Off-Farm Farming

Cutting-edge developments
Designs and prototype demonstrators are emerging for novel intensive urban food production in artificial environments. The most ambitious designs have photovoltaic-driven LEDs with optimal wavelengths for photosynthesis by indoor crops, alongside poultry and animal production, with recycling of water and nutrients, in multi-storey facilities. More straightforward options include green roofs irrigated with grey water for vegetable production. Glasshouse systems are already highly developed, as are intensive pig and poultry units. The potential is greatest for higher value products e.g. vegetables, salad crops, soft fruit, animals, poultry and fish. There is little potential for staples such as rice, wheat, etc. as their yield per unit area is too low, but intriguing options include producing algae for processing into novel foods.

Verti Crop - a successful trial of vertical cropping

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Innovative concepts
Several concepts for integrating food production in to urban infrastructure and buildings were proposed in the last decade. One novel idea was for energy-efficient double-skin high-rise façades for buildings, enclosing tray-mounted hydroponics suspended from vertical cables. A heroic master plan was developed for an Agropark at Dongtan in China, with hi-tech closed systems as well as more conventional greenhouses and intensive pig and poultry units. These and other plans have yet to be implemented, but nonetheless provide a vision for advanced urban agriculture. More recently, Arup envisioned modular smart buildings that are adaptive and produce more resources than they consume, housing production of algae as well as plants and fish.

Current trends
In the meantime, large investments are being made in state-of-the-art greenhouses for salad production close to cities, while plans have been advanced for multi-storey ‘cow-parks’ for dairy production near to ports that import animal feed. Commercial drivers include a rapid growth in urban markets, especially in the global megacities, rising transport costs due to higher fuel prices and increasing distances to farm land from the centres of expanding cities and better environmental controls on emissions than are easily achievable on farm.

It seems likely that off-farm production will become ever more competitive with traditional on-farm enterprises over the next decade; traditional on-farm production faces challenges as the supply of land and especially irrigation water tightens and the impact of climate change increases the risk of weather damage to crops.

Most significantly, higher labour costs are a major factor anticipated to drive growth in off-farm production, particularly for higher value crops, with deployment of robotics and autonomous machines for crop establishment, maintenance and harvesting.

Environmental benefits
The environmental costs of agriculture can be substantial. They include pollution of waters with nutrients and pesticides, increased flood risks to urban centres, soil erosion and substantial greenhouse gas emissions. Technological innovation is needed to reduce these damages, for example, to increase the utilisation of nitrogen fertilisers which is currently rarely higher than 60 percent. However, field-based systems are essentially open and inherently leaky. Moreover, management control on farms is both complex and variable, even where aided by advances in precision agriculture. Off-farm farming systems offer an easier route to ‘sustainable intensification’ and a decoupling of yield growth and environmental damage through a combination of higher yields of marketable product, standardisation and access to better control systems and recycling. Through off-farm farming water and nutrients can be applied precisely when needed and recycled easier; biosecurity is more easily achieved than in open-field systems, reducing the need for protective herbicides.

Cultural acceptability
A potential problem for off-farm farming is the acceptability of ‘industrial’ food production by consumers. Factual analysis, highlighting lower environmental costs, may not completely off-set a cultural perception that ‘field is best’ and off-farm food is risky. However, the consumer may respond positively if the price, quality and availability of food from off-farming are better. An enduring difficulty has been the acceptability of off-farm animal production even though housed pig and poultry production has been the norm for several decades and strong welfare practices and regulations have been developed. Consumer support persists for outdoor pigs and free-range chickens, represented by a willingness to pay a premium price, even while a better environmental performance of
housed production is well-documented. From an engineering perspective, indoor pigs, poultry and cows may be more secure, healthy and productive in a controlled indoor environment supported by robotics, but a cultural viewing point may continue that cows belong in fields grazing grass, chickens need to be free-range and pigs like being outdoors.

**Novel foods**

As well as offering advantages for producing traditional foods, off-farm agriculture has potential to produce entirely novel foods. A mature example is Quorn™, a mycoprotein extracted following fermentation of the soil fungus *Fusarium venenatum* and then processed to remove nucleic acids and create appropriate texture. Quorn™ sales exceeded £120 million in 2010. Algae, especially marine varieties, are traditional foods and useful sources of vitamins and nutritionally important fatty acids. Existing development of algal production for biofuel manufacture may release new opportunities for off-farm food production, using photobioreactors with algae pumped in a nutrient solution through borosilicate tubes irradiated with artificial light. Perhaps microscopic algae grown in bioreactors could be processed to produce food for off-farm fish and animal production, or processed to create entirely new human foods.

**Glasshouse – the most advanced sector**

Technology for salad crop production in glasshouses is advancing rapidly. Investment is encouraged by the higher prices achievable when production is close to consumers using non-weather dependent systems, giving better responsiveness to changing market demand via just-in-time production and delivery. Typically, a high proportion of field-grown vegetable and salad crops are not harvested because they mature at the wrong time to match market demand this can be avoided in controlled glasshouse environments. As an illustration of the current state of the art, the largest operation in the UK is Thanet Earth in Kent which has 55 hectares of glasshouses producing cucumbers, tomatoes and sweet peppers using artificial light. A two-engine CHP plant feeds power to the grid and artificial lighting heats the glasshouses, enriching carbon dioxide levels to increase productivity. Water is collected on the roofs and stored in reservoirs for precision nutrient irrigation of rock wool growth media, with recovery of excess water and even condensation from the walls and roofs. The operation is close to the large SE England market and capable of supplying about a third of the UK salad crop requirements, replacing more costly and less reliable supply chains originating in Southern Europe.

Energy consumption is high for glasshouse production in temperate regions and sophisticated control of air entry, movement, recirculation and mixing need to be applied to achieve both energy efficiency and optimal growing conditions. By ensuring that plants are supplied with the light, water, warmth and nutrients for optimal growth, strong, healthy plants are maintained, yields increased and susceptibility to pathogens minimised. Additionally, the advantages of a secure and controlled environment can be exploited to allow biological control of insect pests using introduced predators, avoiding the costs and market risks associated with insecticides.

Labour costs for crop establishment, maintenance and harvesting make up a large part of the overall costs of glasshouse production. The glasshouse environment has both advantages and disadvantages for robotics: it is secure and highly ordered, but its humidity and temperature make it a relatively aggressive environment for electronics. Many of the operations in horticulture are repetitive and relatively tedious, while requiring careful attention to the condition of individual plants – suggesting that robotics could be efficient. This is particularly the case where pots are used and have to be moved and re-spaced; for example, in ornamental shrub production and a system deploying teams of robots has been developed to do this in the USA by Harvest Automation, which is deployed successfully by commercial growers. The cutting edge is represented by an autonomous machine for plant by plant nutrient addition, developed by David Dorhout at Iowa State University. Harvesting glasshouse crops is challenging because of the non-uniform presentation of fruit with variable dimensions that is easily damaged. Nonetheless, both cucumber and pepper robotic harvesters have been developed at Wageningen University in the Netherlands, with sensor and vision systems to allow precise target recognition and response.
Pigs and poultry
Systems for intensive housed production of pigs and poultry are highly developed and widespread. Sophisticated data collection and information management is common place to optimise production and energy, water and feed consumption via climate control and automated watering and feeding. Welfare is strongly regulated in Europe and units are also regulated under the Integrated Pollution Prevention Control Directive so that emissions are minimised. Constraints on urban locations for this production are the need for land to recycle organic waste, however, production is increasingly integrated with waste management using anaerobic digestion and in some cases CHP plants, which reduces the need for land spreading of waste.

Urban dairies
On-farm trends in North-West Europe are towards larger herds that are housed continuously throughout the year. The advantages of housed systems include a more consistent and optimal environment for the cows, avoiding exposure to adverse weather, including heat stress, higher yields and better utilisation of forage from non-grazed fields; and lower environmental impacts via reduced diffuse pollution and more efficient waste management. Commercial success with housed herds requires larger herds than for grazed cows, to achieve the scale economies needed to offset higher costs. A logical extension appears to be very large scale off-farm dairy production close to major ports, where the cost of imported feed is lower. Such facilities could fully exploit recent advances in dairy technology, for example individual cow condition monitoring, robotic milking, automated feed systems and robotic forage sweepers.

They would also support deployment of advanced manure management, including anaerobic digestion, with potential for air pollution abatement, leading to a reduction in energy consumption and environmental damage costs per litre of milk. Overall transport related and other energy costs should be further reducible by co-location of milk processing for liquid consumption and manufacture of dairy products. However, consumer resistance to such ‘mega-dairies’ appears to be significant.

Future developments
Opportunities for innovation based on a cross-transfer of technology from other sectors or de novo technology encompass materials, sensors, control systems, robotics, etc. Engineering these artificial environments requires integration of many disciplines, including architecture and structural, mechanical, electrical, materials, water, information and sensor engineering; as well as agricultural sciences and engineering. Existing technology for clean room and other controlled environments and advanced manufacturing facilities is relevant to new off-farm production platforms. The immediate development path is a progression from advanced greenhouse and intensive animal production technologies.

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Rising demand for food and high environmental impacts are challenging global agriculture. Agricultural Engineering is key to implementing new and better performing systems, including off-farm production close to urban markets.’’
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