Electric Tractor Perspectives

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1. Introduction

Electric drives are rapidly gaining importance in agricultural engineering. Current agricultural equipment is getting close to reach its optimization limits in terms of complexity and efficiency with the current technology. In the future, the expectation is a growing focus in the area of electrification and electrical drives. Moreover, the agricultural equipment manufacturing industry, traditionally mechanical, is investing a lot of resources to test electric motors and batteries to be able to replace, over time, conventional powertrains and hydraulics. Battery life and performance in harsh environments is still a challenge from a technological point of view for off-road missions. On the other hand, merging electrification with more traditional internal combustion engines into hybrid systems can be an effective solution for the medium term and brings some big benefits to the final user.

2. Driving factors of future changes in agriculture – our commitment to the future

2.1. Why Electrification on Agricultural machinery: trend or real need?

Without modern agricultural methods, it would not be possible to feed the current population of the world and certainly not the future population [1]. Moreover, hybridization first and full electrification after, is going to be part of the strategic path for every OEM to not only achieve emission regulations and improve productivity and efficiency but also to position itself as a technology leader as shown in **Figure 1** [2].

2.2. Our commitment to the future [3]

According to 2018 CNH Industrial Sustainability report [3], the three global challenges identified as most relevant to the business of CNH industrial are:

- climate change: which, as a broad concept, encompasses political, judicial, ethical, economic, and scientific factors, and goes far beyond the literal definition of natural climate variations;
- food scarcity and food security: whose effects depend on the efforts of the individuals involved in the agricultural, processing, transport, manufacturing, and consumption production chains;
- the innovative and digital world: which generates excellent opportunities for companies, as they can exploit the connectivity of the World Wide Web to access and manage huge amounts of data, position themselves in new markets, transform existing products, interact with their customers, and introduce new business and delivery models.

Based on CNH Industrial's scenario analysis of global challenges and growth drivers (**Fig. 2**), sustainable product R&D is focused on three main areas:

- decarbonisation strategy, which includes research on alternative fuels and electrification and is linked to the material topics CO_2 and other air emissions and pollution but also to circular economy product life cycle;
- digitalization, which includes research on precision solutions, telematics, and open connectivity. Investments will improve productivity and so reduce energy consumption. Digitalization research is linked to the material topics CO_2 and other air emissions and self-sustaining food systems;
- automation, which mainly includes research on commercial vehicles and is linked to the material topic autonomous vehicles and connectivity.

2.3. Electrification – CNH industrial Approach

Electrified vehicle technologies represent one of the next steps in CNH Industrial's decarbonisation strategy. Not only as an alternative to internal combustion engine but also as a means to further improve the performance, efficiency and sustainability of the agricultural ecosystem. The technology will not be simply applied to existing products, but it will feature different characteristics depending on applications and missions.

Looking at the agricultural environment, electrification is going to play an important role to:

- decouple loads and drives from the engine to reduce emissions and to enable a more flexible design (e.g. simplified machine architecture);
- optimize controllability of power flows across agricultural machines and between machines (e.g. implements);
- increase the automation: "Electronomous", electrification as enabler for automation and autonomous vehicle in order to improve accuracy of operations removing human variables that could cause inefficiencies;
- identify new maintenance models to reduce the machine downtime.

At an R&D level, many activities have been performed in the past to explore electrification and understand the limits and the benefits for the end-user and the special need for off-road use cases.

A key strength of CNH Industrial, is the possibility of leveraging across our business segments on internal technologies and experiences to reduce the time to market of new contents as soon as there is a favourable business case for the end-user.

CNH Industrial, as a group, has a long tradition in the electric vehicle sector: the first IVECO Daily Electric, in fact, dates back to 1986. Today, the Commercial Vehicles segment offers pure electric drive vehicles, and diesel-electric hybrid technology for passenger transport. Furthermore, Heuliez Bus, a CNH leading brand in e-mobility buses, is developing a full range for all urban applications. After the launch of its 12-meter overnight-charge e-bus, the brand has recently expanded its range with an opportunity-charge articulated bus [3].

This approach of knowledge and experience transfer from one sector to the other within CNH industrial, has been already applied successfully in the recent past. The bio-methane tractor, considered the bridge in the decarbonisation strategy from current diesel technology to a full electric tractor, has been built, with off-road adaptation, leveraging on existing technologies from our IVECO and FPT Brands (**Fig. 3**).

3. Tractor electrification and applications: overview

3.1. Overview

Recent scientific literature like [1], [4] and OEM's product presentations give an overview of potential tractor electrification for all functions (e.g. auxiliaries, drivetrain…) and implements. Below a list of hybrid/electric tractor applications presented in the past years.

3.2 Hybrid solutions

- in 2005 at Agritechnica in Hannover, CASE IH presented the ProHybrid EECVT a series diesel hybrid integrated into standard differential axles that combines a 120kW diesel engine offering 800Nm torque with two 50kW electric motor/generator. Excess energy is stored in a large 456V, 11.5kW/h battery that sits on the tractor's nose in place of the front weight [5];
- in 2007 at Agritechnica in Hannover, John Deere presented the E-premium series with a 20kW generator to supply power for auxiliaries like compressors and implements [6];
- in 2009 at Agritechnica in Hannover, Belarus in cooperation with RuselProm presented the 3023 diesel electric tractor. A 220kW diesel engine, a 172kW generator, a diesel-electric drive train and an electrically-driven PTO [7];
- in 2011 at Agritechnica in Hannover, Rigitrac presented the RigiTrac EWD 120 diesel electric tractor with four electric single wheel drives with a power of 33kW per motor. The power is supplied by an 85kW generator, which is directly connected to the 91kW diesel engine [8];
- in 2013 at Agritechnica in Hannover, Fendt presented the X-Concept powered by a 4.9l 147kW engine instead of the classic 6.1l. the electric generator can deliver up to 130kW to power mainly implements [9];
- in 2018 at EIMA in Italy, Carraro presented the Carraro hybrid tractor. Equipped with a diesel engine 3 cyl providing 55kW, a 50kW e-motor and 25kW/h Li-ion battery can work as well in full electric mode. It is a parallel hybrid architecture with 3 working modes full diesel (up to 55kW), full electric (up to 50kW) and hybrid diesel electric (up to 75kW). Moreover, cooling fan, cooling and hydraulic pumps are electrically driven [10];
- Claas electrical powertrain from the website [11];
- in 2019 at Agritechnica in Hannover, John Deere has presented the eAutoPower gearbox e8WD for 8R large tractors as joint development with Joskin. This represents the first electro-mechanical power split gearbox in agricultural technology [12].

3.3 Full electric

- In 2011 at Agritechnica in Hannover, New Holland presented the second NH2™ hydrogen powered tractor (based on a T6.140 tractor). Compared to the first NH2™ (presented at SIMA

2009), the new model has fuel cells that deliver double the power, increased from 50 to 100kW. Each of the new electric motors has a power output of 100kW, with continuous torque of 950Nm and maximum torque of 1200Nm. Other new features include a 12kWh, 300V Li-ion battery [13];

- in 2017 at SIMA in Paris, John Deere presented SESAM (Sustainable Energy Supply for Agricultural Machines), Electrical energy is supplied by a set of 130kWh/670V Li-ion batteries. Electric drive for auxiliary units to the entire vehicle, particularly the push system, and in the power distribution delivered by the two 150 kW electric engines respectively to the traction and the other components (PTO, hydraulic pump) [14];
- in 2017 at Agritechnica in Hannover, Escorts presented the Farmtrac electric tractor. No data is available a part from the rated power, 19kW [15];
- in 2017 at Agritechnica in Hannover, Fendt presented the e-100 Vario. All-electric compact tractor with 50 kW power output, which can operate for up to 5 hours under actual operating conditions. The energy source is a 650 V high-capacity lithium-ion battery with a capacity of around 100 kWh. The battery is charged either with 400V and up to 22kW via a standard CEE outdoor socket, or by a supercharging option with direct voltage. With a standard CCS type 2 plug, the battery can be recharged up to 80% in just 40 minutes. [16];
- in 2018 at Agrama in Switzerland, Rigitrac presented the prototype electric tractor Rigitrac SKE 50. Five electric motors, one for each axle, one for the hydraulics and two for front and rear PTO respectively. It develops a total power of 50kW with an 80kWh Li-ion battery. Operating time is about 3-6 hours per charge [17];
- in 2019 within the GridCon funded project, John Deere presented the GridCon manned and autonomous electric tractor (based on 6210R tractor) continuously grid powered, a power supply of 2.5kV AC is required, and the GridCoN tractor uses a 700V DC bus for electric power distribution both on board and for implements. A 100kW electric motor powers the IVT transmission, and there is an additional outlet for implements powered by a 200kW electric motor. A drum fixed to the tractor carries up 1000m of cable with possibility for extension [18].

4. Architectures and challenges

4.1. Architectures

Hybrid architectures are the most promising for the short-medium term approach in order to maintain current tractor performance and provide less-polluting powertrains (e.g. internal combustion engine downsize and fuel efficiency under certain missions). Full electric technology will continue to improve and the shift will be enabled by the battery/energy storage system evolution (cost and performances).

With a focus on hybrid architecture the well-known configurations are:

- Series hybrid electric: the vehicle is powered by electrical energy from the battery through the motor. The diesel engine is used to charge the battery and is tuned for optimum power generation. In this way it is possible to keep emissions low and overall fuel efficiency high. In this configuration the engine can be smaller and the battery pack larger to provide the necessary power to the vehicle;

- Parallel hybrid electric: the vehicle is powered by both engine and motor. Currently this architecture is preferred for smaller off-highway equipment because it's simpler in construction, relatively cheaper than series hybrids, and simpler in functionality compared to the other types of hybrid powertrain architectures;
- Combination of parallel and series: this combination can offer the best use of both modes with a cost problem because of the larger battery pack and the complex control system to manage the transmission.

As already stated in almost all the technical papers [4], [19], [20] and [21], the electric source can be applied to power, as shown in **Figures 4(a)** and **4(b)**:

- Engine and vehicle auxiliaries like fan drive, air brake compressor, AC compressor, alternator (replacement using the bus out of the generator), hydraulic and liquid coolant pumps. The controllability of all these auxiliaries provides an important degree of freedom on how to manage the power sources. If we consider that a tractor spends up to about 20% of its time idling [22], it is clear that, with a battery system, this condition can be optimized saving fuel and reducing emissions;
- Automated functions on implements. As from [21] and shown in **Figure 5** there can be two architectures: DC that is a cost effective solution for the tractor but more expensive for the implements whereas the AC architecture is more complex for tractor. With the DC architecture, higher complexity system for implements can be developed which is harder with AC architecture. From the control point of view, the AC provides a possibility for a distributed control layout;
- Traction drives. As for [19] in **Figure 6** and as stated in the previous paragraph, the architectures are multiple and how the electric motors are distributed plays a role on the total system cost. According to the tractive effort, the traction motors (**Fig. 7**) can be sized considering an n-gear box or can be oversized removing the need of gears but increasing the cost. Considering the architectures with gearbox (**Fig. 8**), the one with a driveline motor apparently should be selected because it is the most cost-effective one. But, if we consider the different missions, and the needs of each size of tractor, it may end-up that a different architecture is preferred like the one with wheel motors because, for example on small tractors, it is important to have a high manoeuvrability;
- Energy storage. About this, we need to make a distinction between capacitors and batteries. The first, in particular ultra-capacitors, considered the state of the art are favoured for many applications due to their ability to store and retrieve a large amount of energy quickly. Ceramic ultra-capacitors are being developed. If successful, they have the potential for higher energy density while maintaining the benefits of the ultra-capacitors. Regarding batteries, Ni-MH batteries are being supplanted by Li-ion technology (seen in many applications), which has higher power density but higher cost and a challenging thermal management to operate in a safe and reliable way. The technological development of the battery, as for (**Fig. 9**) shows a potential and expected decline in battery prices. This will further drive electrification.

4.2. Challenges

The challenges regarding electrification are multiple, from the pure technical ones related to the vehicle architecture and the thermal management of the electric components to the ones listed below:

- safety: current is not visible, this requires monitoring and diagnostic systems;
- volume, weight and cost of the batteries (**Fig. 10**);
- reliability and performance of electric components in an off-road environment (e.g. vibration level);
- increased component/product cost and payback for the end-user;
- supply/value chain and technical support not yet trained;
- infrastructure around the electric machine not yet clear, e.g. charging system or cables application like the John Deere GridCon or both? Which is the best solution for the end-user?

At this stage, it is clear that OEMs are trying to integrate pure electric drive trains into their existing drivetrain platforms. As a result, inefficiencies and cost will probably be higher in these units. A full picture, in terms of results and real application is not yet available. In the short/medium term, electric power sources will coexist with the conventional engine, PTO, hydraulic and traction.

Even if electric motors have been used in vehicles and other applications for a long time, there is still the need for more development in heavy-duty applications. The compact size, the energy efficiency on a wide operating area, the thermal management, their control and the reliability are important aspects. Moreover, electric energy storage is the key factors for the success of off-road electrification.

The move to electrification does not mean only a change to the vehicle architecture, but also in the way the energy is supplied. To store electrical energy in a tractor is already a challenge, if we think about battery energy density and what is needed for a full tractor mission. However, to charge the battery in an agricultural environment is another big step impacting a wider value chain and more players besides the OEM.

The challenges (and opportunities) increase when we wish to operate multiple tractors and other agricultural machines at the same time. The power needed to charge in the shortest time, to minimize the impact during the mission, can be very high and hence the related infrastructure needed has to be studied in detail to find the right trade-off. An alternative option, is to design machines and operations that avoid the need for in-mission charging and use instead the planned rest time. Machine rest time for charging can be in the depot or in different strategic locations according to the different operations done by the tractor. This implies a flexibility to provide charging power where required, often not where it is easy to be provided. The impact of frequent charging and the related infrastructure can be very complex and varied. A part from energy availability and storage, off-road vehicles also have specific application challenges such as ip protection and the capability to operate safely and efficiently in dusty environments.

Nevertheless, most of these challenges are those that as CNH Industrial face on a daily base in its on-road segments. For example, full electric buses are operated by customers with specifically designed infrastructures. Some of them are suitable of charging many tens of urban buses, each with more than 350 kWh to be charged every night. This means managing huge amounts of power and energy and with it, the huge opportunity to become part of the electric infrastructure network. Megawatts of Power and MWh of energy can be very relevant in frequency adjustment, peak shaving and power grid stabilization for industry operators such as utility providers. CNH Industrial has in production superfast charge technology with 450 kW charging power to "refill" the buses in a few minutes during daily operations.

To bring power and energy when, and where, it is needed in a safe and efficient way is a specific and big challenge for tractors. It is giving some new business opportunities as well, but it involves not only the OEM which makes this change even more complex to implement. Each region, country and sometimes village, may have different needs and constraints. The same vehicle often works in different environments and operates in different ways. This will require different infrastructure solutions. The flexibility of the tractor has always been a key driver for its success and electrification will confirm this.

4.3. Time for a new vehicle architecture?

An electric powertrain must be considered as an innovation platform to design and create new and advanced solutions for the customer. The big challenge is to identify new solutions that create a link to the development drivers previously mentioned such as decarbonisation, digitalization and automation.

To achieve the full electric vehicle, a deep analysis of new architectures, technologies available and the agronomic and environmental aspects is mandatory to arrive to the point of creating a multipurpose machine (as the tractor is supposed to be) to address the future challenges in the agricultural sector.

In order to maintain a link, (in the medium term) with the current Ag equipment, a modular approach with scalable components must be considered in order to serve many different requirements.

The electronic architecture, is another important point to consider. Additional sensors to enable automation, more computational capacity and a different architecture than the current 12V one have to be taken into account during the design phase to ensure performances at a reasonable cost.

5. Conclusions

Population growth, will require a significant boost in agricultural productivity but in a sustainable and environmentally friendly way and with an improved efficiency from the agricultural equipment.

Electric drives are becoming more and more important in agricultural technology. Research in the field of electrification has been conducted over the years by all Ag. OEMs with the goal of understanding the benefits and challenges.

As the on-road industry pursues hybrid and electric vehicle technology and educates society about the technologies, society will get used to and will accept more and more the idea of hybrid/electric Ag. equipment. Despite this, it must be clear that the diesel engine and conventional technology (hydraulics and mechanical PTO) will play an important role still for long time because they offer a robust, reliable and well-known option at a competitive price.

To fully implement the vision of the electrification, it is mandatory to keep focus on R&D and evaluate new concepts to identify the benefits and the best solution for the end-users. Moreover, it is important to understand that electrification is going to be an enabling factor for a new vehicle architecture to address future challenges. Other important factors such as regulations, standards (e.g. AEF), incentives and charging infrastructure will play a major role in determining the adoption of electrification from market to market. Infrastructure creation, will require the support of government subsidies for farmers (as already in place for bio-methane) in order to implement the complete picture of smart farming 4.0 together with the energy independent and sustainable farm. This is the future of the farming industry where CNH Industrial and all OEMs cannot be alone.

A key strength of CNH Industrial, is the possibility to leverage across our business segments on internal technologies and experiences to reduce the time to market of new contents as soon as there is a favourable business case for the end-user. Looking at the infrastructure creation, thanks to the multiple solutions adopted for on-road applications like urban buses or charging stations for light-duty trucks it will be possible to design and implement an effective farm “architecture” to be coupled with the hybrid/electric vehicles that are working on it.

Electrification technology is part of CNH Industrial’s knowledge and background and is driving research and development of the electrification world, whether it be for an on-road or off-road missions. Electrification is increasing the value stream. The vehicle will be part of a more complex system, the mobility system. This is a very strong link with what we, as CNH Industrial do today on another technology and where we have already shifted knowledge from one sector to the other namely Natural Gas.

Technology is changing the way we design tractors, the way we use them, but also how these tractors are interacting with the rest of the world. We need to be fast and smart to anticipate change. We need to know how the technology is changing to understand new possible business models. Then we will have the opportunity to influence the change in the right direction for the agriculture industry and for climate change, at the time when technology fits the needs, not earlier nor later, just on time.

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FIGURES

Figure 1 – Off highway vehicle market – vehicles hybrid technology roadmap (Source [2]).

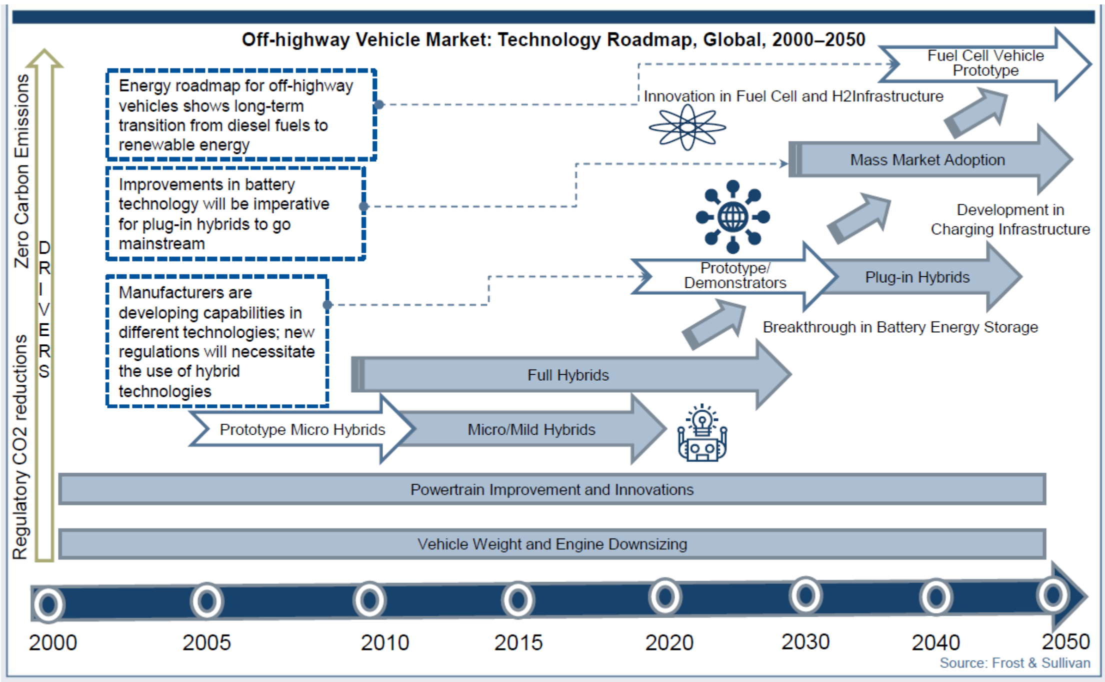


Figure 2 – Growth Drivers (Source [3]).

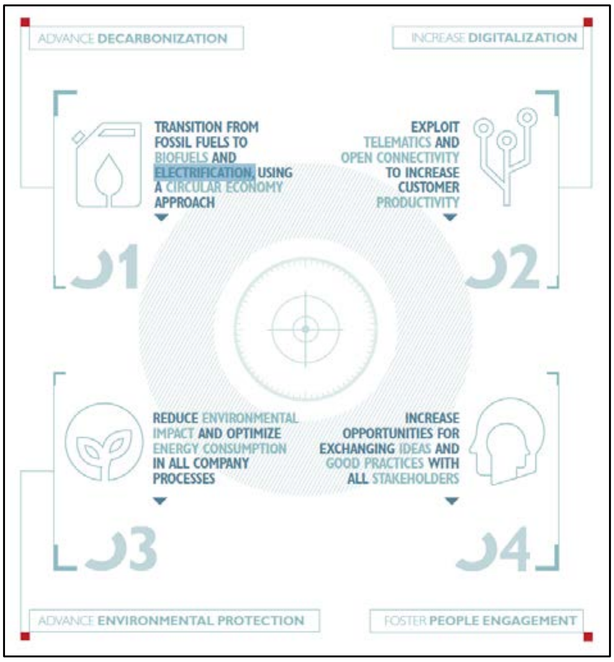


Figure 3 – CNH Industrial approach

Figure 4 – Detailed architecture – (a) with DC/DC converter for low voltage application and (b) high and low voltage generators

Figure 4 (a)

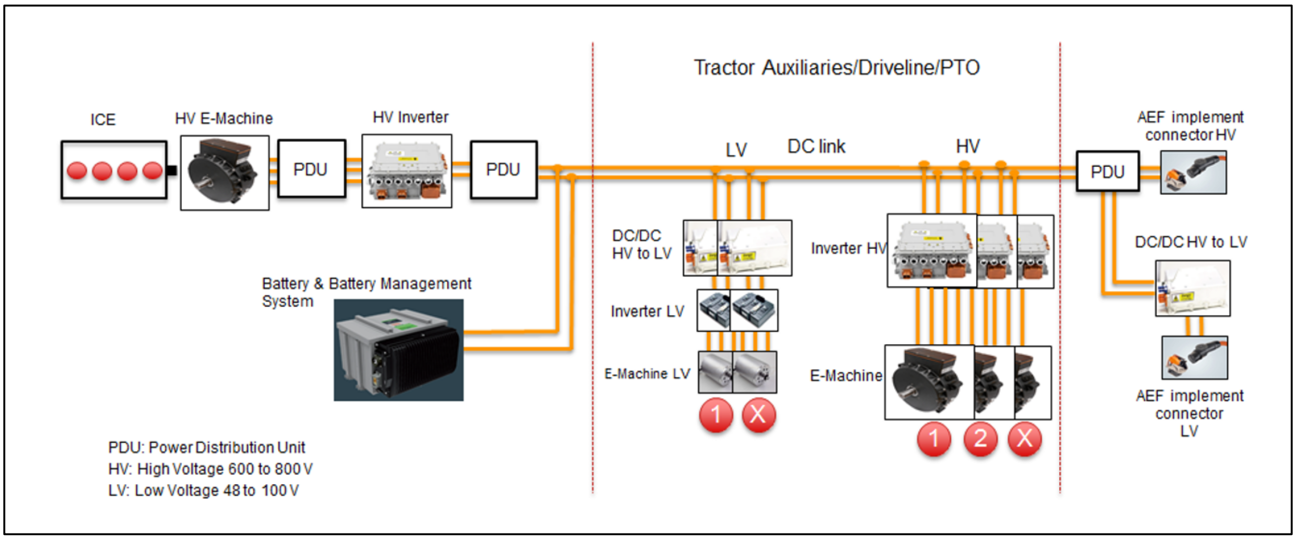


Figure 4 (b)

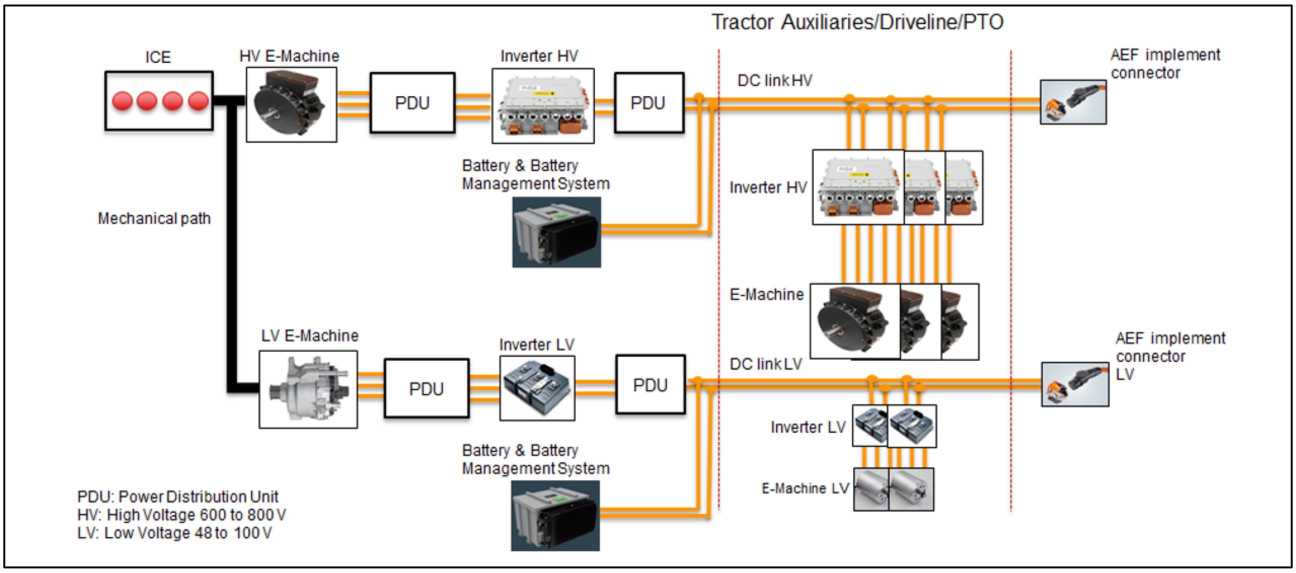
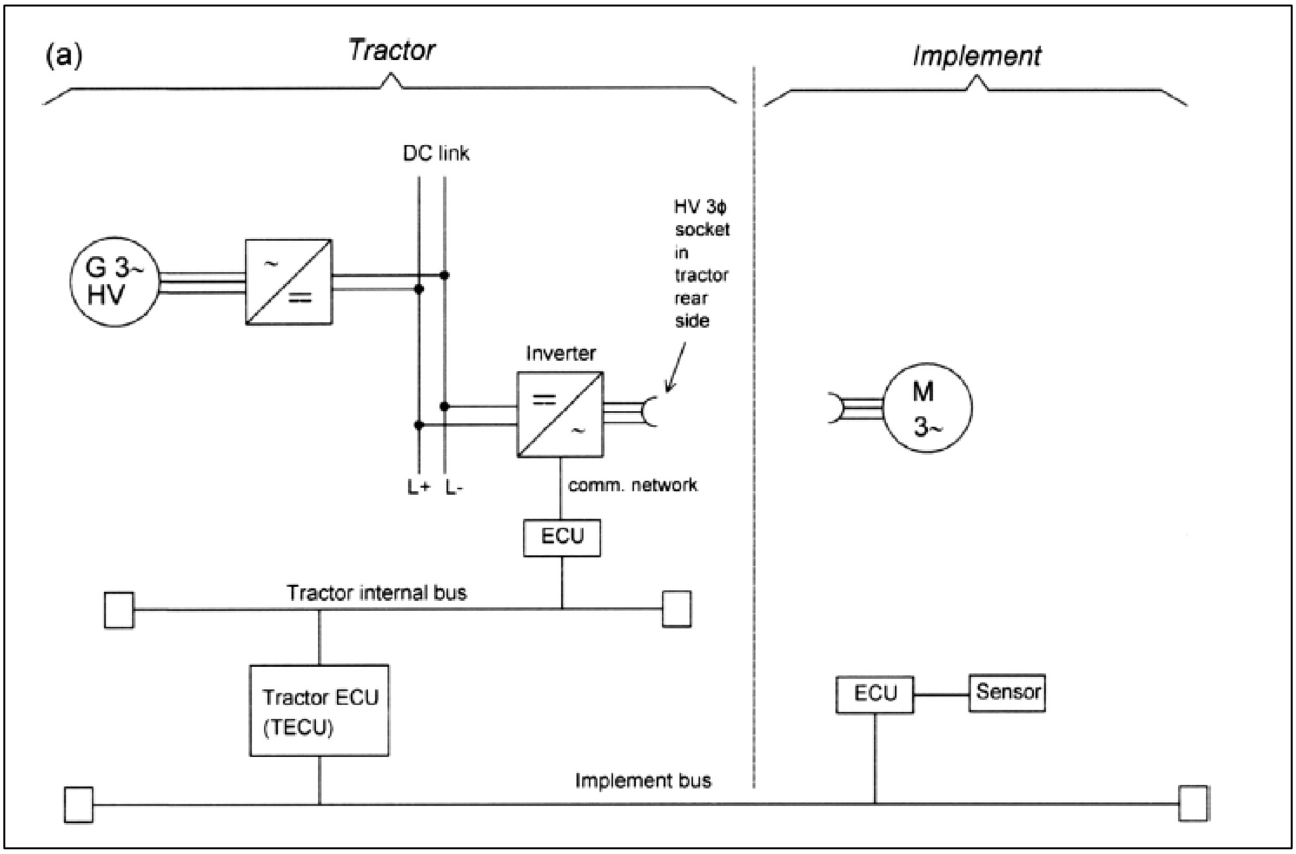


Figure 5 – Detailed architecture – (a) with DC/DC converter for low voltage application and (b) high and low voltage generators (Source [21]).



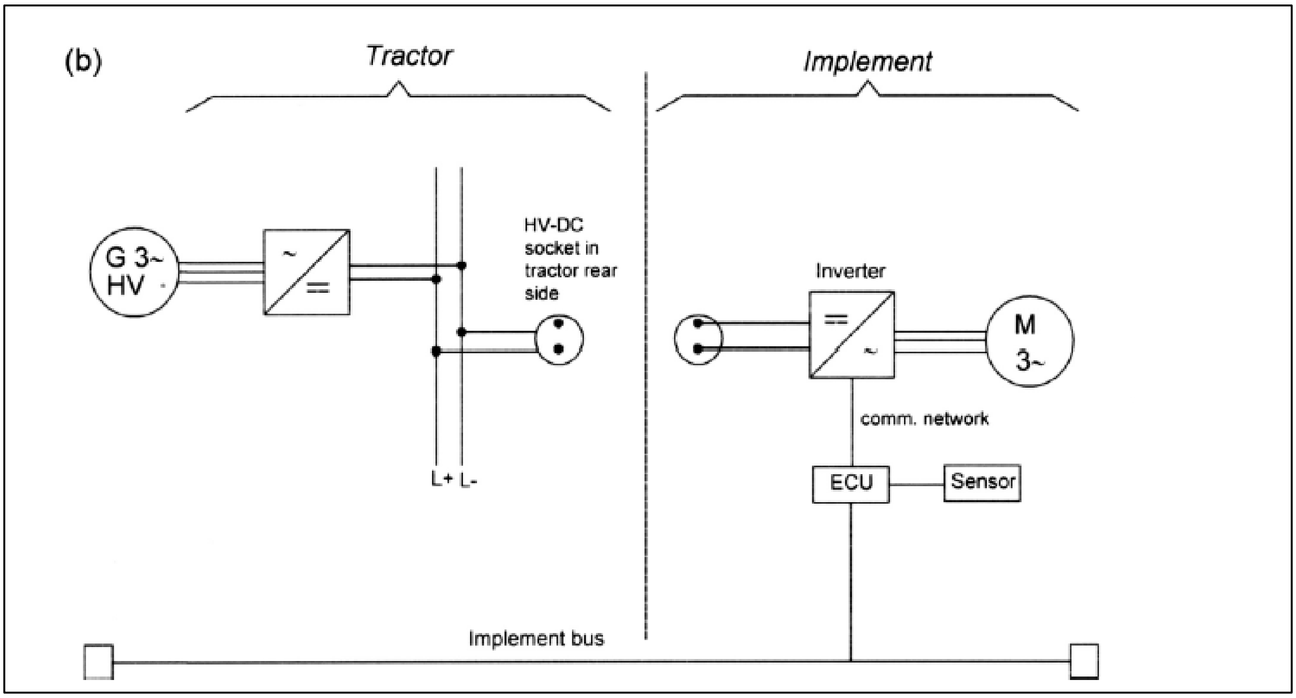


Figure 6 – Drive systems using electricity. Source [17]

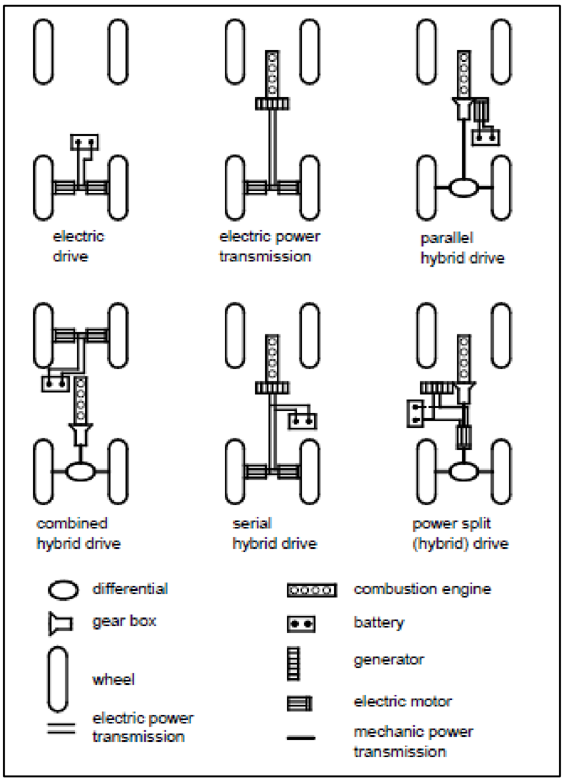


Figure 7 – Electric motor for traction – 2 different approaches

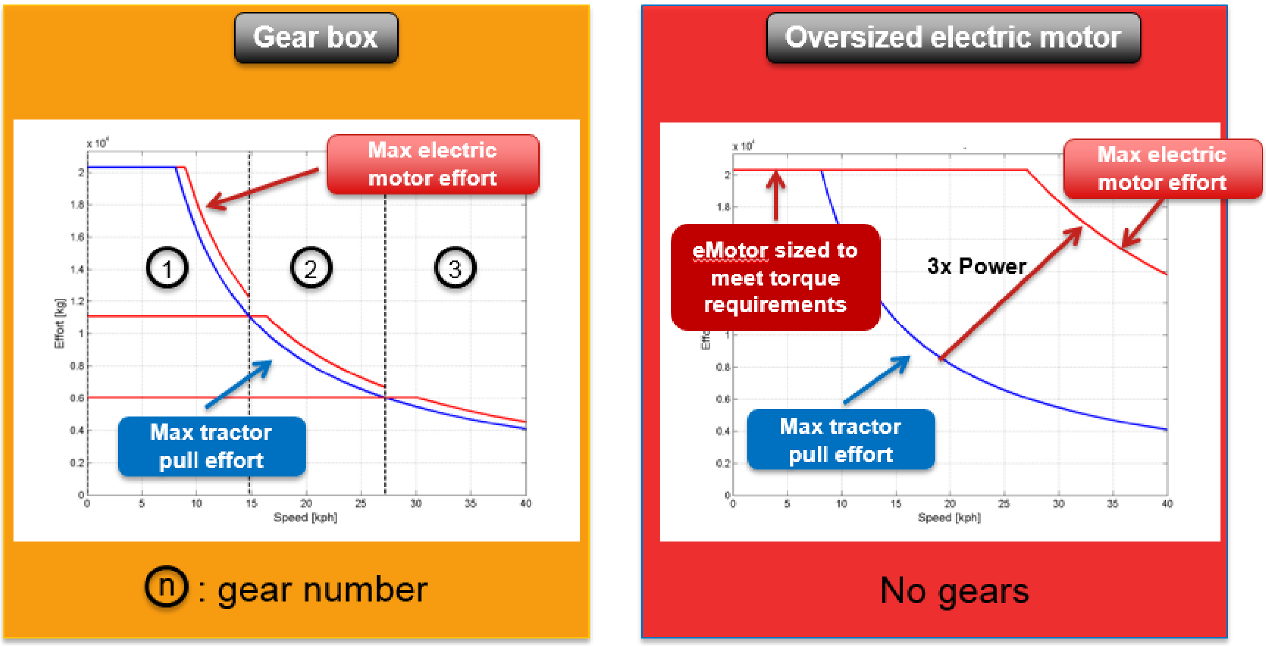


Figure 8 – Electric motor for traction – architecture with gearbox

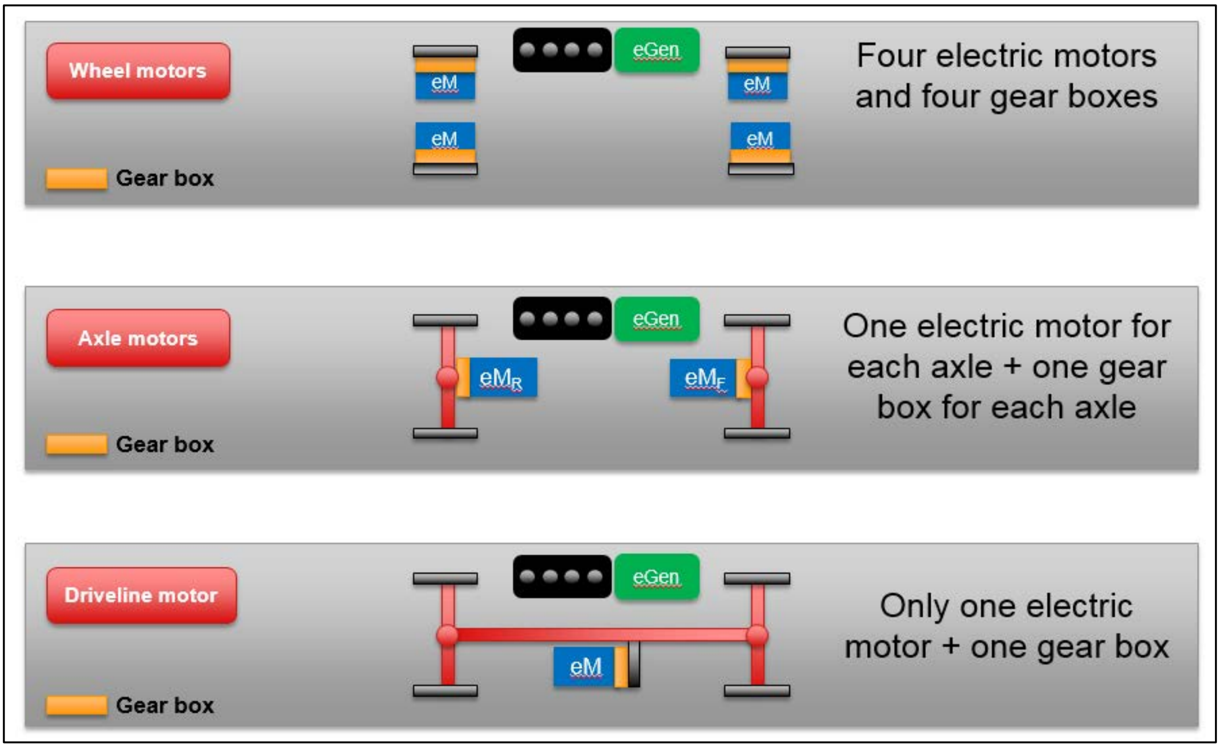


Figure 9 – Off highway vehicle market – decline in battery price. Source [2]

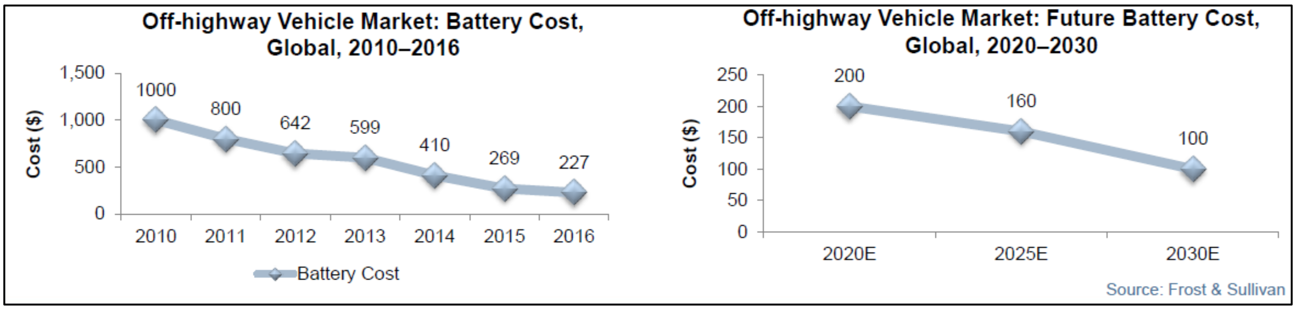


Figure 10 – Volume, Weight and Cost of the energy storage – alternative to diesel