Chapter 15
Energy Solutions for Agricultural Machinery: From the Oil Era Towards a Sustainable Bioeconomy

Per Frankelius and Mattias Lindahl

Abstract Agriculture is at the heart of the bioeconomy. One central factor in agriculture is energy, which is needed for processes such as powering field machines like tractors and combine harvesters but also irrigation pumps, stable fans and grain drying systems. Modern implements like seeders, planters and manure spreaders need energy both for their movement (traction) and onboard equipment like fans, pumps, computer power and hydraulics. The study focuses on energy solutions for field machines in farming. These machines do their job in the countryside, far away from the energy infrastructure found in cities, and that is a challenge. One main part of the analysis in this chapter is a historical discussion on energy provision. Another part is an overview of present initiatives, including both those implemented in practice (like biogas and battery concepts) and those in trials or only discussed among experts in the industry (like fuel cell or hydrogen concepts). Derived from this analysis are some future visions towards a (1) fossil-free, (2) cost-effective and (3) sufficient energy system for farming field machines. In addition to these three dimensions, also discussed, for example, is the need for local production (small-scale circular systems), the weather independency aspect (for energy production) and autonomous vs. traditional machine systems.

Keywords Circular economy · Agriculture · Farming · Tractors · Biodiesel · Fossil-freedom · Fuel cells · Biogas · Ethanol · Robots

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P. Frankelius (✉)
Agtech 2030, Linköping University, Linköping, Sweden
e-mail: per.frankelius@liu.se

M. Lindahl
Mistra REES, Linköping University, Linköping, Sweden

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1 Introduction

1.1 Background

Despite their evidently different assumptions and operationalization strategies, the concepts of the bioeconomy, the circular economy and the green economy are joined by the common ideal to reconcile economic, environmental and social goals (D'Amato et al. 2017) and are currently considered in policy making as key sustainability avenues. Of these three, this chapter is focused on the bioeconomy, which is concentrated on local processes in terms of biosecurity and rural policies.

The term bioeconomy was probably first used in 1992 by Bernadine Healy when, while serving as Director of the National Institutes of Health in the USA, she speculated about the future of biotechnology (Nerlich 2015). Biotechnology is a field with roots in agriculture, for example, the art of using microorganisms in the process of brewing beer (Frankelius 2009). Later, the meaning of bioeconomy became broader; it is referred to today by many as the economic activities derived from biological resources. In this context, the agriculture and forest industries play important roles in providing bio-based substitutes for non-renewables (Roos and Stendahl 2015). The current understanding of bioeconomy is based on the idea that industrial inputs (e.g. material, chemicals and energy) should be derived from renewable biological resources, with research and innovation enabling the transformational process (Kleinschmit et al. 2014; Bugge et al. 2016), something in line with the ideas behind the biological cycle in a circular economy (Ellen MacArthur Foundation 2013).

This implies that agriculture is at the very heart of the bioeconomy because it conducts primary production by means of using soil in combination with photosynthesis. Agriculture contributes to society not only by meeting the world's food needs; it also produces fossil-free fibers and fuels. Moreover, if managed in a sustainable way, and not as sadly described by Carson (1962) in her book *Silent Spring*, agriculture can be an enabler for the important biodiversity of, for example, crops, insects and birds – which can be essential for sustainable agriculture. At the same time, agriculture is highly energy dependent, which is a problem not only from an economic perspective but also from one of climate care. Activities such as soil cultivation, the transport of bulk materials, in-farm handling of animals and crops and the drying of agricultural products are example areas where significant energy is needed.

1.2 The Productivity Revolution

Historically, the energy needed for field work was provided by men and animals, not least, oxen and horses. But, by the end of the nineteenth century, machines took over. This started a productivity revolution in agriculture that also paved the way for

Fig. 15.1 One towed 5-foot header combine harvester (from 1954) that fills grain into sacks compared to the self-propelled X9 combine harvester with a 45-foot header and a 16,200-liter grain tank (from 2020)

releasing the workforce in favour of the growing industrial sector. Some comparisons can be interesting just to understand this revolutionary process. During the eighteenth century, up to 30 person-days per tonne of harvested grain were used in harvesting and threshing work (Myrdal 1993). After the entry of the mowing reaper and threshing machine, the person-days needed dropped to about seven.

With the introduction of modern combine harvesters, things got faster. In 2020, John Deere demonstrated a combine called the X9, then still not launched on the market but with a capacity of 100 tonnes per hour (Stolpe-Nordin 2020). This means less than 2 minutes per tonne, but the energy needed for this mega combine corresponds to 700 hp (by means of a diesel engine); see Fig. 15.1.

The productivity revolution, the shift from manual labour to machinery and constantly larger machines, has led to an increased energy consumption, mainly related to fossil fuels. According to Eurostat, the data on energy consumption in agriculture is not very reliable and mainly reflect consumption for engines used for agriculture-related transportation. The energy consumption by agriculture within the EU in 2017 made up 2.8% of the overall energy consumption and decreased between 1997 and 2017 by 15% (Eurostat 2019). Oil and petroleum products were the main fuel type and contributed to 53% of total energy consumption by agriculture in 2017, but the share of electricity and renewables and biofuels had increased since 1997.

1.3 Why Is Agriculture So Energy Demanding?

There are many energy consumption activities in agriculture, for example land preparation, cultivation, irrigation, harvesting, threshing, grain drying and fan systems in animal stables. This chapter, however, focuses on energy needs in field work. We can begin by ascertaining that agriculture field work is very energy demanding. But why? Some reasons are compiled in Table 15.1.

One can add that heavy machinery leads to more soil compaction, which leads to more soil resistance and, therefore, more energy needed to overcome it. Moreover,

Table 15.1 The ten factors behind the high energy need in modern agricultural field work

	Factor	Explanation
1	Scale	Modern farm production is a large-scale activity. For example, farmers use 35-m-broad sprayers or 45-foot combines. Although the average farm in the EU has only 15 hectares of land, the majority of the land area is managed by large farms (defined as more than 100 hectares). Today, farms of well over 1000 hectares are not uncommon. The structural change from smaller to bigger farms also means more energy-demanding machines
2	Workforce cost	Because labour cost is high, there is a need for time-saving and, therefore, high-speed processes, which demand efficiency
3	Soil resistance	Soil is a heavy material, and many activities, for example, weed hoeing, are about dragging tools in the soil
4	Weather and "short time windows"	Agriculture is weather dependent, and timing is everything. Therefore, much work must be done in a short time frame at "weather windows", meaning a need for high power
5	Image	Attracting people to farming has partly been related to "cool machines", and in some people's eyes, that means "big machines" (no matter if those big machines are needed)
6	The imitation game	It seems that agricultural machinery companies compete by making faster, bigger and stronger machines, which drives a greater need for energy
7	Lackof energy efficiency	Optimal would be 100% energy efficiency in fuels and other energy categories, but losses are a matter of natural laws, so more energy is needed than what is actually transformed into target actions
8	Population increase	In 1800, the world population was 0.98 billion, in 1900, the figure was 1.6 billion, and in 2000 it was 6 billion. In 2050, the UN projects it will be 9.8 billion. In combination with changing food habits, this means more food demand and more energy needed in farming
9	Organic trend	Transforming from conventional (chemicals and fertilizers) to organic farming for meeting political and consumer trends also means more physical actions regarding, for example, weed management, and that means a greater need for energy
10	Demand for fossil-free fibres and fuels	The will to phase out fossil products means more demand for bio-based products like biofuels and bio-fibres, and this means more farming leading to a greater need for energy

soil compaction means decreased soil health, which brings harvests down, and farmers try to compensate for this by still more activities in the field.

1.4 The Pursuit of Fossil-Free Agriculture: The Political Perspective

Diesel is still the main energy source for field work in agriculture, but this may change in the near future. The search for fossil-free energy in response to not least climate problems has, as everyone has seen, intensified, not least through laws, regulations and supranational agreements, for example, the Kyoto Protocol and the

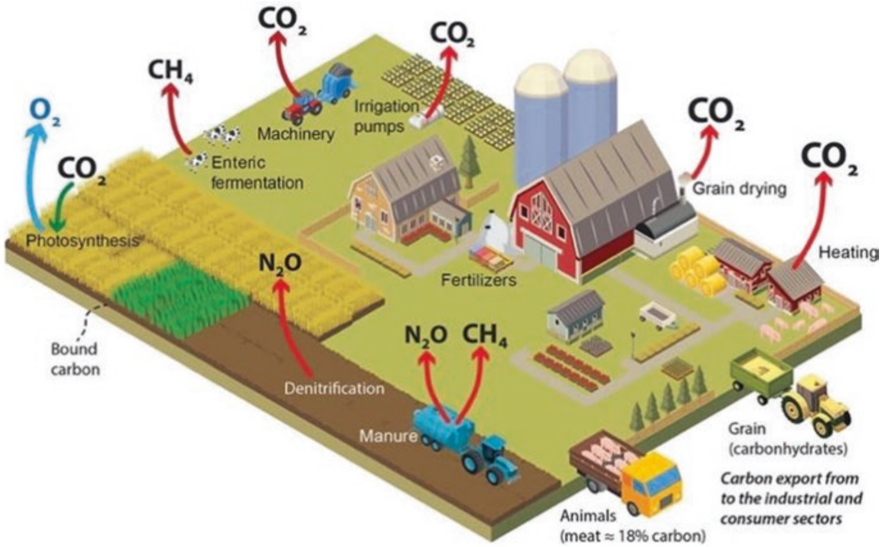


Fig. 15.2 Farming activities and climate effects (based on Frankelius 2020)

Paris Agreement. While the Kyoto Protocol was about reducing annual global carbon emissions to 1990 levels by 2020, the Paris Agreement set the goal of limiting global warming of greenhouse gas emissions to 1.5 °C by the end of this century. The EU also set similar goals in line with the UN framework and has put in place legislation to reduce CO_2 emissions by at least 40% by 2030. This is a part of the EU’s 2030 climate and energy framework and contribution to the Paris Agreement.

In agriculture, there are several sources of greenhouse gas emissions. Most of these different kinds are negative, but some are actually positive, not least oxygen production and the “opposite-to-emission” carbon dioxide uptake by plants (Frankelius 2020); see Fig. 15.2. In this chapter, we only focus on machines and the negative impact of them as well as how to decrease this negative impact.

1.5 The Pursuit of Fossil-Free Agriculture: The Customer Perspective

Many actors in the world, not least in Europe, are conducting processes and projects to convert agriculture to fossil-free activities. In Spain, for example, the MASLOWATEN project commenced in 2017 to run high-power photovoltaic irrigation systems for productive agriculture irrigation consuming zero conventional electricity and 30% less water (Lorenzo et al. 2018). Another example is the European Investment Bank, which decided in November 2019 to stop financing fossil fuel projects by the end of 2021 (Ekblom 2019).

Individual farmers are also acting on the stage, but it is not as easy for them to make the necessary investments. Nevertheless, there are a lot of proactive farmers who have already started to convert their farms to fossil-free ones. Biogas plants, solar power and wind power are examples of local energy production, while heating boilers used in, for example, the drying of grain is increasingly done using fossil-free energy, such as straw pellets. There are several driving forces behind an individual farmer wanting to switch to fossil-free agriculture. One is simply a climate commitment. But farmers also have high energy costs and are looking for ways to reduce them. They dream of producing their own energy.

2 Development of Different Traction Energies

2.1 *The Steam Engine Era*

Petroleum-based fuels became the most common energy source in agriculture after the era of oxen and horses. However, steam engines first dominated traction during a period up to the beginning of the twentieth century. In fact, the world's first high-pressure steam engine was invented by Englishman Richard Trevithick in 1802 (Hodge 1973), and it made its way into society through the Hayle Foundry, which built it in 1811 for the farmer Christopher Hawkins. He wanted it to run a (stationary) threshing machine on his farm in Probus, Cornwall, and it came into operation in 1812. Thus, the modern steam engine became an innovation thanks to agriculture, not train transports or industrial use, which many may assume.

2.2 *The Gasoline and Kerosene Era*

Following the steam era, the mainstream fuel became gasoline (petrol), which dominated from 1900 to the 1950s. The world's first true tractor, introduced by John Froelich in 1892, ran on gasoline. Driven by a lower price, kerosene did enter the fuel market. One of the first kerosene tractors was made by Hart-Parr in 1904. However, one needed to start it on gasoline (ASME 1996). Another was the Rumely Oil Pull tractor, built in 1908 and introduced in 1910, which ran on kerosene rather than raw oil despite its name, and for which the chilling medium was oil, not water.

2.3 *The Struggle to Make Use of the Cheaper Raw Oil*

There were some early initiatives to produce engines that could be driven by (cheaper) raw oil (also called crude oil). Herbert Akroyd Stuart invented the hot-bulb engine, or heavy oil engine, with Charles Richard Binney and in connection with the Richard Hornsby and Sons company. The first prototype appeared in 1886, and the patent was filed in 1890 with the title "Improvements in Engines Operated by the Explosion of Mixtures of Combustible Vapour or Gas and Air", and this engine was stationary.

In 1896, Richard Hornsby and Herbert Akroyd Stuart filed the Hornsby-Akroyd Patent "Safety Oil Traction Engine" (Ransome-Wallis 2001). In 1897, this tractor was bought by Mr. Locke-King, which was the first recorded sale of a tractor in Britain. In the same year, the tractor was presented at the Smithfield Show and at the Royal Agricultural Show. This tractor was, by the way, taken back to the company and equipped with tracks later on (the company became one forerunner to Caterpillar). Another initiative to use the hot-bulb engine for traction in farming was taken by J.V. Svenssons Motorfabrik in Augustendal in Stockholm, Sweden (Funke 2013). This company used hot-bulb engines in its Type 1 motor plough called Avanceplogen, produced in 1912. The inventor of this machine was Gustaf E. Jonsson from Norrköping. In 1921, the Lantz Bulldog tractor appeared in Germany. This tractor could run on many kinds of fuels, including crude oil. In 1930, the Swedish firm Munktells launched a hot-bulb engine for cheap raw oil.

John A. Secor, a consulting engineer at Advance-Rumely Co. in La Porte, Indianapolis, USA, made this reflection about raw oil engines in 1920 (Secor 1920, p. 700):

> None of the early types of oil engines was suitable for or used in the farm tractor. As recently as 1900, the steam tractor practically monopolized the field of power farming; but the supremacy of steam power was soon challenged by the gas tractor, and within recent years, the gas tractor has commanded a much broader market than the steam tractor.

During the 1960s, diesel became the new mainstream fuel in agriculture. According to Crister Stark, part-owner of the implement manufacturer Väderstad, the diesel engine has been extremely important for the productivity development in agriculture after the Second World War. "Most modern high-efficiency implements need tractors with lots of power" (Stark 2020). So, let us look into the development of this engine.

2.4 The World's First Diesel Tractor

The first diesel tractor, and indeed the world's first series-produced diesel engine vehicle, was the Benz-Sendling S 6, introduced in 1923 (Fig. 15.3). Its background was related to Karl Friedrich Benz and Otto Vollnhal. Benz founded the company Benz & Cie in 1883, and he received the famous patent on what is considered the world's first automobile 2 years later. Following a few unsuccessful attempts in the tractor field, Benz created a joint venture with Münchner Motorenfabrik München-Sendling in 1919, founded by Otto Vollnhal in 1899. Vollnhal had started manufacturing motor ploughs in 1909. The new company was called Benz-Sendling

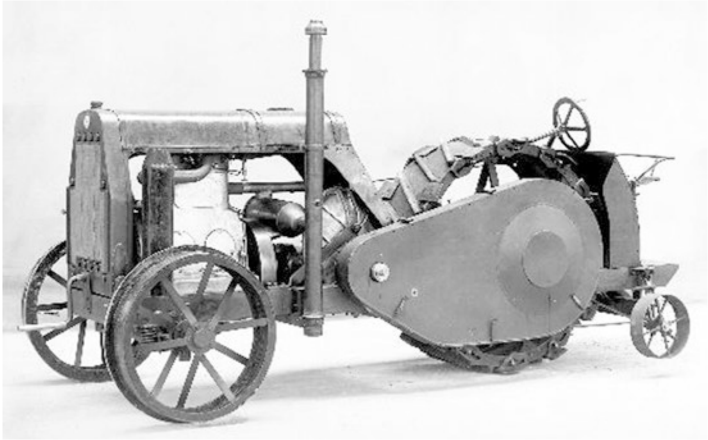


Fig. 15.3 The Benz Sendling S 6. (Photo courtesy of Mercedes-Benz Classic)

Motorpfluge GmbH. Initially, a three-wheeled tractor with a petrol engine, called the Model T3, was developed. But soon, the engine was changed. Here is how it happened (Jung 2019):

The inventor Prosper L'Orange joined Benz & Cie in 1908 after having worked for Gasmotorenfabrik Deutz on big compressorless, stationary diesel engines. At this time, diesel engines were only used as stationary and marine engines, due to their size and weight. In 1921, L'Orange developed a more compact and high-speed engine by means of inventing first an afterchamber (patent 1908) and then a prechamber (patent 1909). However, the prechamber patent was neglected by the company. But when L'Orange came across a competitor's engine from Sweden, he got new inspiration and started to modify his prechamber, resulting in a new patent in 1919. The Swedish engine, called Ellwe, was invented by Harry Leissner at around 1913 and produced by the company Ljusne-Woxna AB. This engine had a new kind of prechamber and was launched on the market in 1918 (Spade 2008).

But L'Orange did not stop inventing. He also developed a variable injection pump in 1921, and now the engine concept was ready for wheeled vehicle installment. But what vehicle to choose? L'Orange found what he wanted at the joint-venture company Benz-Sendling: a tractor. As early as in 1921, he had put the new engine into a Benz-Sendling T3 tractor with three wheels. The engine had two-cylinders and developed 25 horsepower.

In 1922, three new prototypes were created with diesel engines. These tractors developed 30 horsepower and, like the T3, had three wheels with a large rear drive. The model was presented as "Benz-Sendling S 6" (see Fig. 15.3) at Ostmesse in Königsberg in 1923, and information tells that all three copies were sold quickly, of which at least one was sold at the trade fair. In 1923, as many as 100 tractors were manufactured.

The first four-wheeled Benz-Sendling tractor was called "BK", developed 32 horsepower, and began development in 1923. It was the result of a new collaboration, now between Benz and motor-plough manufacturer Automobilfabrik Komnick AG in Elbing ("BK" stood for Benz-Komnick). That tractor had three gears and was more expensive than the S models, and it is unclear if any were sold in the first few years. There is information that one may have been sold in England in 1930, but this is unclear.

Benz & Cie merged with Daimler-Motoren-Gesellschaft and, in 1926, formed Daimler-Benz AG. After that, the "Mercedes-Benz" name appeared, as well as the legendary three-point star on the new company's products. In 1928, a new variant of just one cylinder (inspired by Lantz) was launched, under the name Mercedes-Benz Model OE Diesel Tractor. The partly owned company Benz-Sendling also sold that tractor. But sales were slow, and in 1933, Daimler-Benz AG finally gave up tractor production for many years to come. Later on, however, it started again and had success with Unimog-based MB-Trac. But that is another story.

2.5 Biodiesel Fuels

Over time, environmental and political concerns paved the way for so-called biodiesel fuels, meaning vegetable oil – or animal fat – based fuels with molecules similar to petroleum diesel. The history of biodiesel is even longer than the history of the diesel engine itself. The transesterification of vegetable oils was conducted by Patrick Duffy already in 1853. In fact, Rudolf Diesel's first engine model, created in Augsburg, Germany, on the 10th of August 1893, ran on "biodiesel" in the form of peanut oil or hempseed oil (Saß 1962). Logically, it must, for the farmer, be a pleasant dream, using fuels that can be produced at the farm itself, for example, rapeseed oil.

Time went by, but not much happened in the biodiesel area – until the 1980s. It was then when the Elsbett company in Germany developed a type of cylinder head suitable for direct running on vegetable oils. This engine was announced around 1982. The Valmet company in Finland made some tractors with that type of engine, and some farms in Sweden ran them in field work; Sjösa near Nyköping was one of them (Hansson 2020).

It took a long time for biodiesel production on farms to gain its foothold in the market. The farmer, Axel Lagerfelt at Tolefors in Sweden, was one of the early adopters when installing a compact biodiesel plant in 2006. The equipment was developed by David Frykerås at the company Ageratec, later acquired by Alfa-Laval (Frykerås 2011).

In the same year as the Tolefors investment, in 2006, New Holland probably became the first tractor manufacturer to offer 100% biodiesel compatibility (Overall 2018). Some farmers have expanded this idea into pure fossil-free farming concepts. One pioneering effort was made by the company Energifabriken in Sweden 2012, something we will come back to later in this chapter.

2.6 Ethanol Fuels

Regarding ethanol, it is a complicated story. Such fuel was common in the early history of internal combustion engines, starting with Samuel Morey's fuel-flexible engine (including ethanol), in 1821 in the USA (Morey 1820). Due to US tax regulation in 1862, this fuel could no longer compete with coal (steam engines) or gasoline. Interestingly, Henry Ford's Model T was developed to run on ethanol (Hansson 2020). Sadly enough, we have not found any robust historical information about the first ethanol-driven tractor. But we know that in some countries, ethanol, over time, made a foothold on the market as traction fuel. Not least during times of war and during oil crises did ethanol gain more attention. Here are some ethanol projects in modern times:

In 1983, the Finnish tractor producer Valmet introduced an ethanol tractor made for the "ethanol country", Brazil. In 2006, Saskatchewan Industry and Resources in Canada also presented a modern ethanol tractor. Scania was early with an engine running on ethanol. It was mainly an engine for trucks, and it ran well on ethanol (Hansson 2020).

Besides new engines, one option is to convert older engines so that they can be fuelled with ethanol. One shall keep in mind that it has been hard to get diesel engines to accept ethanol fuel. The US company ClearFlame Engines, together with Cummins, announced in 2020 that it was trying to make a combined diesel and ethanol engine. Scania in Sweden already has many ethanol engines based on the diesel engine principle. However, its engines need additives (ignition improver and lubricants) to function, and these engines are not applied to tractors. Later on, we will describe the robot concept Alina, which can run on ethanol.

2.7 Wood Gas and Methane

During the Second World War, there was a lack of fuels. That led not only to interest in ethanol but also to wood gas, in the USA called "producer gas". Authorities in many countries promoted this technology for both automobiles and farm tractors. In Finland, for example, there were at most 4000 tractors driven by wood gas (De Decker 2010). The first wood gas vehicle was presented by Thomas Hugh Parker in England 1901. One of the tractors that were prepared for wood gas was the McCormick Deering 10–20 from International Harvester.

Methane is one of the ingredients in wood gas, and pure methane is still one kind of fuel that has been used for traction, and interestingly enough, not least because farmers can produce their own methane through biogas plants. Valtra, in the first decade of this century, presented and test ran in practical work dual-fuel models (methane/diesel). It started this development in 2008, and in 2009, the first model, N101, was taken into use and tested in various contexts. In 2010, the time had come for public launch; it happened at the Borgeby Field Days in Sweden. The next year, Valtra presented the improved version T133 HiTech at the Agritechnica fair in Hannover. Testing of this tractor was conducted in Sweden during 2012, and in 2013, limited sales had begun.

New Holland Agriculture was right behind this development. In 2013, it presented its first prototype of a tractor powered by methane, the Methane Power T6. In December 2018, the company announced a new prototype tractor propelled by methane, which was presented at the Farm Progress Show in Decatur, Illinois, USA (Overall 2018). These initiatives were part of the New Holland vision "Energy Independent Farm". More on this will be discussed later.

2.8 Early Electrical Visions

Besides the energy variants mentioned above, there have been more interesting innovation projects heading for creative traction concepts. One early attempt was electricity in different forms and related to either cable provision or batteries, but also wire or chain systems. One early but strange example is the F. Zimmermann u. Company in Halle, which in 1894 demonstrated an electrical ploughing system (Williams 2019). It was a motor plough with an electric engine onboard. The engine dragged the vehicle along a chain that was laid over the field; see Fig. 15.4.

Notice that the Zimmerman system needed a chain and had the motor onboard. Williams (2019) describes another electrical tractor concept: the Brutschke system. In this concept, the motor was placed at the side of the field, and a plough was dragged by means of wires across the field. Fritz Brutschke's electrical plough concept, the so-called single-engine system, was designed around 1900 so that there was one cart with an electric motor (weighing 5.5 tonnes) placed at one side of the field. The second cart, at the other side of the field, was an anchor carriage. The motor was 60 hp (44 kW), with a working voltage of 380 volts. One challenge with the 5.5-tonne carriage was moving it by horse.

Sweden was among the countries that became inspired by the German development. In 1909, the first Swedish electric plough concept was manufactured by the company ASEA (Lagnelöv 2014). It was implemented the following year at the Ahlby farm in Stockholm, and the electric motor on the side of the field produced

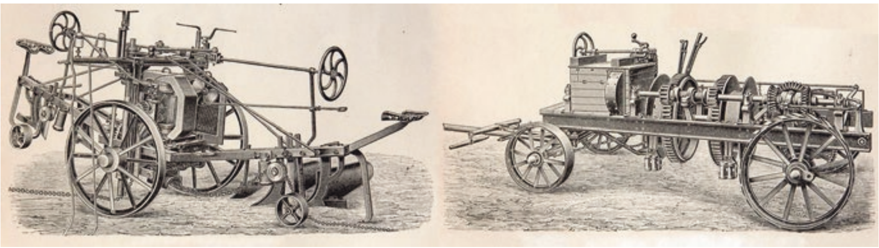


Fig. 15.4 Zimmermann's electric plough. (Unknown artist from old lithography)

24 hp (18 kW). The owner of Ahlby farm, as well as the first adopter of this, was a manager at the tech company L.M. Ericsson. Subsequently, ASEA began to construct a larger plough which appeared at the Agricultural Meeting in Örebro in 1911. Now the engine had 35 hp (26 kW). Although ASEA's plough received good reviews, the spread was slow. In 1919, there were only four electric ploughs implemented in Swedish agriculture.

The mentioned concepts suffered from high friction because of the wire or chain being dragged along the ground. This led to more inventions. In 1920, E.A. Grafström from Electro-Agricultur Aktiebolag in Stockholm received a patent for a device for transferring electrical power to freely moving electric machines that could hold a cable freely hanging in the air with the help of regulators and cable drums. In 1921, he received a new patent on the regulator for keeping the cable at a good height (Lagnelöv 2014; Svensk Tidskrift för Industriellt Rättsskydd 1923).

Another example during the 1920s was the experimental tractor Elektrotanken (ASEA 2011), a concept invented by Hjalmar Cassel. Unlike the previous electrical plough concepts, it was now a moving machine that was electric motor-driven and could pull whatever implement, not only a plough. The machine (a converted US-built Cletrac) had tracks and a three-phase alternating current motor of 15 hp (12 kW) using 500 volts. The electricity was transferred through a high-voltage cable to a transformer wagon, and from there to the cable reel via a 250-m-long reinforced cable. The cable went through an 8.5-m-high mast on the cable car that connected to a high mast that was fixedly mounted on the tractor. The mast construction caused great strain on the cable, as the mast swayed very strongly when the tractor passed over uneven parts of the field. This was reported to be the reason why continued production failed.

In 1922, an attempt was made with the so-called June motor plough outside the ASEA city of Västerås in Sweden (Landtmannen 1924). The Royal "Vattenfallsstyrelsen" contributed financially, ASEA supplied the electrical equipment, and AB Juneverken contributed with its three-wheel motor plough. ASEA engineer Nils Forssblad converted the June plough to electric power. This concept was about a wheel-driven motor plough, and it received power from a transformer wagon via a 400-m-long insulated cable. The June plough initially had an electric motor of 16 hp (12 kW), but it was considered too weak, so a 50 hp (37 kW) engine was later installed and marketed. The cable was laid on the ground, and only the last 30–40 m hung freely from the ground in the mast that the tractor was equipped with. Integrated into the tractor was a cable drum which, using a small electric motor, wound the cable. The tractor mast also contained a series of switch rollers that would prevent the laid cable from looping or twisting while driving. The run still needed to be planned and performed according to predetermined patterns so that the cable was not damaged. Despite this, the life of the cable was relatively short due to constant unwinding and reeling on the cable drum. It was estimated that the cable would last at least 2 years if 150 ha were ploughed annually. After being tested in the Västerås area, the electrified June plough from 1923 was used in Ultuna and Täby with good technical results. This is what the magazine *Landtmannen* (1924, p. 433) wrote in 1924 about this:

> An important wish regarding the electric tractor is that it could be made independent of the wires in the field, that it could thus be equipped with an accumulator battery, sufficient for, for example, half a day or longer driving. Solving the question in that way, however, seems at least at present, for practical reasons, to be impossible, as the accumulators become too heavy and expensive. The lightest battery that can now be obtained weighs 33 kg per kWh and costs SEK 85 per kWh. If a motor plow is required for half a day of operation, e.g., 70 kWh., the battery weight will be 2,300 kg, and the price for the same SEK 6,000 or SEK 12,000 for the required two batteries. In addition, such batteries are not very durable. It thus seems to be quite clear that the accumulator operation currently is not to be seriously reckoned with, and the hopes concerning it for the future do not seem to be so bright that, at present, they justify a wait-and-see attitude towards now practically feasible proposals for electric operation.

We will revisit this kind of concept later.

2.9 Battery-Based Vehicles

Besides the energy variants mentioned above, there have been some interesting attempts to fulfil the dream that the magazine *Landtmannen* talked about. One of the first electric battery-based tractors was the one developed by South Dakota State University in the USA in 1983. Williams (2019) commented:

> Agricultural engineers at South Dakota State University started work on their Choremaster tractor project in 1983, using two 32-cell battery blocks to produce a 43.5 kWh electricity supply powering two motors. One motor operated the hydraulic systems, including the power steering plus the power take-off, and the other powered a three-range hydrostatic transmission with four-wheel drive. Because of the limitations of battery power in the 1980s, the Choremaster was designed mainly as a yard tractor working within easy reach of a power point for battery charging.

Time went by, and not much seems to have happened. But in 2007, during Agritechnica, John Deere presented concept tractors called the E-Premium 7430 and 7530, manufactured in Mannheim. The tractors had diesel engines but also crankshaft generators, driven directly by the engine, which could provide about 20 kW of electrical energy. From the generator, the electrical energy was converted to the desired voltage and further distributed to the chosen destination, such as fan drive, air conditioning or compressed air compressor – or for that matter, sockets to machines such as workshop machines. Any connection to driving, such as wagon wheels, was not included in the concept. It was partly an electric tractor, however not battery-based.

Kharkiv in Ukraine, in 2015, presented the electric tractor Edison (40 kW). In 2017 Fendt presented the e100 Vario prototype and in 2018 the Swiss Rigitrac SKE 50 was on display on the Agrama trade fair. The energy came from an 80-kWh lithium-ion battery with which one can drive up to 5 hours on one charge. This yellow, compact and well-designed tractor contained five electric motors, one for front and rear power take-off, one for the front axle and one for the rear axle. The fifth engine drives the hydraulic system.

We will later give some other examples. However, reality has shown that batteries are difficult solutions, due to the huge energy requirements in farming work, in combination with distance from fields to reload stations. A similar problem pained NASA engineers when planning long space flights. One interesting innovation area, therefore, became so-called fuel cells. We will now dig deeper into the fuel cell concept.

2.10 Towards the Fuel Cells Concept and Beyond

A fuel cell converts chemical energy from a fuel, such as liquid hydrogen, into electricity through a chemical reaction that is activated by an oxidizing agent, such as liquid oxygen. Simply put, one can say that hydrogen reacts with oxygen, which leads to water, while electrons are released ($2H_2 + O_2 \rightarrow 2H_2O + 2^{e-}$). This is a continuous process that does not end as long as fuel is supplied, unlike a battery that stores the chemical reactants. Furthermore, the reaction is silent and does not give rise to either smoke or the same heat as internal combustion engines. Compared to most batteries, the weight is small. The disadvantage is high price and (possible) explosion risks.

The fuel cell was probably invented by William Robert Grove in Wales (Great Britain) in 1839 but is believed to have been first demonstrated by the British chemist Humphry Davy as early as 1801. Francis Thomas Bacon (a relative of the famous Francis Bacon) developed in 1939 a practically useful fuel cell powered by hydrogen and oxygen by an alkaline electrolyte. He developed a working prototype in 1959.

Bacon’s concept, the alkaline fuel cell, was to be used in the US space program. First out was the two-person rocket Gemini V, which took off on the 1st of August, 1965, with astronauts L. Gordon Cooper and Charles Conrad. General Electric is said to have constructed the fuel cells in the Gemini spacecraft. However, they did not work as they should, creating great drama. The technology was further developed and later used in the Apollo project, which followed Gemini. The Apollo missions triumphed with the lunar landing in 1969.

However, the first fuel cell engine vehicle was neither a space rocket nor car, but a tractor from Allis Chalmers, and was presented on the 15th of October, 1959, in Milwaukee (Karg 2019). Its fuel cells, 1008 in number, were not driven by hydrogen but a secret propane gas mixture. The power output was 15 kilowatts, which corresponded to about 20 horsepower. The concept tractor was based on a D-10 chassis. During the demonstration, ploughing of a field alpha-alpha was performed. The engine was developed by engineer Harry Karl Ihrig starting in 1951. The tractor is preserved at the Smithsonian Museum, but at the time of this writing, it was loaned to a small local museum called McLeod County Historical Society & Museum in Hutchinson, Minnesota; see Fig. 15.5.

The first car with a fuel cell engine was not introduced until 1966 through the Chevrolet Electrovan from General Motors. We can thus conclude that agriculture

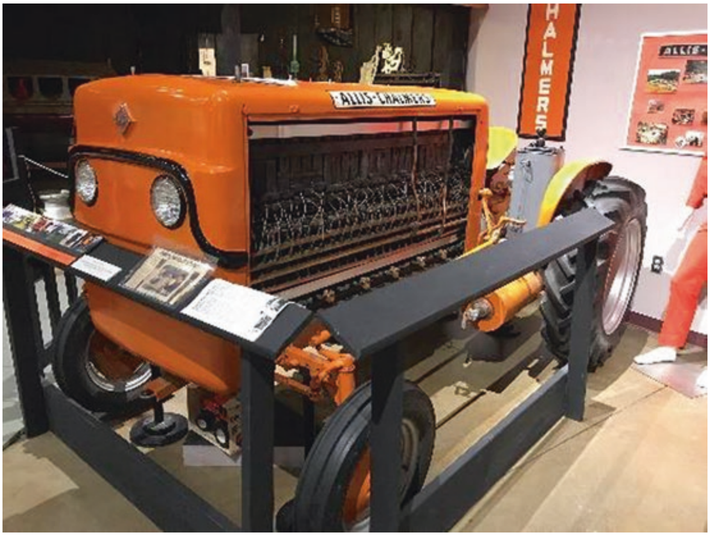


Fig. 15.5 The Allis Chalmers fuel cell tractor at the McLeod County Historical Society & Museum. (Photo courtesy of Larry Karg)

was not only ahead of the automotive industry but also NASA in the midst of space-intensive years. NASA documents (Austin 1966) show that NASA carefully investigated Allis-Chalmers fuel cells and developed space-adapted solutions based on these fuel cells. This is also confirmed by Larry Karg, who is active in the Allis-Chalmers club and handled the tractor during museum stays. He wrote: "Some of the fuel cells were removed and sent to NASA" (Karg 2019).

3 Examples of Electrification in Modern Times

3.1 Modern Fuel Cell Concepts

What, then, about fuel cell tractors in modern times? The manufacturer New Holland (part of CNH) launched a hydrogen fuel cell tractor in 2009. This concept was called NH2 and was driven by compressed hydrogen and only emitted water, no exhaust gases. Furthermore, this tractor was part of New Holland's earlier mentioned vision of an "Energy Independent Farm". The company established three test farms in Italy, France and Germany, respectively. Here's how the company reasoned (Johnson 2009):

> The main obstacles to the use of hydrogen are distribution and availability. The concept of the New Holland energy independent farm involves the farmer producing his own supply of compressed hydrogen either from water (using electrolysis) or directly from methane (by burning waste or biomass). The production plants are supplied with energy from wind tur-

> bines or solar panels and the hydrogen can be stored on the farm in underground tanks. One benefit is the short distance (compared with cars and trucks) that tractors and combines cover between the farm and the field. Farmers are ideally placed to use hydrogen technology. They have large areas of land for alternative energy generation plants (solar power, wind energy, biomass plants or waste systems) and for the storage of energy in the form of hydrogen. In addition to the environmental benefits, a system of this kind would allow farmers to be independent of external energy suppliers and to increase their financial stability, as fuel represents a significant proportion of overall farm costs.

The company wrote that it believes the tractors of the future will run on electricity, but at the same time, it does not believe in battery operation for tractors (Johnson 2009):

> Because of the large amounts of power needed for these large machines and the low levels of energy recovery, batteries are not a suitable power source for this type of vehicle, unlike cars and industrial trucks.

But the NH2 concept was soon put on ice. Overall (2018), Corporate Communications Manager, CNH Industrial, commented: "The tractor did function well, but became too expensive to gain broad market adoption".

In 2018, Fiat Power Train (also owned by CNH) revealed its Cursor X concept. It was a powerpack or multi-use engine, also called "modular power source", for tractors but also trucks, wheeled loaders, combine harvesters and other machine types. The concept was as much a design as an engineering project (created jointly by the engineering and design departments of CNH and Fiat Power Train); see Fig. 15.6.

Fiat Power Train had produced a hydrogen fuel cell bus back in 2001 and the fuel cell tractor from New Holland in 2009 that we already have mentioned. The new concept had more capacity and thus made possible longer working times between reloads of hydrogen. The Cursor X powertrain included not only a fuel cell and

Fig. 15.6 The fuel cell engine by Fiat Power Train introduced at Agritechnica in 2019

hydrogen tanks but also a lithium-ion battery pack, an "eAxle" and an energy management system. The maximum fuel cell output was 200 kW, which was said to generate a motor output of 400 kW (Gilkes 2018). The 350-bar hydrogen tanks were said to hold 64 kg hydrogen, and reloading took 20 minutes. The negative aspect was that the concept was new and fragile and that the price was about four times higher than diesel engines. Another downside was that the powertrain weighed around 6 tonnes.

3.2 Modern Battery Concepts

Fuel cells are not the most common pathway in the electrification of agricultural vehicles. Most initiatives are based on battery systems.

In a speech on the 19th of April, 2016, Prof. Peter Pickel at John Deere European Technology Innovation Center described the SESAM concept, which stood for Sustainable Energy Supply for Agricultural Machinery (Pickel 2016). The concept, appearing in real life later that year, was a big, 6R-series tractor, but the diesel engine and fuel tank were replaced by an extremely large battery. They showed this concept during SIMA in Paris in 2017. The electric tractor had a lithium-ion battery, corresponding to a capacity of 150 kWh, and was equipped with two 150 kW motors (a total of about 400 hp). The idea was that one motor drives the tractor wheels, while the other can drive power take-offs or other functions. If the motor were working at full capacity, for example, the tractor could run for 30 minutes when ploughing. It then took 3 hours to charge the batteries. The battery was assumed to handle 3100 charge cycles. The chassis came from the Mannheim factory's 6R series. The transmission consisted of the DirectDrive dual-clutch gearbox (launched in 2011). As a curiosity, it can be mentioned that the engine growled aggressively like a Formula 1 car.

Prior to Agritechnica 2017, Fendt (part of AGCO Group) announced the e100 Vario, an all-electric compact tractor based on the Fendt 200 Vario. With a 600-volt battery of 100 kWh under the hood, a 50 kW electric motor could be operated for about 2.5 hours at fairly hard work. For lighter work, the battery lasted up to a full day. By fast charging, a discharged battery could get back 80% of its capacity within 40 minutes.

3.3 Modern Cable-Based Tractors

The earlier-mentioned cable link concept is still alive today. One interesting example is a project by the inventor Kurt Hansson at the farm Sörgården in Norrbäck (Sala municipality), Sweden. He bought an 11-kW electric engine and placed it into a Fordson Major tractor and added about 400 m of cable. The energy was produced by 6 solar trackers with a total of 324 square meters of panel surface. By this, he was able to produce a maximum of 72 kW every sunny hour of the working day from March to September and, in total, about 100,000 kWh per year. The concept was formed in 2014 (Hansson 2020).

Another example is the John Deere project to combine cable concepts with robotics, which was conducted by John Deere's European Technology Innovation Center in Kaiserslautern, together with B.A.U.M Consult GmbH and the Technical University in Kaiserslautern. The company calls it GridCON. The prototype, announced in April 2018 but presented in December, produced 400 horsepower through the provision, via a 1 km long cable, of direct current of more than 6000 volts, which is transformed onboard to 700 volts (Bensing 2018). The vision includes that the farms shall produce their own electricity in some way.

4 Hybrid Concepts

Already in 1954, International Harvester launched the Farmall 450 Electrall. It was a tractor with a diesel engine also equipped with a 10-kW generator big enough to drive implements. It developed an electric baler, but that was it. The market was not ready for changing mechanical power take-off to electricity. Interestingly, it developed a large-scale bug zapper to electrocute insects in the field at night (Ag and Food Newsletter 1954). Remember here also the John Deere E-premium in 2007.

But let us turn to modern times. On the 2nd of September, 2017, ZF Friedrichshafen AG announced a concept where a tractor with a diesel engine was equipped with a powerful generator, which in turn generated power that drove hub motors mounted on a connected trolley (Zillner 2020). The central parts of the concept were a high-voltage generator called Terra+ (60 kW), in combination with the electric hub motor eTRAC. It, in turn, could be mounted on any vehicle. If only power corresponding to 15 kW was needed, a low-voltage generator was also offered. The transmission in the system was either a powershift gearbox or a hydrostatic transmission. The concept was thus a hybrid between an electric and mechanical driveline. In addition to the transmission, ZF included a number of sensors and the potential for artificial intelligence. For example, there were radars so that the system could keep track of slippage, and based on that, optimally distribute the power between the tractor and, for example, the wheel drive on a plough.

In November 2019, during Agritechnica, Carraro launched something called the "Mild Hybrid", a driveline intended for special tractors. The idea was to be able to reduce the size of a diesel engine by combining it with an electric motor, and everything was done in light of the legal requirements that exist within the EU. The Carraro 3E22 diesel engine had three cylinders and produced 55 kW. It meets the emission limits for T3B, Stage V, and does not need to be equipped with an SCR catalyst (to meet the mentioned requirements). In addition, there is an electric motor of only 48 V, which gives 20 kW. Together, the concept can correspond to a 100 hp diesel tractor but with significantly lower fuel consumption. Or, to put it simply, it is about the electric motor helping when extra-high power is needed.

In fact, Carraro had launched an electric hybrid tractor already during the EIMA International trade fair in November 2018. It was created in collaboration with the company 4E Consulting (in Porotto, Italy) and was named Ibrido, and it had a 105 hp electric motor in combination with a diesel engine. The driver could choose between driving in fully electric mode (e.g. in riding stables or in courtyards), only in diesel mode (e.g. on roads) or in both electricity and diesel modes (e.g. when pulling or driving heavy with the power take-off).

The Indian company Protecto Engineering Services launched a small hybrid tractor called “HAV S2 hybrid” in 2019. It was equipped with hub motors powered by electricity, either from a battery or diesel engine (alternatively, a natural gas engine) via a generator.

The Steyr brand, acquired by CNH, has been given the role of an experimental platform for CNH. In 2019, its concept – called Konzept – was launched. It is a diesel-electric concept with a lot of innovation. The diesel engine from Fiat Powertrain has four cylinders and drives a generator, which in turn drives several electric and separately regulated wheel motors on all four wheels. A battery also enables it to get a “boost” for short distances. The battery has, at a maximum, 3 kWh. What used to be hydraulics and mechanical power take-off are also electrically driven; see Fig. 15.7. This enables variable power take-off speeds as well as the ability to reverse it. At the rear of the tractor are 700 V and 48 V connections for power tools. In addition to its hybrid driveline, the tractor is equipped with details, such as a head-up display and a drone that flies in front of the tractor and captures data.

Also, during Agritechnica in November 2019, Deere & Co and Joskin launched a concept called eAutoPower, in combination with e8WD. Just like ZF in 2017, it

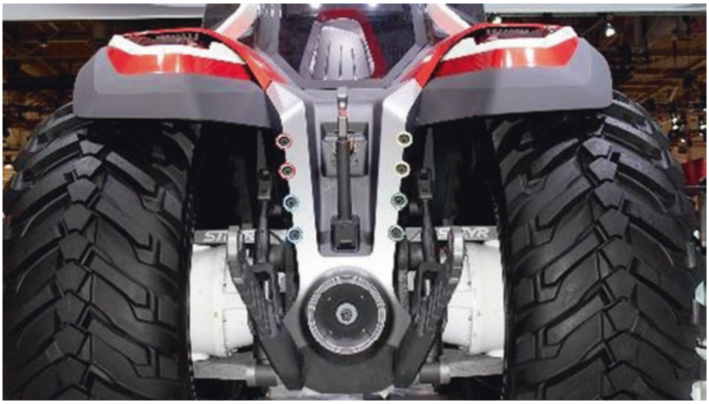


Fig. 15.7 The electric power take-off on the concept tractor from Steyr

was about an engine that powered a generator, but it is more complicated than that. Deere & Co and Joskin were talking about motors rather than generators, which then generate electricity for motors at the wheels. The concept was stated to be "the first electromechanical power-shifted gearbox in agricultural technology". In their own words: "Technically, the hydro unit (pump/motor) was completely dispensed with; instead, two electric motors are used as a continuously variable actuator" (DLG 2019). Note that DLG (2019) writes "motors", not "generators"; a more accurate term would probably have been electric machines because they can – if we understand this right – change roles between being a motor and being a generator. The electric motors, when acting as generators, gives 100 kW to power whatever one wants. In the configuration shown in the autumn of 2019, cables from the generator led to an engine located at the front of the manure barrel chassis behind the tractor. That engine, in turn, drove mechanical axles that were connected to two pairs of wheels via gears.

5 More About Fossil-Free Thinking

The electrical concepts mentioned are not, by definition, fossil-free concepts. For example, this is dependent on how the electricity used is produced. Around the world, various projects are underway to convert agriculture to fossil-free. Here are some examples.

5.1 Biogas Tractors Making Use of Farm Manure

In 2009, CNH presented a biogas tractor in the form of the Steyr CVT 6195, with a stepless transmission. The tractor could also be run on natural gas or ordinary diesel. The tractor was a result of cooperation with the company Lu Power. In connection with the presentation, CNH said that biogas, in particular, is interesting because the farmers themselves can produce the energy on their own farms.

Valtra presented a biogas tractor in 2010 called the N111 HiTech. A few years later came the N101, which was a 110 hp four-cylinder engine, and which was a hybrid between biogas and diesel. The next step was the T133 Dual Fuel, a six-cylinder engine. In biogas mode, about 80% of the power of the gas was produced, while the reset was produced from diesel.

The company Gomselmash from Belarus presented a combine powered by biogas in 2017. During Agritechnica 2019, the Palesse GS4118K model was then launched on the market. The 12-liter gas engine with 350 hp came from Cummins (IS12G). Perhaps it is the only commercially available agricultural machine in the world that meets strict Stage V engine emissions without using Adblue or a particulate filter. The combine can also be powered by natural gas. The gas is stored in eight containers with a capacity of 1816 litres (450 m^3), which is said to last 8–10 hours.

New Holland (also part of CNH) has long invested in gas engines of various kinds. As early as 2013, it launched a biogas tractor called the T6, and in 2018, the company demonstrated its prototype “New Holland T6.180 Methane Power”. It was equipped with a six-cylinder gas engine of 180 hp from Fiat Power Train with spark ignition. The gas was partly stored in a front tank, and with it, the tractor could handle 48% of the operating time compared to a diesel tractor and could run for about a day without refuelling. Hubertus M. Mühlhäuser (2019), CEO at CNH Industrial commented: “People think electric engines mean fossil-free. No, that is not the case. But biomass is. So, biogas is the future”. The tractor was launched on the market in 2020.

5.2 The Case of Energifabriken

Internationally one famous example of a fossil-free farm initiative is La Bellotta in Italy, which in 2013 was selected as the first “Energy Independent Farm concept” by the CNH company New Holland. However, already in 2006, three farming families in Sweden made substantial steps in this direction. Their farms were Smedberga, Kasta and Jolstad, and together, they formed the company Energifabriken, which has since been selling and distributing biofuels (Varverud 2020). In the same year, the companies’ common combine was converted to biodiesel. In the spring of 2011, the three farms decided, in principle, to go full circle and replace all fossil fuels needed for their own production and operation of the farms with biofuels. It was not only about the fuel in tractors, combine harvesters and other field machines, but also oil for heating, drying plants and transport of materials to and from the farms. In addition to diesel vehicles, there were petrol-powered vehicles on the farms, such as cars, quad bikes, chainsaws and high-pressure washers. These machines were converted to ethanol operation. During this experimental innovation process, the farmers received support from AgroÖst and the Energy Office Östra Götaland. In 2012, they had replaced 95 percent of all fossil fuels. The remaining percentage was related to leased services, but 2 years later, many of these were also made with renewable fuels.

The next step was to create (and start marketing) products that were produced using the fossil-free method. In 2014, they could start selling “fossil-free flour” and “fossil-free rapeseed oil”; see Fig. 15.8. They hereby created completely new segments alongside traditional dimensions such as organic-conventional. The families continued to engage in smart business development, such as launching “more friendly wheat” in 2018 together with the grain company Lantmännen. Today, this company is one of the main players in fossil-free fuels in Sweden.

Fig. 15.8 Energifabriken managed the art of creating new, value-added products out of the fossil-free production philosophy

6 The Future of Farm Traction Energy

The path forward is largely about systemic development work. For example, it is not fruitful to only analyse vehicles that are powered by one or another energy source if one does not also address issues such as the supply of the energy needed. Let us just point at some future concepts that might be of interest because they could provide fossil-free, cheap, locally produced, and in one of the two cases, also weather-independent energy for farmers.

6.1 Agrosolary

One possible innovation is Agrosolary, invented by the farmer Kurt Hansson (2020). The concept includes tree and shrub alleys, which, through a new type of solar-tracking panels (invented by Saab), also generate renewable energy. Thus, the fields will produce not only food and feed but also electrical energy. Many people still think that it is negative for agriculture to have solar panels on agricultural fields, but today's focus on sustainability and trends around "regenerative agriculture" or the "Green Deal" (European Commission 2019) means that the time may be right for this concept. The trees can be perceived as natural in the arable landscape, increase the biological diversity in agriculture and hinder soil erosion caused by wind. But, at the same time, the concept must enable rational and highly efficient use of the land between the alleys and, therefore, the lanes must be placed at a large and, in relation to modern machines, well-adapted distance. If a farmer decides to work with machine widths of, for example, 36 m, a suitable width of the arable land between the tracks could be 72, 108 or 144 m. Furthermore, the tracks should not go all the way to the edge of the fields so that modern machines can easily turn around at the end points of the tracks.

6.2 Modern Steam Engines

Another possible idea for the future might, in fact, be modern steam engines making use of biomaterials of different kinds. The Swedish company Ranotor, together with the institute RISE and Linköping University, are planning to start a project on this and build a modern steam tractor (Platell 2020, Pettersson 2020). Ranotor has its roots in the Saab-Scania Steam Power Project, which started back in 1968.

The new kinds of steam engines are very much different from the old steam engines we know from history. One way to illustrate this is by comparing the power density. This means the output power in relation to weight (kW/kg), volume (kW/l) or time (kW/SEK). The Ronator concept has a power density of far beyond 50 kW in relation to the old of about 15 kW/l.

This might create an opening for using steam engines in vehicles such as tractors. The interesting thing about modern steam engines is that they can utilize basically all energy sources, including straw, wood pellets, discarded grain or even solar energy, not least via concentrating solar power. Ranotor is now also running an EU project together with some large companies and the Fraunhofer Institute, where it will use ammonia as energy for a steam engine.

6.3 The Hydrogen and Ammonia Vision

We mentioned ammonia (NH_3), which is very central in the new EU hydrogen strategy launched in 2020. Especially interesting is the vison of producing ammonia in a climate-friendly way. Let us give two examples:

One project is called The Carbon-Free Farm and driven by the MIT and NASA engineer Jay Schmuecker and others at Pinehurst Farm in Iowa, USA. They built a hydrogen tractor demonstrator already in 2010 by installing a Ford 460 V8 otto engine into a John Deere 7819 tractor and mount tanks on the roof. In 2011, they started to produce hydrogen by means of solar power. In 2015, they could present the world's first tractor to run on NH3. See Fig. 15.9.

Another example is the Canadian innovator Roger Gordon, who has developed a synthesizer for H_2 and NH_3 by using wind power. Moreover, he has made a Ford tractor that can be operated by this "green ammonia". He received a patent on this 2015. Among his visions is the intention to have direct-acting fuel cells on NH_3 (Hansson 2020).

Fig. 15.9 The solar hydrogen ammonia tractor. (Photo courtesy of Jay Schmuecker)

6.4 Robots and Their Energy Provisions

Last but not least: What about autonomous vs. traditional machine systems? We did not focus on this dimension in this chapter, but we did touch upon it in some examples. The GridCON concept was based on cable electricity and an autonomous vehicle. It might be relevant to point to the fact that autonomous vehicles need energy systems that are not dependent on manual observation and adjustments. Therefore, external or internal combustion engines have been said to be less suited for robots than electric systems. If this is true or not, we cannot be sure.

Terry Anderson, in North Dakota, USA, started a project in 2012 that led to the Spirit prototype in 2013. It looked a bit like a huge air compressor on tracks. This machine had twin 202 hp, 5.2-liter Isuzu diesel engines (that could accept biodiesel), and these engines, in turn, propelled electric wheel motors.

Another example is the Swedish robot concept Alina, developed by Mapro Systems, RISE and SLU, which was tested in the summer of 2020 at the Testbed for Digitalized Agriculture in Uppsala; see Fig. 15.10. This is a tool carrier platform, fully autonomized with sufficient power enough for using a three-unit seeder. It has no electric motor but instead a Vanguard engine (37 hP) that one starts with gasoline and then turns over to fossil-free ethanol. The engine is coupled to a hydrostatic drive (hydraulic wheel motors). The reason for not using electric wheel engines is, according to the inventor Mats Andersson (2020), that “Electric wheel engines are not reliable enough for work 24/7 in clay and wet environments”. He adds: “Electric wheel motors also need quite high rotation speed to be efficient”. The intention is to use the machine for horticulture. This machine can work at least 6 hours before refuelling.

Despite cases like Spirit or Alina, most field robots in agriculture use electric energy. One example is found in the EU-funded project Mars (Mobile Agricultural Robot Swarms) that started around 2015 and was run in collaboration between

Fig. 15.10 The Alina ethanol robot in test

AGCO and Hochschule Ulm. The project led to a robot called Mars, which consisted of four pneumatic wheels and a single seed bill. The basic idea was to use swarms of such small robots. In 2017, some Mars robots underwent testing in Germany. After Fendt (AGCO) took over the project, the robot was renamed Xaver, and in September 2020, changes were revealed (Vale 2020). The pneumatic wheels had been changed to rubberized steel wheels (interestingly, just like the era of the iron wheels). The four wheels had been reduced to three, where the two iron wheels drive, and the rear wheel partly steers and partly packs after the seed bill. The robot is electrically powered by a 2.6 kWh lithium-ion battery and needs to be charged after 1.5 hours of driving. With six such small robots, it is stated that one can sow three hectares per hour. Perhaps this is a taste of the future; see Fig. 15.11.

Are electrical robots effective enough for modern farming? Will we see fleets or swarms of many small robots or fewer but bigger ones? Or is the future about some middle way? The future will tell. Simulation research indicates a huge potential. Engström and Lagnelöv (2017) showed that one could manage a 200-ha dairy farm on two autonomous 36 kW (100 kWh) electrical robot machines. At present, Engström, together with Arvid Örde and others, is trying to fulfil the dream by means of the electric mid-steered robot Drever with 120 kW power. This is quite small and flexible but big enough for having ordinary farm implements; see Fig. 15.12.

However, the question remains: How can we produce electrical energy in sufficient quantity and in a fossil-free, weather-independent and cost-effective way, preferably locally produced on the farm? In light of these questions, we can mention that the robot project called Farmdroid, with its six saw bills, offers alternative solutions. It has solar panels (1 kW) that catch solar energy in real time. Another concept is the Ekobot robot, which has a battery but is possible to reload using solar-powered charge stations.

Fig. 15.11 The Xaver robot in test in September 2020. (Photo courtesy of Manja Morawitz (Deputy Press Officer AGCO/Fendt EME))

Fig. 15.12 The robot project Drever 120 kw at the testbed for Digitalized Farming in Sweden (September 2020)

We need to underline that robots can work longer than manned machines, simply because labour is expensive per hour and needs to sleep. Moreover, robots can be lighter because they do not require cabins or human bodies among their load. This means less energy is needed and less soil compaction, which in turn can lead to looser soil demanding less energy to go through with farming implements.

The future will tell if the robots will take over farming work or not, what kind of energy they will use and how that energy will be produced.

7 Concluding Discussion

Future visions in the area of energy for field work in agriculture should be related to the following dimensions: First, are they fossil-free? Second, are they cost effective? Third, are they sufficient in relation to the energy needs of farming field machines? The three dimensions can lead to a fourth and fifth dimension: Is there a need for local production (small-scale circular systems), and will autonomous vs. traditional machine systems using wind power to make H_2 and NH_3 be used?

7.1 Fossil Freedom

Regarding fossil-free agriculture, we can conclude that there are many technical solutions for being fossil-free and that this is also the will of many actors. Electrical concepts are popular to discuss in the farming business industry, but often forgotten is a discussion on the processes behind electric energy production.

7.2 Cost-Effectiveness and Sufficient Concepts

The dimension of cost-effectiveness is important. Ethical arguments and feelings might point in a certain way, but the wallets of farmers have limitations. The dimension is related to the other dimension of sufficient energy in relation to the energy need of farming field machines. Let us discuss these two dimensions together a little bit deeper. Some concepts have been successful on the market, while others are stuck in the idea or prototype stage. Let us take battery-powered electric tractors as an example. Despite the extensive development of holistic systems, the electric concept has not yet been successful. A basic problem is spelled energy density. From 1 kg of diesel, it is possible to obtain 45 MJ under ideal conditions. If we consider the typical efficiency of a diesel engine to be 33%, it means 15 MJ of mechanical energy per kg of diesel. It can be compared to 1 kg of a modern lithium battery that gives only 0.2 MJ. There are more advanced batteries under development, for example, lithium sulphide, which can give up to 1.5 MJ per kilo (or lithium thionyl chloride batteries are stated to give 2.5 MJ/kg). Although an electric driveline gives 90% efficiency, the battery solution is far behind diesel in energy density. Furthermore, of course, the cost is a problem, as prices are falling, but then from a high level. An opening may be a hybrid concept.

Another issue with batteries is that their production is not considered sustainable. Nevertheless, there is hope: One striking piece of news was the discovery that hemp batteries work eight times better than lithium-ion batteries (Wang et al. 2013). So, can industrial hemp be a part of the future of battery-powered vehicles? It might be a step towards sustainable and efficient ways of creating battery power. The idea is not new. In 2014, researchers in the USA discovered that unused fibre from hemp could be converted into an “ultrafast” battery that is better than graphene. David Mitlin of Clarkson University, New York, led this experiment (Hansson 2020).

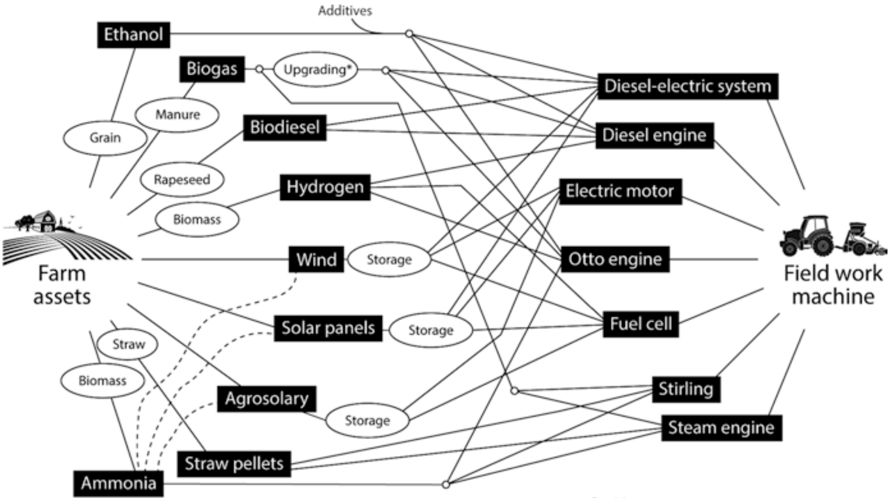
7.3 Local Production of Energy at Farms

One dimension is the need or wish for local production (small-scale circular systems) of energy. We all know that the local production of things is not always the best from an economic or even a sustainability point of view. Farmers have local resources and are often located at long distances from alternative resources. There are many good reasons for trying to create locally produced energy, and we have seen in this chapter some examples of this.

7.4 Notes on the Robotics Revolution

Robot concepts pave the way for many advantages from a climate care perspective. They can be powered by electricity, which can also be produced fossil-free at the local farm by means of, for example, biogas-fuelled generators or solar trackers. They can also, like the Alina robot, be fuelled by biofuels such as ethanol. Moreover, they do not require as much energy as ordinary machines, partly because their weight can be lowered. One can, as said before, avoid the load from, for example, cabins, air-conditioning systems or driver's bodies. The Fendt corporation assumes that the weight can be reduced by ca 80%, which will save energy, costs and not least the soils through less soil compaction. Less compaction, in turn, means less resistance on later passages of the fields as well as better soil health, meaning more harvest in relation to all stakes. But another aspect is that they can work 24 hours a day and, therefore, do not need to be as productive as man-operated systems.

Figure 15.13 summarizes potential combinations of locally produced energies at farms and different kinds of engines or motors.



* Liquefied biogas is one option

Fig. 15.13 Combinations of farm energy assets and different kinds of engines

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