CHAPTER 4

Development in Energy Generation Technologies and Alternative Fuels for Agriculture

Janusz Piechocki, Piotr Sołowiej, Maciej Neugebauer, Guangnan Chen

4.1 Introduction

Agricultural productivity largely depends on energy, water and land resources. The increasing uses of energy resources are currently one of the major challenges to agriculture (Chen et al., 2015; Bundschuh and Chen, 2014; Bundschuh and Chen et al. 2017). Continuous high fuel and electricity prices and the needs for significant reductions in greenhouse gas emissions make the improvement of farming energy efficiency essential. Exploration of new alternative and renewable energy sources is also vital.

Agricultural production relies on heavily solar energy which is indispensable in the photosynthetic process to transform inorganic compounds into organic substances that give rise to living organisms. Light, including visible, infrared and partially ultraviolet light, is required for plant and animal production. The sun is the cheapest and the most effective source of light in the wavelength range required for the growth of all living organisms. Sunlight best meets the developmental needs of plants and animals in all stages of growth (year) and times of day, and it induces growth phases in plants (Folta, Maruhnich 2007; Franklin 2009). Contemporary agriculture consumes significant amounts of energy, and it relies on both direct and indirect energy sources. Direct sources of energy include fuel for agricultural vehicles and machines, whereas indirect sources involve energy accumulated in fertilizers [Arizpe 2011]. At present, fossil fuels, in the various forms, supply most of the energy required by agriculture that feeds the world. The demand for energy per 1 ha of farmland is presented in Figure 4.1. It is determined by the level of technical advancement and population density in a given country.

Energy is one of the most important factors for business, and it significantly influences the development of modern agriculture. The progressing automation and mechanization of agricultural production increases the demand for energy in the form of heat, electricity and fuel for powering agricultural machines.

The growing demand for energy spurs the development of new solutions for energy generation in agriculture, including the use of heat from biomass processing, milk cooling or composting of biological wastes. The growing popularity of renewable sources of energy in agriculture also stems from technological progress, including small biogas plants which are fueled with biodegradable wastes from various types of farms. Advanced technological solutions rely on solar energy to dry agricultural produce, heat buildings, water and greenhouses, pump water or generate electricity with the involvement of photovoltaic cells. Some agricultural processes generate heat which is irreversibly lost. Those processes are optimized to reduce energy losses and increase their economic efficiency, which contributes to more rational energy generation and more sustainable agricultural performance in the face of limited resources. By relying on renewable sources of energy, energy consumption in agriculture can be reduced without compromising performance.

This chapter will discuss some of the selected energy generation technologies and alternative fuels in agriculture, including the recovery of heat from biomass composting, production technology and uses of biogas and biodiesel, solar energy technologies, and optimization of production processes to minimize energy losses in agriculture.

4.2 Recovery of heat from biomass composting and its use in agricultural production

Biomass is obtained from plant and animal sources and can be converted from stored chemical energy (originally from solar energy captured during photosynthesis) into bioheat, biopower, biofuels and biomaterials. Biomass feedstocks are wide ranging but can be broadly classified into forest residues, crop residues, animal wastes and dedicated energy crops. The challenge is to develop environmentally sustainable and economically viable practices to produce, collect, process, store, transport and deliver the biomass to bioenergy conversion plants.

Bioenergy uses biomass to generate either heat, electricity or transport fuels. Bioenergy can be regarded as a form of solar energy, as photosynthesis combines atmospheric carbon dioxide with water in the presence of sunlight to form the biomass, while also producing oxygen.

Increasingly, agriculture is being looked to as a source of energy. Bioenergy crops, or agricultural products, which can be converted to solid or liquid fuel offers the potential of a lower carbon emitting source of energy. Owing to the concern over global warming, unstable diesel fuel prices in the world market and a limited supply in the future, many farmers have been looking for alternative fuels or growing their own. To achieve best outcomes, there are many factors to be taken into account for each bioenergy resource, such as moisture content, resource location and distribution, and type of conversion process.

Composting is a biological degradation process which mineralizes organic matter and releases energy as heat. Organic matter is produced from inorganic substances under exposure to sunlight in the process of photosynthesis (equation 4.1).

$$6CO_2 + 6H_2O + \text{solar energy} \rightarrow C_6H_{12}O_6 + 6O_2 \tag{4.1}$$

During photosynthesis, glucose and oxygen are produced from carbon dioxide and water in plant cells exposed to sunlight.

Organic material is biodegraded by microorganisms. When oxygen is available, biomass is broken down in the process of aerobic decomposition which is the reverse of photosynthesis. Composting is the sum of microbiological processes during which biological material is transformed by microorganisms into humus [Alexander 1977; Ros et al., 2006; Moreno et al., 2013; López-González et al., 2014]. Microorganisms also produce significant amounts of carbon dioxide, which are released into the atmosphere, and heat [Liang et al. 2003, Miyatake, Iwabuchi, 2006]. Microbial biomass increases significantly during composting. The processes that take place during aerobic decomposition of organic matter can be described with the use of the following equation [Alexander 1977]:

$$\begin{gathered}\text{Organic matter} + O2 + \text{aerobic microorganisms} \rightarrow \\ CO2 + NH4 + PO4 + \text{microbial biomass} + \text{heat} + \text{humus}\end{gathered} \tag{4.2}$$

Temperature is the most important parameter during composting [Liang et al. 2003; Miyatake and Iwabuchi 2006]. The composting process can be divided into three phases: mesophilic, thermophilic and stabilization. The mesophilic phase is characterized by high activity of mesophilic microorganisms that feed on readily digestible organic matter, mainly sugars and amino acids. Temperature in this phase ranges from 25 to 45°C. The thermophilic phase begins when temperature exceeds 45°C. The activity of mesophilic microorganisms is slowed down, thermophilic microorganisms are activated, and their metabolic processes raise substrate temperature to 70–80ºC. Biodegradation processes are most intense in the thermophilic phase. The third phase involves substrate cooling and maturation. The population size of thermophilic bacteria decreases, temperature drops to 35-40°C, mesophilic microorganisms are activated, and they decompose the remaining biomass. The thermophilic phase can be prolonged by aerating the substrate and keeping its moisture content at a stable level. This maximizes the effectiveness of biomass degradation, it shortens composting time and reduces methane emissions to the atmosphere. Air supply should be optimized to provide thermophilic microbes with the required levels of oxygen without excessively cooling or drying the substrate, which could slow down or even completely inhibit the composting process.

In addition to oxygen and water (the recommended moisture content of composted material is 60-70%), microorganisms use nitrogen to increase their mass, and they rely on carbon as a source of energy. The optimal carbon to nitrogen ratio (C:N) in a compost heap is 30:1 (with a tolerance limit of 25-35 parts carbon to 1 part nitrogen). When the C:N ratio exceeds 35:1, the process is significantly slowed down and the composted material is partially decomposed, and when the C:N ratio falls below 20:1, nitrogen can be released into the atmosphere. Various substances are added to composted matter to maintain the optimal C:N ratio (urea, liquid manure) and substrate porosity (cereal straw) [Adhikari et al., 2008; Chang and Chen, 2010; Estevez et al., 2012].

The rates of carbon dioxide release, oxygen uptake and biomass decomposition have been analyzed in several studies [Finstein 1975; Strom 1978, Rothbaum 1961; Wiley 1957] which demonstrated the highest levels of microbial activity at a temperature of around 60°C which creates optimal conditions for most thermophilic microorganisms. The production of heat with a temperature of 60–65ºC inside a compost heap contributes to pasteurization and pathogen elimination, it promotes aeration and decomposition of organic matter in deeper layers [Macgregor et al. 1981]. Due to the specific structure and physical characteristics of composted biological material, heat is accumulated in the heap whose temperature can exceed 80°C. When optimal composting conditions are maintained and fresh biomass is continuously fed into the system, the high temperature achieved in the thermophilic phase of the process can be used to heat farm buildings or water.

A pioneering method for recovering heat and biogas from compost was developed in seventy's years last century by Jean Pain, a French farmer who relied on the composting process to heat his home, prepare hot water and recover biogas (Figure 4.2). A compost heap can be a source of heat for up to 18 months [Poulain 1981]. The compost heap generated approximately 500 m^3 of gas which was used to supply two heating stoves and a combustion engine in a power generator which charged batteries for household lamps. Jean Pain developed a sustainable method for recovering low-temperature heat and safely managing biological wastes.

In 1992, Japanese scientists Hirakazu Seki and Tomoaki Komori proposed a novel method for recovering heat from exhaust air leaving the compost heap [Seki and Komori 1992]. Exhaust air was passed through a specially designed column where it was used to heat water. Water was heated to a temperature of up to 30°C, and up to 72% of composting heat was effectively recovered on average (Figure 4.3).

In the article entitled "Extracting thermal energy from composting", Truckner described one of the first systems for recovering heat from composted cattle manure and organic farm wastes [Truckner 2006]. The recovered heat served two purposes: to heat water which was then used to prepare calf feed, and to supply the floor heating system in the calf barn. Heat meters were installed in the system to optimize heat production, the composition of the compost heap and the structure of the compost container.

In an experiment conducted in 2005, Sołowiej investigated the effectiveness of compost heat for heating a vegetable greenhouse in northern Poland in early spring [Sołowiej 2007]. The test stand comprised two plastic tunnels with an area of 120 m^2 each (an experimental tunnel with preheated soil and a control tunnel without heating), compost heaps, a system of pipes (PVC, Ø 16 mm, wall thickness 1.5 mm) connecting compost heaps and soil in the experimental tunnel, a circulation pump distributing water in the pipe system, an expansion vessel and thermometers for measuring compost, supply water and return water temperature. The diagram of the test stand is presented in Figure 4.4.

The compost heap had five layers. Each layer was composed of: dry straw (15-20 cm), fresh organic matter (cabbage leaves, carrot and beetroot discards, etc.), dry straw and soil (10-15 cm). During the construction of the compost heap, every layer was watered to obtain the required moisture content. A system of pipes collecting heat was placed inside the heap. The highest demand for energy was noted at the beginning of the experiment because soil in the experimental tunnel was frozen after winter. This demand was met by utilizing the highest composting temperature which is noted at the beginning of composting. Soil temperature was stabilized after 10 days and remained constant at 9-11°C until the end of the experiment. The energy generated by the heap was used only to maintain constant soil temperature. Lettuce grown in the heated tunnel was harvested on experimental day 34, i.e. 22 days after planting.

The experiment was concluded on day 42 when lettuce from the control tunnel was harvested. Lettuce grown in the heated tunnel was harvested 6 days earlier than the crops grown in the control tunnel. Compost produced during the experiment was used as fertilizer.

Scientists from the University of New Hampshire developed a heat recovery system for preheating water in a farm [Smith and Aber 2014]. The UNH heat exchange system operates by blowing compost vapor (110-170°F) against an array of two-phase super-thermal conductor heat pipes which were developed by a Canadian company named Acrolab. The six heat pipes (Isobars) are 30-feet long, with 22-feet contained within a 24-inch diameter vapor duct, and another 8-feet contained within a 295-gallon water tank. The Isobars provide thermal uniformity across the entire length of the pipe, meaning if one end is heated, the energy is immediately distributed evenly across the entire length of the pipe [Acrolab 2013]. More specifically, when compost heated vapor is applied to the evaporator side of the pipe (portion contained within the 24-inch diameter pipe), the refrigerant inside the Isobar heats up and vaporizes. The vapor stream within the Isobar travels up the pipe, condensing on the cooler side, releasing its energy in the bulk storage water tank through the latent heat of condensation. After condensing, the refrigerant is returned to the warm end of the pipe through gravity, repeating the process without any moving parts (Figure 4.5).

Compost heaps are also used inside greenhouses. The energy produced by the composting process heats the greenhouse, and the released carbon dioxide is used up by plants during photosynthesis [Manure compost as a passive greenhouse heating. 2009]. Some passive heating systems rely on vermicompost whose temperature reaches 40°C (Figure 4.6). For the composted waste to generate the optimal quantities of heat and carbon dioxide, the biomass has to be suitably aerated and kept moist. The use of a compost heap as a source of low-temperature heat:

- improves the cost-effectiveness of greenhouse vegetable production by significantly speeding up plant growth and harvest;
- reduces the demand for conventional sources of energy and minimizes air pollution associated with traditional heating methods;
- promotes the reuse of organic wastes from the field and contributes to sustainable agriculture;
- produces valuable organic fertilizer which can be used on the farm or sold.

4.3 Production technology and use of biogas

Agricultural biogas is a gaseous fuel which is produced from farm wastes, mostly agricultural biomass and by-products of agricultural production, including liquid or solid manure, plant residues from food processing as well as forest biomass [Deng et al. 2012, Kafle G.K., Kim S.H. 2013, Deng et al. 2014]. Farm wastes can be fermented to produce methane. Agricultural biomass is increasingly being obtained from farms that specialize in the production of energy crops (Figure 4.7).

Biogas is also produced naturally from organic matter that decomposes under anaerobic conditions. This process takes place already at temperatures higher than 10°C when organic compounds are fermented by symbiotic microbial communities in the natural environment.

The process by which gas is produced during anaerobic decomposition of biological matter has been long known, but it was first described in the 17th century by von Helmont (1630). In the following years and centuries, this phenomenon was investigated by Shirley (1667), Volta (1776), Priestly (1790) and Dalton (1804). In 1806, the first laboratory experiment which resulted in the production of methane from organic waste was conducted by Davy. In 1868, Bechamp demonstrated that sediments from the production of starch and sucrose were decomposed by microorganisms, which led to the release of methane and carbon dioxide. Anaerobic decomposition of cellulose was investigated in a series of experiments conducted by Mitscherlich, Hoppe-Seyeler, Popoff and Tappeiner in the 19th century [Marchaim, 1992].

Further scientific inquiries into methane-generating processes were made in the 1930s, and research aiming to harness methane for energy generation was also undertaken in China and India. At present, those countries operate the highest number of biogas plants which play a significant role in their energy production systems. In Europe, the interest in biogas plants peaked in two distinctive periods. The first period covered the late 1940s and the early 1950s, and it resulted from energy shortages and economic hardships after World War II. The interest in biogas plants was revived in the 1970s in the face of the global energy crisis, and it paved the way to research work into biogas production in the United States and other countries.

The recent interest in methane production can be attributed not only to its energy generating potential, but mainly to the fact that this process can be used to effectively manage organic matter which accumulates in waste and sewage sludge. This method can help solve environmental problems, in particular in rural areas where the sludge that remains after digestion can be used as organic fertilizer which is much more available for plants that non-digested sludge. In municipal wastewater treatment plants, energy can be recovered from sewage sludge through methane production during anaerobic digestion (Figure 4.8).

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Methane production processes can be conducted on an industrial scale to control biogas production in biogas plants. Biogas plants supplied with farm waste are referred to as agricultural biogas plants, and the generated biogas is known as agricultural biogas (Figure 4.9).

Methane is produced by mesophilic bacteria which readily proliferate under the conditions found in biogas plants. Mesophilic bacteria thrive at a temperature of 37-40°C. Biogas production relies on living microorganisms which have to be provided with optimal physical and chemical conditions as well as strictly controlled quantities of biomass as substrate for the fermentation process. When those conditions are not met, biogas is not produced or the generation process is not energy efficient [Dublein, Steinhauser, 2008].

The quantity of biogas produced from different substrates during methane fermentation is different (Table 4.1). The C:N ratio of composted substrate is also a very important parameter which determines the rate at which organic matter is decomposed. The optimal C:N ratio is 20-30:1. A narrow C:N ratio contributes to excessive release of ammonia (NH_3), whereas a very wide C:N ratio prolongs the time between fermentation and biogas production. Both narrow and wide values of this parameter lower pH, which inhibits the growth of mesophilic bacteria [Pang et al. 2008].

The composition of biomass fed to biogas plants can be varied, but it should be noted that fermentation can only take place within a given range of physicochemical parameters and that bacteria have a limited capacity for processing biomass components. Not all biomass is decomposed in the digester tank. In addition to biogas, the fermentation process also generates substantial amounts of anaerobically digested biomass which constitutes valuable fertilizer, alone or in combination with other compounds. Nitrogen found in fermented biomass is converted to the ammonium form that is easily available for plant uptake and less readily leached from soil (Table 4.2).

Agricultural biomass can be used to produce biogas and vehicle fuel, which is a valuable resource in agricultural production. Most importantly, fuel can be used locally in agricultural production, including processes that produce biomass for the generation of biofuels. Agricultural biomass is also used in other fermentation processes to obtain substances for the production of biofuels. Such substances include methanol and ethanol which, together with liquid hydrocarbons, are used as biofuels for powering tractors and agricultural machines.

It is important problem related to the use of renewable energy sources in farming systems and this requires separate discussion.

The content of methanol or ethanol in biofuel varies considerably across countries. It usually ranges from several to less than 20%, but in some countries, such as Brazil, it can be as high as 30%. For combustion engines to burn biofuel with high methane content, their compression ratio has to be modified. Biogas can also be used directly in the fuel combustion engines of power generators. Generators produce electricity, and heat recovered from exhaust gas can also be used in agricultural production. [Woodhead Publishing Series, 2013, The Biogas Handbook: Science, Production and Applications].

The principles of energy generation and use of renewable energy sources have been laid down in EU Directive and the relevant regulations are applicable in all Member States.
[EU Directive 2009/28/EC].

4.4 Production technology and use of biodiesel

Tractor is a mobile power unit and one of the most widely used farm equipment. Modern tractors are often powered by internal combustion (IC) engines due to its high reliability and efficiency, and ability in carrying out heavy workload (particularly for draft of implements). The engine’s reliance on fossil fuels and the emissions to the atmosphere from the combustion process has contributed to global climate change. Biodiesels present a genuine opportunity as the future of renewable fuel for agricultural and other machinery, both to eliminate the further depletion fossil fuels and to provide a significant reduction in greenhouse gas emissions.

Biodiesel is a liquid fuel made from processing of either tallow (animal fat) or vegetable oil in a process called “esterification”. Overall, biodiesel production is a relatively simple process, basically consisting in putting together the animal tallow or vegetable oil with an alcohol in a catalyst to have the process of transesterification, in which the oil is separated from the glycerine. This can be possibly done in a small scale on farm to provide fuel for diesel-powered farm machinery. By comparison, ethanol production involves a fermenting process and is more expensive to set up a processing plant.

Biodiesel is renewable, and can be used as a fuel in diesel engines either as biodiesel or even as straight oil that has been filtered. The energy content of biodiesel is approximately 36.2 MJ/L. Compared to petro-diesel, biodiesel gives considerably lower emissions of particulate matter (PM), carbon monoxide (CO) and hydrocarbon (HC). For example, it is found that switching to a B20 fuel will reduce greenhouse gas emissions by some 17%, together with reductions in other aspects of air pollution (Chen et al., 2015).

Although biodiesel has better combustion efficiency and lower emissions, there are a number of issues that could potentially influence the future production and utilization of biodiesel, including poor performance at low temperature, fuel quality standards, and decrease in power and torque generated by biodiesels (Sadeghinezhad, et al., 2013). Others may include carbon deposits formation, fuel filter clogging and engine wear etc. Higher costs of maintenance may thus be likely for biodiesel.

Biodiesel blends up to 5% by volume in North America and 7% in Europe are now routinely used in agriculture machines without impacting machine performance or durability. Other research showed that biodiesel blends of 20% (B20) or less would also not change the engine performance in a noticeable way. At higher biodiesel blends, however, additional care would be needed to ensure performance and durability. For higher blending, it may also be necessary to modify the machinery, particularly the fuel delivery system. A second fuel tank and other modifications to machinery may be required.

Food versus fuel balance is an important issue when using food crops for the production of biodiesel (Girard and Fallot, 2006). Excessive uses of food for fuel could either decrease the food supply around the world, or increase deforestation to provide more farmland, both of which are undesirable. It was said that filling one tank of biodiesel could use one year’s food for poor people. It was also estimated that biofuel production needed to replace just 10% of fossil fuels in transport in the US, Canada and the European Union could require between 30 and 70% of existing crop areas. The co-products from the production of biodiesel, canola and soybean meals may be used in pig and poultry diets.

Alternative sources of new second or third generation feed stocks for biodiesel, for example, from ‘‘industrialized’’ sources such as agricultural and food wastes or algae oil are being actively investigated (Girard and Fallot, 2006; Bhuiya, et al., 2016). It is predicted that the technology for the second generation biofuels may still take several years to become viable to compete with “cheap” mineral oils.

4.5 Solar energy technologies in agriculture

Solar energy is a renewable resource that can be harnessed for agricultural production. The potential solar energy around the world is presented in Figure 4.10. According to Devabhaktuni et al. [2013], there are three main methods of capturing solar energy for agricultural use:

- Photovoltaic systems integrated with buildings. Photovoltaic systems offer a promising solution for sites that are located remotely from power grids, including farms. They can be used off-grid, which means that stables and other buildings can be situated far from the main farm building and do not have to be connected to the grid. In buildings connected to the grid, the electricity generated by PV panels can be distributed to specific circuits or systems. Alternatively, two-way meters can be installed to sell excess power back to the grid during the day. This solution does not differ from other PV installations, and it is not limited to agricultural use only.

  Photovoltaic systems have been described by many researchers [Tudisca et al. 2013, Moosavian et al. 2013], and various commercial solutions are available on the market (Viessmann, PhotoEnergy) [http://photonenergy.co.uk/agriculture]. A model PV system is shown in Figure 4.11. A system with the annual energy output of 67,000 kWh can reduce CO_2 emissions by 38 tons. The system has rated power of 84 kWp, and all PV panels are connected to the grid via six inverters and two-way electricity meters. The presented system is used in agriculture, but identical solutions are used in urban areas. Agricultural facilities can be supplied with electricity not only directly from the grid, but also from PV panels, but due to annual and daily fluctuations in photovoltaic generation, such solutions are not used to power farm machines. Such installations are referred to as on-grid or grid-tied systems, which means that all of the generated energy is sold to the grid, and the power required for machine operation is purchased from the grid. Farms that generate electricity can also balance their energy output. The produced electricity is used by the farm, and only excess power is sold to the grid. When the farm needs more energy or when the local generation system is down, electricity is purchased from the grid. Such solutions are cost-effective, and they have been used for many years outside the agricultural sector. Tudisca et al. [2013] described efficient PV systems in Sicilian farms. According to the authors, the payback period in such projects, including PV installations that were financed solely by farmers, ranged from 5 to 7.5 years. However, the results of economic analyses evaluating the cost-effectiveness of PV systems may vary depending on both sun exposure in a given region and electricity prices. Legal regulations are another important consideration, including whether private entities and natural persons are allowed to sell energy or not. This can significantly affect the profitability of PV installations even in regions receiving similar amounts of sunlight.

- Off-grid systems are yet another popular solution. They differ from on-grid systems in that excess energy is stored and used when the PV installation is down (e.g. at night). Such solutions are relatively rarely used outside the farming sector because they require expensive and ineffective electrical batteries. Akikiur et al. [2013] demonstrated that off-grid systems (in this case, hybrid systems combining PV panels and wind farms) are cost-effective only when the distance between the farm and the nearest power grid exceeds 3 km. According to Ghafoor and Munir [2015], off-grid systems are profitable in regions with high solar potential (Middle East, Africa, tropical countries) due to the steady decrease in the prices of PV installations.
- Strictly agricultural uses of PV systems. For example, solar energy can be used to dry agricultural produce and in other farming operations.

The above Points 2 and 3 will be discussed in greater detail below.

4.5.1 The use of PV systems

The main rationale for the use of PV systems in farming is to increase the percentage of energy from renewable sources in agricultural production [Bardi et al. 2013]. At present, the farming sector relies primarily on energy from fossil fuels. Tractors and agricultural machinery are powered by petroleum products derived from crude oil. In systems that directly generate electricity, this problem can be addressed in two ways:

- electricity can be converted to fuel for powering combustion engines (or other engines). The only solution of the type that has been implemented in practice involves water electrolysis and vehicles powered by hydrogen. However, it is not used in agriculture due to problems with hydrogen storage and distribution [Bardi et al. 201].
- electricity can be used directly in agricultural production. This solution is not related to on-grid or off-grid systems for powering ordinary electrical devices, which were described in previous sections, but it involves supply of electricity to equipment which is powered by other conventional energy carriers.

An electric vehicle (low power tractor) developed as part of the RAMSES project is an example of the second solution [Faircloth et al., 2013; Mousazadeh et al., 2009b]. The vehicle differs from conventional electrical tractors. In addition to performing standard operations, it acts as a power source for other agricultural machines and mechanical devices, including watering, sowing, planting and harvesting equipment. The vehicle weighs 1700 kg, it has a maximum speed of 45 km/h and carrying capacity of up to 1,000 kg. The battery is charged via a PV system, and it can power the tractor for a range of around 80 km on roads or 4 h of work in the field. The batteries can be connected in series (96 V) or in parallel (48 V). The tractor is presented in Figure 4.12.

A greenhouse where a PV installation is used for passive cooling is yet another example of a system which directly uses electricity from PV cells (Figure 4.13). Photovoltaic louvres installed on the roof can be rotated at different angles to control the amount of energy generated by each panel and to create shade (and lower temperature) inside the greenhouse. The amount of solar energy reaching the greenhouse has to meet the crops' energy requirements. The energy balance is calculated based on the amount of solar radiation reaching the greenhouse and all energy losses (Figure 4.14 and Figure 4.15).

Based on the calculated values of solar irradiation and energy losses inside the greenhouse (Figure 4.14 and Figure 4.15), photovoltaic louvres are manipulated to achieve the optimal degree of shading which meets the energy requirements of crops at each growth stage [Marucci, Cappuccini, 2016].

4.5.2 Heat use

Heat from solar radiation can also be used in a variety of practical applications:

- in solar thermal collectors – for heating water. This solution is widely used outside agriculture [Viessmann, 2016];
- in conventional greenhouses – to create optimal conditions for thermophilic plants grown in colder climates;
- for drying agricultural produce [VijayaVenkataRaman et al., 2012]. According to El-Sebaii and Shalaby [2012], this is one of the key uses of solar energy in agriculture. Losses in food drying processes can be as high as 30-40%. Freshly harvested agricultural produce can be quickly and effectively dried with the use of freely available solar energy to substantially minimize those losses.

The latter solution is still relatively rarely used in agriculture. According to El-Sebaii and Shalaby [2012], there are four main drying processes that rely on solar energy:

- Natural drying. The material intended for drying is placed in a well-ventilated location with ample sunlight exposure. A photograph of naturally dried raisins is presented in Figure 4.16.
- Direct drying. The material is placed in containers (with or without side walls) covered with transparent material. The heat from solar radiation evaporates moisture from the dried product, and hot air is evacuated by convection. The drying process is presented in Figure 4.17, and a photograph of various fruit dried with the use of this technology is shown in Figure 4.18.
- Indirect drying. In this technology, air is heated by solar energy, and it is directed to drying chambers (Figure 4.19). The continuous flow of hot air dries the food inside the chamber. A photograph of an indirect drying system is shown in Figure 4.20.
- Mixed drying. The mixed drying system combines direct and indirect drying processes described in points 2 and 3. A diagram of the mixed drying process is presented in Figure 4.21.

Sun drying is one of the oldest food preservation methods known to man, but according to the literature [VijayaVenkataRaman et al. 2012, Kalogirou 2014], it is not widely used in industrial production. Forced-air drying methods that rely on heat from fossil fuels are much more popular in the food processing industry, including in countries with a high solar potential. Sun-drying methods are generally regarded as outdated and are used only in small farms.

4.5.3. Other examples of solar energy use in agriculture – desalination of seawater

Water is one of the major resources in agricultural production of both crops and livestock. Global water resources are being depleted at an alarming rate, which necessitates the search for new source of water. Desalination of seawater offers a viable solution [Kalogirou 2014]. The existing desalination methods are presented in Figure 4.22.

The percentage of renewable energy sources involved in the process of seawater desalination is shown in Figure 4.23.

An example of a stationary system for water desalination is presented in Figure 4.24.

According to Shatat et al. [2013], desalination methods that rely on renewable energy sources have reached technological maturity and can successfully compete with conventional solutions. They are highly recommended for regions which have extensive access to renewable energy sources but have poorly developed infrastructure for transmitting conventional energy carriers, in particular the Middle East and Africa where sunlight is ample most of the year (Fig. 4.10). The development of water desalination plants in those regions, including in agriculture, will increase the supply of potable water, reduce the consumption of energy from conventional sources, increase agricultural output and minimize CO_2 emissions.

4.6 Improving energy efficiency in agriculture by optimizing production processes and minimizing energy losses

According to Bardi et al. [2013], the global renewable energy resources that can be used to implement modern technological solutions are estimated at 8.5 EJ. The present demand for energy in agriculture is approximately 30 EJ. The main renewable sources of energy with the greatest potential for agricultural production are wind and solar power. If energy were to be supplied by PV panels only, photovoltaic cells would have to cover the area of 30,000 km^2 (with only 20% conversion efficiency and average solar energy levels of 8x10^9 J/m^2; Fig. 4.10) to fully meet the energy demand of the farming sector. This accounts for only 0.2% of farmland which is presently used to grow cereals worldwide. An environmental impact assessment, including changes in the intensity of sunlight reaching the Earth (reflected radiation) and effects on biodiversity, should also be carried out [Statistical Review of World Energy 2012, Hernandez et al. 2014].

The costs associated with the desalination of seawater have been decreasing steadily in recent years and are presently estimated at [Shatat et al. 2013]:

- with energy from fossil fuels – EUR 0.35-2.70/m^3;
- with wind energy – EUR 1.0-5.0/m^3;
- with energy from PV panels – EUR 3.14-9.0/m^3;
- with energy from solar thermal collectors: EUR 3.5-8.0/m^3.

Methods for generating energy from biomass, in particular biological wastes from agricultural production (livestock manure, mixture of chicken manure and straw), deserve special attention. Biogas production and composting utilize waste by turning it into methane and heat – energy carriers that can be used locally by the farm to significantly improve its production efficiency.

The Energy Returned on Energy Invested (EROEI) ratio is a highly useful indicator for evaluating the efficiency of renewable energy sources. It measures the relationship between the amount of usable energy delivered by a particular source or device and the total amount of energy that was invested to obtain that source or manufacture that device. When EROEI is less than one, the energy source is inefficient, and the analyzed process does not generate usable energy. According to Bardi et al. [2013], energy generation methods are not profitable when the EROEI is lower than 4 or 5. The EROEI of fossil fuels has been decreasing steadily due to their depletion and increasing mining costs. In contrast, renewable sources of energy are characterized by increasing EROEI values. At present, wind energy and solar energy can effectively compete with fossil fuels as reliable sources of high-quality power. The progress made in renewable energy technology has driven down the prices and increased the efficiency of green solutions. Unfortunately, the above does not apply to energy generated from biofuels. According to Bardi et al. [2013], this can be explained by the low efficiency of photosynthesis as well as the relatively high cost and complexity of processing substrates for biofuel production. The EROEI of biofuels can be improved by using the generated energy as close as possible to its generation site. This goal should not be very difficult to accomplish in agriculture.

4.7 Conclusion

A significant amount of energy is consumed in agriculture. Most of this energy comes from non-renewable sources. At present nearly all the tractors and agricultural machinery available run on petroleum products such as diesel, kerosene and petrol. Significant research has also been done in the past to reduce our dependency on the petroleum products. A number of alternatives like biodiesel and biogas have been investigated. However, there are still a number of cost and technical issues related to their usage to be overcome.

Energy use is now seen as one of the key indicators of sustainable development. Agriculture can play a dual role as an energy user and as an energy supplier in the form of bioenergy. Advanced technologies and alternative fuels can be used to improve the efficiency of agricultural production while minimizing energy consumption in the farming sector.

Despite of the current arguments, the long-term future for renewable energy is positive since the prices of fossil fuels will continue to rise as the resources are depleted while the prices of renewable energy will continue to decrease. Renewable energy sources should contribute to energy security and should cover the needs of consumers who obtain energy from green sources. For this reason, renewable energy sources are highly recommended for farms. Many farms are set remotely from power grids, and they produce organic materials that can be converted into energy. Those materials include wastes which have to be sustainably managed without causing harm to the natural environment. Biological wastes constitute biomass which is an excellent substrate for composting, a process that generates heat for agricultural production. Biomass can also be fermented to produce biogas which is used in hybrid systems that cogenerate electricity and heat. Biomass can be used to produce other biofuels for powering combustion engines in tractors and agricultural machines. Advanced technologies that convert solar energy into both heat and electricity are increasingly used in the farming sector.

Another important problem related to the use of renewable energy sources in farming systems is energy storage. A variety of technologies are being developed. However, due to its extensiveness and complexity, this problem should be thoroughly discussed in a separate paper. Overall, considerable technology demonstration will be required to prove the technical performance, understand implementation requirements and build local knowledge and capability. In addition, farming practices of precision agriculture, controlled traffic farming (CTF), direct drilling and minimum tillage could also be used to reduce energy use.

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Biogas Wiki with a lot of useful information about basic principles and documentation from various sizes:
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Figure captions

Figure 4.1. Demand for energy in agriculture.

[Source: http://na.unep.net/geas/articleImages/Apr-12-figure-4.png]

Figure 4.2. Diagram of the heat and biogas recovery system developed by Jean Pain.

[Source: http://journeytoforever.org/biofuel_library/methane_pain.html]

Figure 4.3. Schematic diagram of the experimental apparatus.

[Source: Seki and Komori 1992]

Figure 4.4. Testing station diagram: 1 – control tunnel, 2 – compost heap, 3 – tunnel with preheated soil, 4 – system of pipes collecting heat, 5 – system of pipes preheating soil, 6 – thermometer measuring compost temperature, 7 – thermometer measuring supply water temperature, 8 – thermometer measuring return water temperature, 9 – circulating pump, 10 – expansion vessel.

Figure 4.5. Flow diagram of a heat recovery system

[Source: https://www.biocycle.net/2014/02/21/heat-recovery-from-compost/]

Figure 4.6. Vermicompost bin.

[Source: http://www.permaculture.co.uk/articles/heating-greenhouse-compost-and-manure]

Figure 4.7. Stages of biogas production during methane fermentation.

[Source: https://en.wikipedia.org/w/index.php?title=Biogas&oldid=709899992]

Figure 4.8. Bacterial communities involved in biogas production.

[Source: https://en.wikipedia.org/w/index.php?title=Biogas&oldid=709899992]

Figure 4.9. Diagram of a biogas plant in a farm.

[Source: https://en.wikipedia.org/w/index.php?title=Biogas&oldid=709899992]

Figure 4.10. Annual and daily sum of solar energy in the world in kWh/m^2.

[Source: https://upload.wikimedia.org/wikipedia/commons/9/9d/SolarGIS-Solar-map-World-map-en.png]

Figure 4.11. Photovoltaic system in Broadwater Farm.

[Source: http://photonenergy.co.uk/agriculture/case-studies/58-case-study-broadwater-farm]

Figure 4.12. Battery-powered RAMSES agricultural vehicle.

[Source: Mousazadeh et al., 2009a].

Figure 4.13. Greenhouse with a PV system.

[Source: Marucci, Cappuccini, 2016].

Table captions

Table 4.1. Quantity of biogas produced from different substrates during methane fermentation.
[Source: https://en.wikipedia.org/w/index.php?title=Biogas&oldid=709899992]

Table 4.2. Typical composition of agricultural biogas.
[Source: https://en.wikipedia.org/w/index.php?title=Biogas&oldid=709899992]

Tables

Table 4.1.

Substrate	**Biogas quantity (m^3/Mg)**
liquid cattle manure	25
liquid pig manure	36
Whey	55
sliced beetroot	75
brewer’s spent grain	75
dried distiller’s grains with soluble	80
green waste	110
biological waste	120
maize silage	200
Fat	800

Table 4.2.

Typical composition of biogas		
Compound	**Formula**	**%**
Methane	CH_4	50-75
Carbon dioxide	CO_2	25-50
Nitrogen	N_2	0-10
Hydrogen	H_2	0-1
Hydrogen sulfide	H_2S	0-3
Oxygen	O_2	0-0.5