or may reduce the number of appendages, e.g. leaves, through which transpiration may occur, or may promote longer roots to obtain water, or may encourage the plant to continue producing seed should drought occur. Scientists are also investigating transcription factors, that is, genes that can control the activity of other genes to help plants manage stress due to insufficient water. Modifying plant genomes has proven successful for Canadian company "Performance Plants". The company demonstrated that the

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[5] http://www.nytimes.com/2008/10/23/business/23drought.html?pagewanted=print
[6] http://www.cgiar.org/impact/global/des_fact2.html
[7] http://www.nature.com/news/2011/110111/full/469144a.html

yield of its genetically engineered canola remained stable with much reduced irrigation, in contrast to the 14 percent drop of a comparison crop[8]. Genetic engineering of drought-resilient crops may provide a solution for surviving a thirsty future, but the effect of gene therapy on plant metabolism and the economics of patented transgenic seeds require the solution of important, as yet unresolved, issues.

2. *Prevent rainwater run-off*

Another strategy for minimizing water use may be to improve management of water resources. Rainwater run-off due to soil agitation that occurs during tillage is troublesome in hilly areas, because it causes loss of water and topsoil. No-tillage farming kills weeds with a non-persistent herbicide such as paraquat or glyphosate to avoid ploughing the soil and other practices that disturb the soil[9]. Non-tillage farming may be useful for mountainous areas such as the fruit orchards and tea plantations surrounding the Yangtze River where testing has shown a water loss of 420 m^3 per hectare per year on tilled land in comparison to a loss of 220 m^3 per hectare per year from no-tillage, paraquat-treated land[10].

Responsible use of agrochemicals is achieved with non-persistent herbicides developed by chemical research. Paraquat has been used since the 1960s. It is considered safe because it leaves no residues on the crop; it leaves the roots of weeds in the soil to ensure soil conservation, and it only affects the green parts of the plants on which it falls. Miraculously, paraquat is also “fast-acting, not washed off by rain.”[11] Because paraquat is deactivated on contact with soil, it presents no threat to the next-planted crop.”[12]

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[8] http://www.nytimes.com/2008/10/23/business/23drought.html?pagewanted=print

[9] See 3.

[10] See 3.

[11] See 3.

[12] See 3.

3. *Reuse industrial or municipal water for agriculture*

Another method for water conservation may be to recycle industrial or municipal waste water for industrial agricultural uses. Many countries already use reclaimed water for agriculture irrigation; indeed, using reclaimed water for agriculture is commonly practiced in arid and semi-arid regions of the United States; reclaimed water may be necessary in a future with more limited surface and groundwater. Agronomics will dictate the design of all stages of a reclaimed-water-irrigation project that may require monitoring the amounts of trace elements and nutrients, suspended solids, and microbes for their impact on soil, crops, and environment.[13] Depending on the crop variety and its stage of growth, different levels of water- treatment may be necessary. In the United States, several states have established water- treatment and quality criteria that reclaimed water systems must achieve. For barley, corn, and oats, reclaimed water is subjected to a routine of secondary treatment and disinfection, whereas vegetable crops that can be consumed raw will require an additional filtration step[14]. To obtain a consistent standard for reclaimed water quality, California sets specific ceilings for parameters important to reclaimed water, such as turbidity and levels of coliform, a broad group of bacteria that may be found in human feces and animal manure[15]. If reclaimed water becomes a significant contributor to water use in the agricultural industry, water-treatment facilities should be built close to those places where re-used water is applied.

4. *Desalinate seawater*

If water shortage remains a problem, even with careful management and re-use of existing water supplies, desalination of seawater may be useful. Because seawater is not

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[13] Asano, Takashi; Burton, Franklin L.; Leverenz, Harold L.; Tsuchihashi, Ryujiro; Tchobanoglous, George (2007). Water Reuse - Issues, Technologies, and Applications.. McGraw-Hill.
Online version available at:
http://www.knovel.com/web/portal/browse/display?_EXT_KNOVEL_DISPLAY_bookid=2578&VerticalID=0

[14] See 12

[15] http://water.epa.gov/type/rsl/monitoring/vms511.cfm

immediately applicable for many crops, methods to extract freshwater from seawater will need to be implemented. Chemical technology has established existing methods of desalination, such as reverse osmosis and distillation. Reverse osmosis applies a positive pressure gradient across a semi-permeable membrane with salt water on one side to obtain pure water from the salt solution. Unfortunately, this process is energy-intensive, usually requiring pressures near 70 bar, and therefore expensive. Energy-efficient desalination plants may help, as demonstrated by a plant in Singapore that produces 135,000 m^3 a day of pure water but costs only $65,000.

However, better membranes may improve the efficiency and lower the costs of reverse osmosis. Currently, desalination membranes are made from polymeric materials, predominantly cellulose acetate, polyamide, and polysulfone. Because reverse osmosis requires not only removal of suspended solids but also removal of microorganisms, the surface of the membrane is fouled over time, requiring regeneration. Because chlorine for water-disinfection prevents contamination of the membranes but attacks the polyamide membranes, chlorine must be removed prior to membrane use for water-desalination[16]. Recent innovations in membrane technology that may be adopted include membranes of porous polysulfone on polyester that are immune to chlorine corrosion, and membranes embedded with carbon nanotubes that enable water molecules to flow 1000 times faster than expected.

Distillation plants are used to produce a significant amount of drinkable water. Boiling produces salt-free water vapor that is condensed to recover liquid water. Energy-efficiency is improved upon introducing heat exchangers in process design. Scale formation can be minimized with scale inhibitors.

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[16] See 3.

B. Ensure that crops will absorb sufficient nutrients

Healthy human diets require vitamins and minerals. Similarly, plants also need nutrients, especially those that contain nitrogen, potassium, and phosphorus[17]. Even if genetically-modified plants exist that demand fewer amounts and varieties of phyto-nutrients, more crops than at present may be required to feed a large population.

1. Use synthetic fertilizer produced from the elements or from reclaimed waste

Plants easily extract the necessary carbon from carbon dioxide in air, but synthetic fertilizers are necessary for soils thirsty for scarce nutrients from the debris of dead plants, animal excreta, and soil fauna and flora, or ash. Synthetic fertilizers provide soils with their essential nitrogen in the form of nitrates and ammonium, phosphorus in the form of phosphates, and potassium in the form of potassium salts.

One of the great achievements in chemical technology is the Haber-Bosch process; using elemental nitrogen and hydrogen, this process produces ammonia that is easily converted to nitric acid. The recent Norwegian-patented Birkeland-Eyde process for producing nitrate from multi-step reactions of nitrogen, oxygen, and water provides a method for generating the nitrogen that plants need to build proteins and enzymes. To obtain forms of phosphate more easily accessed by plant roots, human sewage and animal waste provide rich sources of phosphate. Research has shown that, because *Acinetobacter*, *Aeromonas*, and *Psuedomonas* bacteria can transform aerated sewage into usable agricultural fertilizer, they could perhaps be used to recycle phosphates in biological phosphorus reclamation facilities. Nitrogen can also be recovered from wastewater that typically contains a total nitrogen content of 20-70 mg nitrogen per liter of water[18]. Depending on the type of wastewater treatment, nitrogen can be obtained as ammonium or nitrate. Obtaining a sustainable reserve of potassium is less of an issue than that

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[17] See 3.

[18] See 13

for obtaining nitrates and phosphates; potassium for agricultural fertilizer can be easily obtained from extracting potassium salts from ash that is obtained from burned biomass.[19]

C. Minimize the harm inflicted by agricultural pests and crop diseases

Changing weather patterns and agricultural pests may thwart actions taken to harvest a greater crop yield for a large human population. Microbes and animals that prey on staple crops may become a major problem as the planet warms into a prime incubator for bacteria, fungi, and insects that further strain the food supply for a growing global population. For that purpose, pesticides may be employed. An ideal pesticide must avoid harming species other than the target pests and must decompose into harmless substances within a short life-span.[20] The chemical structure of some synthetic pesticides may mimic those of chemicals produced by plants to deter harmful pests; for example, *azadirachtin* dissuades insects from feeding on a species of tree after the first bite. Other predatory insects or microorganisms, like *Bacillus thuringiensis* (Bt), do not harm the host plant but eat or kill pests.[21] Still other chemicals mimic sex pheromones to attract insects into a trap, or act on the plant to encourage production of natural defense mechanisms.

Herbicides that have been licensed as safe by government agencies can provide a welcome armory against fungi and other pests. If farmers understand and implement proper pesticide use, this line of defense can be an advantage rather than a hazard in food production.

<u>Food security: Other considerations</u>

Food security encompasses stable access to food. In 2011, while Americans in the wealthier areas of the United States cannot complain about food shortage, the majority of Somalians are encountering famine due to drought.

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[19] See 3.
[20] See 3.
[21] See 3.

Food security implies that everyone must have access to sufficient macro and micronutrients. A better transportation infrastructure is needed to limit the time from harvest to market. Waxes or synthetic ethylene gas can preserve the edible condition of produce. Better communication between geographical regions may provide methods to ensure that food is distributed efficiently to a needy population.

Growing and consuming locally-produced food provides another strategy for ensuring food access; the strategy has gained momentum on the West Coast of the United States. The “local” philosophy guides international foundations’ support of small farmers in under-developed nations who suffer from famine and blight.

Vertical farming that can be imagined as a skyscraper of plants living in carefully controlled indoor conditions, has also been proposed as an alternative to traditional farming because it may minimize the need for land and resources. The disadvantage of vertical farming is that some plants would not be exposed to as much light as others, requiring artificial lighting[22].

Timely disbursement of food to the entire population will require coordinated efforts of engineers from civil engineering, industrial engineering, and especially from chemical and biochemical engineering, coupled with political controls.

Conclusion

Cultural and socioeconomic groups throughout the world give rise to a large number of eating habits and lifestyles. To ensure that each person is satisfied with the quality and composition of affordable meals will be difficult. Judicious policy decisions regarding methods for sustainable farming or population control may be as important as decisions regarding the development and implementation of agricultural and infrastructure technologies. From the construction of irrigation systems by ancient civilizations to the manufacture of nitrate fertilizer by Haber-Bosh plants, engineers and scientists from a variety of disciplines have advanced methods of food production for an expanding population. It is important to continue their legacy

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[22] http://www.economist.com/node/17647627

with generous financial support and prudent regulation to ensure that the human race does not suffer the fate predicted by Malthus’ theory.

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