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Industrial vehicles' Electrification: Innovation Strategies for a leading powertrain supplier

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Introduction

E-mobility is one of the most important technological trends of the new century.
In recent years, almost any types of vehicle approached electrification, replacing polluting sources of energy (e.g. fossil fuels) with cleaner or zero-emissions alternatives.
This thesis is focused on the electrification process of industrial vehicles, a category which is often overlooked compared to automotive, despite having a strong impact on everyday working activities. They comprises off-highway (construction, agriculture and material handling) and commercial vehicles (i.e. on-highway vehicles for carrying goods).
The research will be carried out by analyzing a case-study of a leading powertrain supplier engaged in these vehicle markets, with the aim of assessing the impact that the electric transition would imply for the company business.
The company has built a stable position through products designed for the traditional hydraulic-ICE powertrain, while its electrification path has just begun.
Hence, approaching the research from the company point of view allows to investigate the strategies and the modifications of current business that a supplier have to manage to lead the shift. In this way, it will be possible to ascertain what are the opportunities arising from the transition, and what are the challenges that must be faced to capture the benefits.
The *first chapter* will illustrate the reference market, framing what kind of vehicles have been analyzed and what is the current contribution of the company to their functioning.
In the *second chapter*, the electrification trend will be generally described, through an exhaustive presentation of available powertrain technologies and advantages / disadvantages that they can offer, together with key drivers and enablers leading the transition.
As the electric transition can be seen as a technological innovation which in turn implies other type of innovations, the *third chapter* will review the literature of innovation management and technological innovation with the purpose of understanding the phenomenon under analysis. Furthermore, the chapter will treat the role of suppliers in the innovation processes triggered by the transition, together with the importance of collaborative strategies across the supply chain.
In the *fourth chapter*, the thesis will disclose the resulting strategies, for a supplier like Bonfiglioli, to approach the technology transition with innovative solutions, by employing a business model canvas to represent the change.
In order to collect data and insights useful to respond to the research question, interviews

have been conducted at company level, involving managers from different departments. Through their responses to tailored questions, it will be possible to evaluate the obtain a feedback of the company's readiness to match the electrification process in terms of acquired and missing competencies.

As it will be argued, the solution to share the efforts and knowledge required for the transition might be an extensive use of co-development partnerships.

The resulting company strategy will encompass a new positioning towards a different business, characterized by innovative solutions and new addressable markets opened by the electrified powertrain adoption.

1. Industrial Vehicles Market

1.1 Description of Industrial Vehicles' category

In this first paragraph, a panoramic overview of the markets under analysis will be detailed. The label 'Industrial Vehicles' is used as a reference to reflect the intended use of these types of vehicles. Off-highway vehicles and commercial vehicles share professional purposes which distinguish them from private passenger cars.
Their final users are mainly industrial or public actors looking for means to fulfill a certain work. For the purpose of this thesis, we will focus more on off-highway vehicles, the most important sector for the company businesses.

Off-Highway Vehicles
Off-highway vehicles (OHVs) are wheeled or crawler (tracked) machine operating in off-road conditions, suitable for both indoor and outdoor use. Their common aspect lies in the intensive work to carry out specific duties within specific operating environment. This latter ranges from warehouses to airport, from road to forestry. They are usually employed for more than a typical eight-hour work shift, while in working places such as mines and harbors, their operation can last even up to 24 h per day. The professional purpose of off-highway vehicles allows us to divide them into three main sectors:

- Construction or Earth-moving machines – including all kinds of loaders, excavators, bulldozers, etc.
- Agriculture machine – tractors, combine harvesters, sprayers, etc.
- Material Handling equipment – forklifts, mobile cranes, aerial work platforms (AWPs), etc.

Interact Analysis, a market intelligence company specialized in global technology, conducted a research highlighting 5.2 million of off-highway vehicle units delivered in 2020[1]. Figure 1.1 exhibits an example of vehicle for each category.

[1] Source: The Off-Highway Vehicle Market – Second Edition (2021)
Notes: the report focuses on tractors and combines (Agriculture); bulldozers, excavators, dozers (Construction); AWPs, telehandlers and forklifts (Material Handling)

(a)

(b) (c)

Fig. 1.1: Examples of Off-highway vehicles for each subcategory. (a) Excavator (Construction), (b) Sprayer (Agriculture), (c) Forklift (Material Handling)

Even if tailoring is a universally recognized trend, there are cases of multipurpose vehicles designed to fulfil tasks across the board. For example, telehandlers can be used also in construction and agriculture application. Concerning design features, the choice between wheels or tracks depends on cost and suitability. Tracked drivetrains are more expensive to produce/maintain and are better performing in case of difficult environment conditions than wheeled. Wheeled vehicles, instead, provide higher top speed. There are many vehicles of different weight, power, layout, etc., that will affect the evaluation of electrification adoption, as it will be discussed in next sections.

Commercial vehicles

Commercial vehicles are a macro vehicle category having at least four wheels and used for the carriage of goods. Within the European vehicle classifications, they fall into category N, which then divides them by various weight classes. The light-duty vehicles (N1), best known as light commercial vehicles (LCVs), are defined by a maximum mass measure not exceeding 3.5 tons, which is valid for both EU and China's vehicle classifications. In US, technical standards issued by the Environmental Protection Agency (EPA) defines LCVs as commercial vehicles smaller than 3.8 tons (8.500 lbs).

Car vans and pickup trucks are the most popular examples of LCVs, even if for the latter it can be difficult to separate commercial use from private one.

Fig. 1.2: Fiat Ducato, one of the most popular LCV in the world

Medium-duty commercial vehicles (N2), instead, have a mass between 3.5 and 12 tons, while if this latter limit is exceeded, they fall into the heavy-duty classification (N3). These two heavier categories include the vast array of trucks, which have a specific and complex classification in US. For this analysis, it is sufficient to rely the just mentioned European classes. According to Interact Analysis[2], 12.5 millions of light-duty vehicles were delivered in 2020, while medium and heavy-duty units were 2.5 millions.
Commercial vehicles are the backbone of world's main economies, since they represent an integral part of the freight transport industry. It follows that decarbonizing these vehicles is a crucial challenge for authorities committed to lower greenhouse gases (GHG) emissions.

[2] Source: The HEV and Electrified Truck and Bus Market - 2020 Edition (2021)

1.2 Layout and Mechanism of Off-Highway Vehicles

Off-Highway vehicles is the market about which this study will concentrate most of the time and efforts. For an easier and correct comprehension of the potential powertrain evolution for OHVs, it is necessary to make a quick refresh of technical terms that will be frequently used throughout the analysis. If commercial vehicles follow mechanical rules of passenger cars, off-highway vehicles differ a lot from road vehicles.

Mechanical Transmission vs Hydraulics

Powertrain, the beating heart of any vehicle, indicates the whole system that provide power from the source (engine) to the wheels (or tracks as in many OHVs, or any other tools responsible for movement). The power created by the engine is then transferred to the final drive shafts by the transmission. Considering an automotive vehicle with an internal combustion engine (ICE), transmission system adapts the higher engine speed to the slower wheel speed, increasing torque in the process. Torque (i.e. rotational force, measured in Nm) is the variable that expresses the capability of the engine, and consequently of the machine, to execute hard works such as towing, hauling or climbing steep grades. It is the peak output of the engine in a specific moment of effort. If we multiply torque and speed, we obtain the power of the engine, the measurement of the engine's overall performance commonly expressed by horsepower (or Watts[3]). Since this value is fixed, it is possible to understand how a conversion torque-speed is required in movement of any vehicles: they are inversely proportional, as torque increases, speed decreases. The transmission is able to switch between different (gear) ratio by using a gearbox, the tool that reduces speed in exchange of torque. This is the reason why we select lower gears when we have to make a climb with our car: in this circumstance, our vehicle requires higher torque, while the speed decreases according the gear reduction. The clutch is the last element, used to connect/disconnect the engine from the transmission system. These concepts have to be stressed because OHVs, for their working tasks, require more torque than speed.

[3] kW is the official measure of output engine power in the International System of Units (SI), but horsepower (hp) is often used for technical specifications

In order to performs works, OHVs use hydraulic systems and their related transmission rather than normal mechanical transmissions previously described. These systems transmit power by leveraging the pressure of an in-compressible fluid (e.g. oil) within a sealed system. They are capable to cope with large weight range, providing the higher power demanded by these mobile machines (Lajunen et al., 2017).

It is useful to take a crawler excavator design as an example of the whole category. Excavators consist a bucket mounted on a two or three-piece boom and stick assembly, on a rotating platform with the operator's cab, engine compartment and hydraulic pump. All movement and operations are achieved through hydraulic systems. Beneath the rotation point (slewing ring), excavators may be mounted on either a crawler (tracked) or wheeled undercarriage. This design is common in applications such as drilling machines, track cranes and forestry machines, so that it can be used as a sample to generally describe hydraulic-ICE powertrain functioning. Fig. 1.3 shows the four parts of a Caterpillar's crawler excavator. The machine in the picture is equipped with a bucket, but other special attachments can be found, such as hydraulic hammers and scissors.

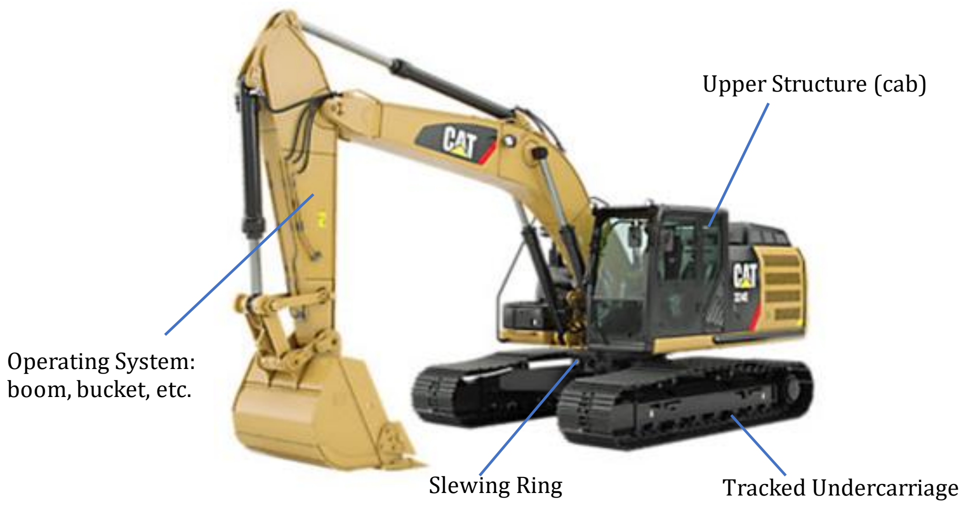


Fig. 1.3: Crawler Excavator Design

Furthermore, the main components of a traditional hydraulic-ICE (diesel-powered) crawler excavator are illustrated in figure 1.4. Observing the two sides of the machine help the inspection by describing how hydraulic transmission works.

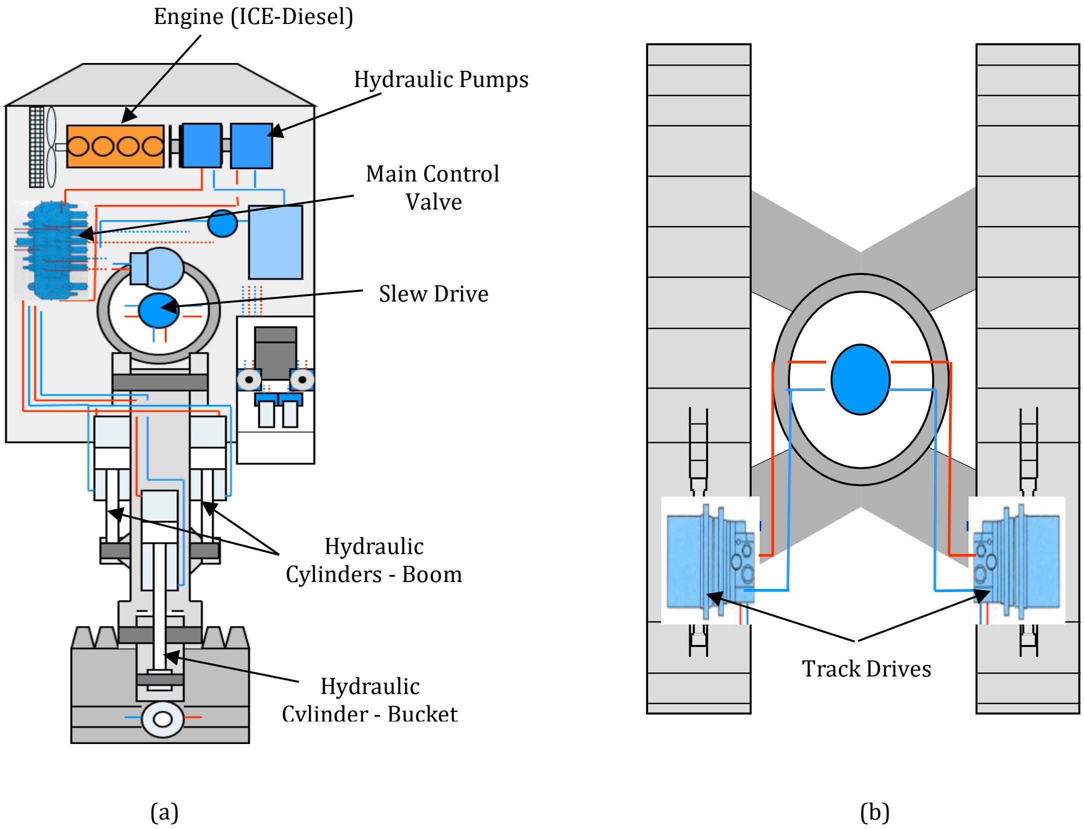


Fig. 1.4: (a) Upper structure and (b) Undercarriage for a Crawler Excavator

These are the steps characterizing the functioning for this powertrain technology:

- one or several hydraulic pumps, mechanically powered by a diesel engine, pushes the fluid to high pressure
- a system of valves located in a block called "main control valve" (MCV) are controlled by the operator through joysticks in the cab
- by manipulating joysticks, the operator can send the fluid to hydraulic cylinders used by actuators of the operating system (e.g. bucket, boom, etc.)
- the incoming pump flow can be also applied to tracks (track drive) or wheels if it's a wheeled excavator (wheel drive) and to rotate the machine on the base (slew drive).

Hydraulic systems have so far proved to be well suitable for off-highway applications. However, their major downside is their inherently lower energy efficiency due to the flow and pressure that have to be maintained even if the machine is not moving or working (so-called pressure drops) (Vukovic et al., 2017).

The next chapter will explain how alternative powertrain can solve this problem, increasing energy efficiency, in addition to other benefits.

1.3 Current Company Positioning on OHVs

Bonfiglioli Riduttori SPA is a worldwide power transmission manufacturer, supplying a wide range of products including gearboxes, gearmotors, drive systems, inverters[4] and other applications suitable for industrial automation, mobile machinery, wind energy and any other related industry. The vast array of market opportunities lies on the infinite possible use of gearboxes (*riduttori*), which as we said in the previous paragraph are relevant components of the transmission system.

Financial highlights for 2020 shows a corporate turnover of 921 million, divided among company's three business units:

- Mobility and Wind Industries BU deals with drive applications for construction, agriculture and material handling machines (the off-highway vehicle category), but also wind energy through components suitable for wind turbines, and electric-mobility to address electric solutions towards new markets
- Discrete Manufacturing & Processes Industries BU offers gearboxes, gearmotors and electric motors for smaller machinery such as packaging, food and beverage and logistics applications
- Mechatronic & Motion Systems BU is specifically dedicated to robotics and automation processes and related applications

For the markets under analysis, the study will focus on the domain of Mobility and Wind (M&W) BU, which reported a turnover of 617 million. Its portfolio includes drives for travel (tracks or wheels based on the vehicle design), slew (commonly known as swing, the rotating function owned by many OHVs), winch (hauling or lifting function typically associated with cranes, consisting of a rope or chain winding round a horizontal rotating drum), and others. Each of these drive applications respond to a specific function, which vary from a more common one (e.g. track or wheel drive is required for every machine) to others which are specifically tailored to vehicle purposes. Fig. 1.5 represents the pie chart of Bonfiglioli Mobility & Wind's[5] turnover among the different sectors covered.

[4] Gearmotor=gearbox coupled with an electric motor, Inverter=device which converts direct current (DC) into alternate (AC)

[5] From now on, the term Bonfiglioli will refer specifically to this BU

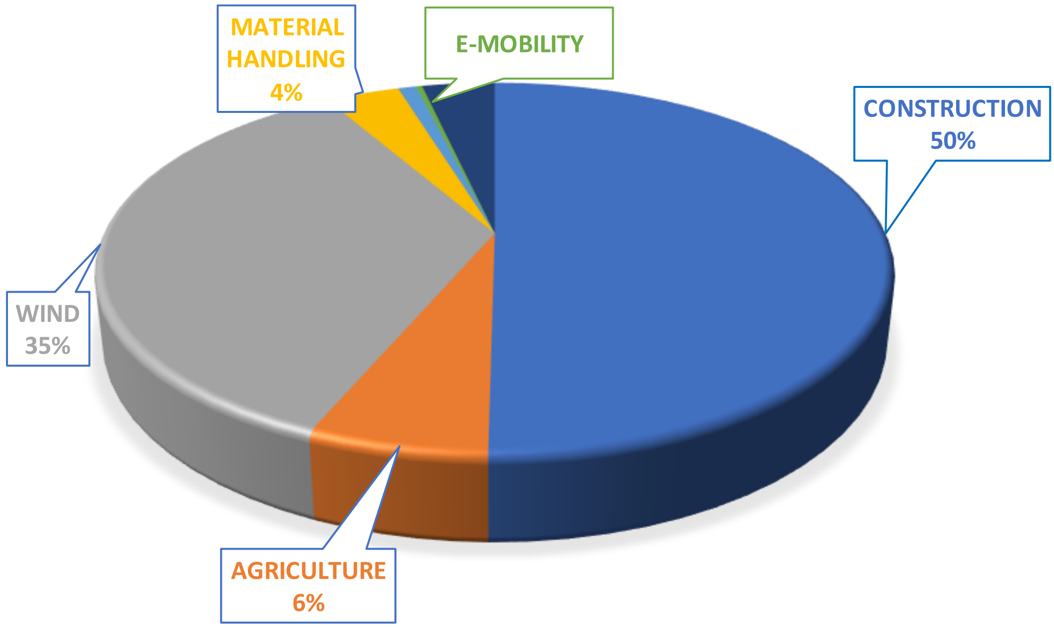


Fig. 1.5: Percentage of turnover across Bonfiglioli's sectors for 2020.
Notes: Marine (0.88%) and Other (3.55%), which are not part of this thesis object, complete the 100%

Wind solutions, the second most important source of profit for the company, will be not taken into consideration in this analysis. Concerning e-mobility sector, which currently accounts only for the 0.30% of total turnover, it includes wheel drive solutions for LCVs and other prototypes for on-highway applications (e.g. urban vehicles). The electric transition and following solutions for OHVs, which represent the most important slice of the cake, is yet to come, and it is the object of this study.

Currently, the dominant powertrain technology for OHVs is the previously described hydraulic-ICE. This means that a supplier engaged in the off-highway business like Bonfiglioli has to satisfy, through its components, the requirements of hydraulic-powered vehicles. Material handling equipment represents an exception because, as it will be explained later, they are by nature predisposed for electrified powertrain.

Even if we don't deepen the mechanism of each drive that the company design for OHVs, it's sufficient to know that all of them share the same structure in hydraulic configuration: a Bonfiglioli's gearbox coupled with hydraulic cylinders which exploits fluid power to perform the task required. The company assembles its gearbox produced in-house, with associated hydraulic motors which are purchased externally. Then it sells the final drive applications directly to the original equipment manufacturer (OEM).

In this sense, Bonfiglioli is positioned as a Tier 1-supplier of components of OHVs.

It is firmly integrated in the supply chain of this category of vehicles, dialoguing with OEMs and sub-suppliers to ensure cutting-edge products.

The company has a global presence through its 20 branches and 13 plants scattered in almost all continents. Table 1.1 highlights the geographic division of off-highway sectors' turnover across world regions for the year 2020.

Region	Off-Highway Sector			
	CONSTRUCTION	**AGRICULTURE**	**MATERIAL HANDLING**	**Tot Region**
Europe	36.93%	17.74%	91.71%	**38.45%**
China	32.38%	0.00%	0.60%	**27.45%**
North America	18.79%	51.07%	5.67%	**21.01%**
India	5.90%	4.06%	0.05%	**5.38%**
South America	1.75%	25.90%	0.99%	**3.96%**
Rest of APAC	3.45%	1.18%	0.87%	**3.08%**
MEA	0.80%	0.05%	0.11%	**0.69%**
Tot Sector	**84.67%**	**9.31%**	**6.02%**	**100.00%**

Table 1.1: Off-Highway sectors' Turnover by Region - 2020

Construction is the biggest off-highway market for the company, with a total turnover of 314 million, against 35 million for Agriculture and 22 million for Material Handling applications. The leading market, as well as the other two, is concentrated in three macro regions (Europe, China and North America), which together make up almost the 87 % of the entire OH category. The global extent of the company allows it to collaborate with the major OEMs for these applications. Fig. 1.6 shows who have been the top-five customers per sector in terms of turnover.

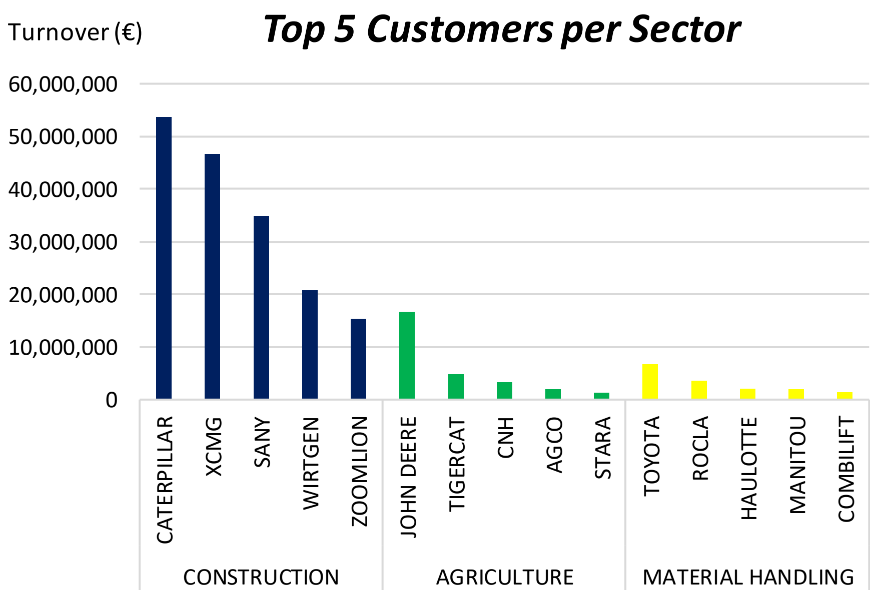


Fig. 1.6: Top five customers in terms of 2020 turnover (€) for each Off-Highway sector.

The US Caterpillar, with Chinese XCMG and Sany, contribute for more than 35% of the total turnover generated by the three off-highway sectors.

As for every B2B market, the demand is usually derived, i.e. it follows OEMs' requirements with customizable solutions. However, this doesn't mean that a supplier keeps a passive role, waiting for customers' needs. Especially in a technological industry such as Bonfiglioli's one, suppliers have to cooperate with their customers, co-engineering products and applications able to suit emerging technologies (Wognum et al, 2002). Suppliers must be able to foresee the evolution of markets.

According to market forecasts that will be illustrated in chapter two, electric powertrain adoption for OHVs will increase over the next decade. The resulting goal of Bonfiglioli consists in designing and developing innovative solutions able to drive the technological transition from internal combustion to electric powertrains. The e-mobility boost aims at improving company's position in mobility markets, without undermining the leadership acquired over the years in traditional technologies. Therefore, the new electric solutions must be integrated to the existing product portfolio, enhancing the final value offered by Bonfiglioli.

2. The Electrification Trend

Electric Mobility is one of the major technological trends of the new century.

Cleaner sources of fuel have been implemented in almost every category of vehicles.

This has diffused alternative powertrain technologies competing with the traditional internal combustion engine.

Vehicles' electrification has been mainly pushed by an increasing attention paid on environmental sustainability, greenhouse gas (GHG) emissions and air pollution. According to the Global EV Outlook 2021 issued by the International Energy Agency (IEA), there were more than 10 million electric vehicles at the end of 2020 (Fig.2.1).

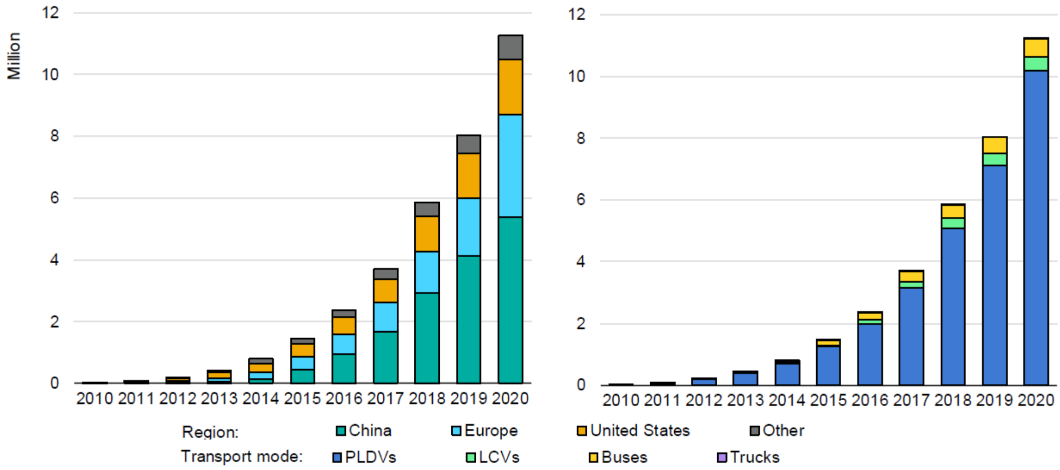


Fig. 2.1: Global electric vehicle stock by region (left) and transport mode (rights), 2010-2020
Notes: PLDVs = passenger light-duty vehicles, LCVs = light-commercial vehicles. Electric vehicles include battery electric and plug-in hybrid electric vehicles.

The graphs highlight an exponential growth of electric vehicles, supported primarily by China, then Europe and US. Regarding vehicle categories, the report focuses only about on-road vehicles, excluding OHVs.

In this chapter we will analyse the electrification adoption for off-highway machines by looking at its key drivers and enablers.

Comparisons will be made between off-highway and on-highway (on-road) vehicles' electrification development, in order to motivate their different adoption rate.

The chapter will review current and potentially implementable powertrain technologies, highlighting strengths and weaknesses of each one. At the end of the chapter, market forecasts for different powertrain technology and applications will be collected.

2.1 Drivers and Challenges for OH Electrification

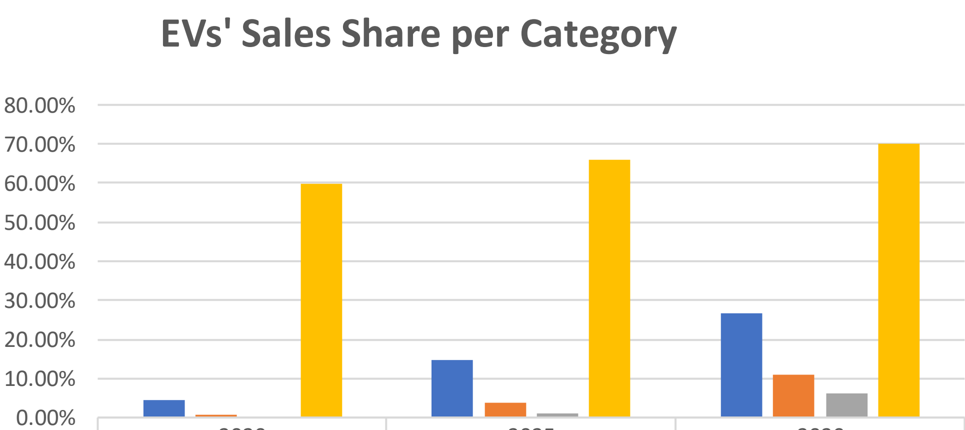
Environmental concerns regarding air pollution and greenhouse emissions are the common driver for any kind of vehicles' electrification.

However, off-highway vehicles' industry has to face more challenges compared to automotive vehicles, due to their technical and operating features.

This in turn implies further drivers to enable the powertrain transition for the category.

2.1.1 Automotive vs Off-highway EVs Development

Experts in the field agree that 2020s will be the decade of the final mass adoption of electric cars (Forbes, 2021). This is also confirmed by forward-looking analyses carried out by authoritative research institutes. Table 2.1 combine data from two of these sources, Interact Analysis and IEA[6], respectively focused on off-highway (i.e. construction, agriculture and material handling) and on passenger cars.



	2020	2025	2030
Passenger Cars	4.60%	14.65%	26.65%
Construction	0.57%	3.66%	10.97%
Agriculture	0.00%	1.03%	6.28%
Material Handling	59.82%	66.02%	69.99%

Table 2.1: Electric Vehicles' sales share per category of vehicle
Source: Author's elaboration from Interact Analysis (OHVs) and IEA's Global EV Data Explorer (passenger cars)

[6] IEA provide two scenarios for future projections (Stated Policies Scenario and Sustainable Development Scenario). Data for passenger cars are the average calculated between two forecasts (link)

The table shows how the development of electric powertrains for passenger cars is in a much more advanced stage than for Construction and Agriculture machines.
For Material handling a different discourse must be made and it has to be excluded by the debate on challenges for off-highway electrification. Its high adoption rate doesn't reflect what will happen in other off-highway applications, where power requirements are higher and duty cycles are very different.
Construction and agriculture appear far behind cars in terms of electrification.
To use a term belonging to the field of innovation, borrowed from mathematics, it can be stated that the cars have reached the inflection point, while the construction and agriculture machine are at the primordial stages of the electric development process.
The term *strategic inflection point* was first coined by Andy Grove, CEO of Intel in the 1990s, when his company began to lose market share to Japanese memory-chip manufacturers. The new technology brought Intel to refocus its main business on microprocessors. (Grove, 1996)
As in mathematics, inflection point means a point where a curve changes from convex to concave, so the way of conducting a given business can be upset, irrevocably changed. The change can refer to an introduction of new technologies but also to an introduction of different regulatory environment and a change in customers' values: all these events require a fundamental modification of the business strategy.
That's what the electrification transition for passenger cars is about.
Technological developments and linked costs reductions, incentives for EVs, increasingly stringent emission regulations and the concept of sustainable mobility driven by consumer behavior towards environmental issues, have brought the electric car market to the inflection point.
If traditional ICE-powered vehicles still coexist with electric vehicles, in the future there may be an unchallenged dominance of the latter. Nowadays, almost all car manufacturers are reorganizing production lines, deploying new business models to exploit EVs' proven opportunities. (Mckinsey, 2021-a)
Fig. 2.2 portrays the different development phase of passenger cars and OHVs with respect to the strategic inflection point of electrification.

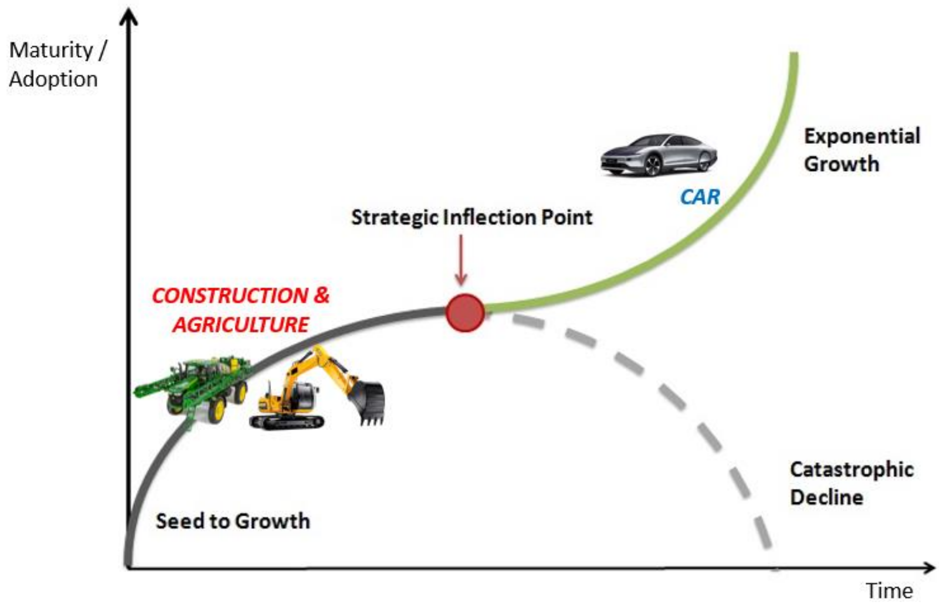


Fig. 2.2: Electrified development of OHVs and passenger cars related to Inflection point
Source: Author's adaptation from Grove (1996)

Off-highway market is lagging behind. Regardless of the application, OHVs are mostly in the research and experimental phase, with few of them already on the market (Roland Berger, 2020). However, OEMs are planning to extend their electric fleet over the next years. The off-highway electric transition will take several years to reach the inflection point, if it should really occur. What is certain, independently from Grove's theory, is the need to anticipate the market and competitive dynamics, because if the inflection point should occur, there would be no going back (Fortune, 2020).

2.1.2 Technical Differences and Challenges for OHVs

The delay that off-highway industry has accumulated relative to the automotive sector is due to inherent technical aspects limiting a faster and wider transition. The differences mainly concern duty cycles and operating conditions. As we argued in the first chapter, these are peculiarity of OHVs linked to their professional purpose that directly affect their design and functioning.

Duty Cycles

Driving cycles, or drive cycles, are fixed schedules of vehicle's operative attributes, collected through experimental tests made before the introduction in the market.

They plot vehicle speed versus time, highlighting simulations of engine performances and, above all, polluting emissions. Consequently, any available information about fuel consumption is based on these tests (Barlow et al, 2009).

Within the European Union, the official drive cycle standard procedure for vehicle homologation has become the World harmonized Light-duty vehicles Test Procedure (WLTP)[7], represented in Fig. 2.3. As the name suggests, it regulates fuel consumption and exhausts of light-duty vehicles (i.e. passenger cars and LCVs).

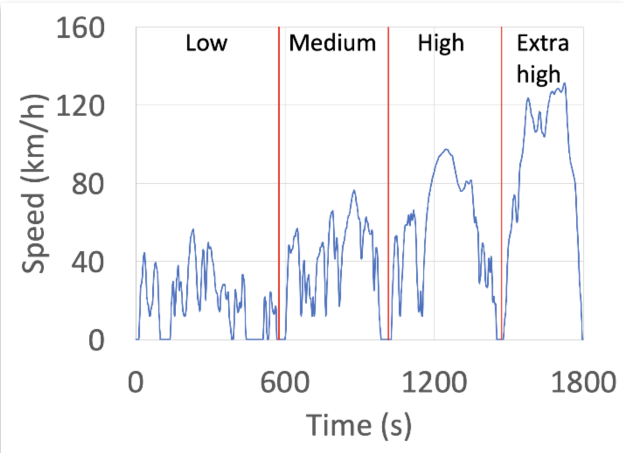


Fig. 2.3: Example of a WLTP Drive Cycle
Source: TransportPolicy.net

Automotive vehicles can be ideally represented by speed-based drive cycles because their only power request is the traction power, i.e. they have just to travel on roads. On the other hand, OHVs must respond to different types of loads, based on the purpose for which they are designed. Whether they have to dig into the ground or lift materials, their duty goes far beyond traction. For this reason, it's better to talk about duty cycles rather than drive cycles when we refer to off-highway machinery (Malavuta et al, 2019).

The duty cycle of a machine is the description of its operations during its lifetime, both at an overall level and for each single operating phase.

[7] Tests are conducted at different maximum speeds – Low (up to 56.5 km/h), Medium (up to 76.6), High (up to 97.4), Extra-high, (up to 131.3)

Duty cycles originates from experienced values, estimations, data collecting, measure records and monitoring processes. It can be displayed by figures such as tables, diagrams and histograms, which include operation types and performances values such as movements, angles, loads, torques , speeds , etc.

As we can see by Fig. 2.4, different movements characterize the duty cycle of an excavator, taken as a sample for off-highway machines.

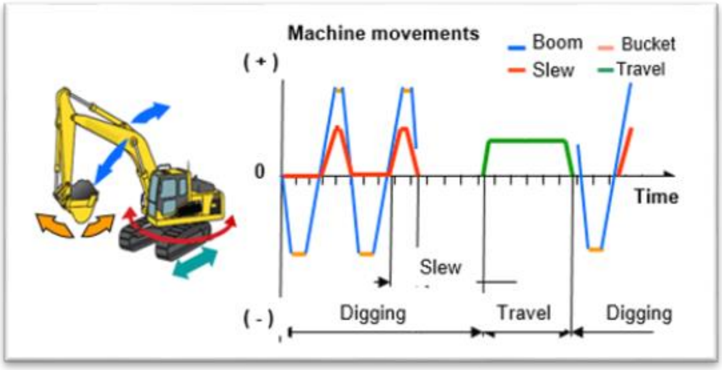


Fig. 2.4: General operations in an excavator duty cycle

Each operation reflects a function, which in turn is satisfied by specific drives (i.e. wheel, slew, track, winch drive, etc) described in the previous chapter.

Regardless of the vehicle under analysis, duty cycles reflect a higher intensity in terms of magnitude and frequency of peak power for OHVs, as depicted by torque versus speed projections in Fig. 2.5. Power requirements are variably divided into different outputs related to mechanical or hydraulic loads, with an average power demand considerably lower than the peak power. Finally, OHVs have a much broader range of power rating needs (from 10 kW to 3 MW) (Beltrami et al., 2021).

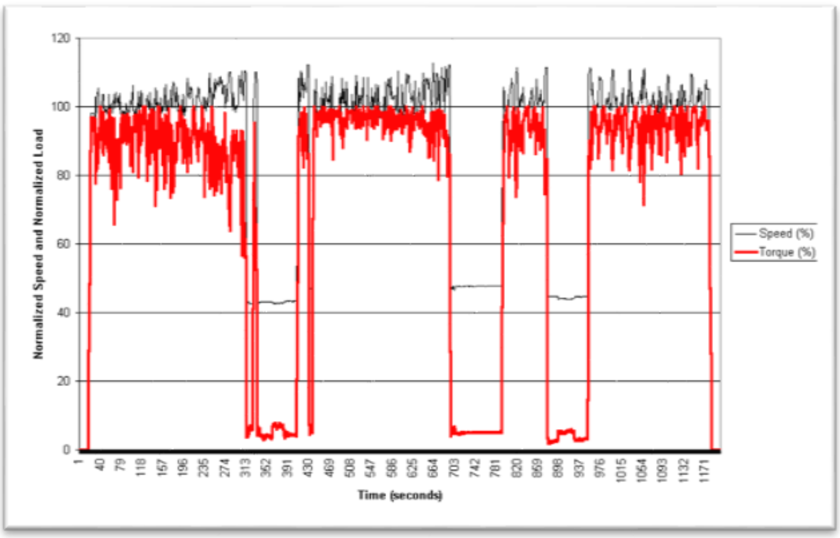


Fig. 2.5: Example of an excavator's duty cycle

Concluding, duty cycles allow to know power and torque request of a machine during its different operations. Due to the intensity of duty cycles and higher power requirements, off-highway is investigating electrification to improve energy efficiency and lower operating costs.

Operating Runtime

Another difference between automotive and off-highway vehicles lies in the operational runtime. While for automotive purposes runtime means the distance to travel on full charge, for off-highway it is defined as how long the equipment can be used (Malavuta et al., 2019). OHVs' harsher operating conditions are characterized by longer operating hours and intensive use, with very little or even no time for recharging during the day. Operational runtime becomes a critical design parameter as it has direct implications on the battery capacity choice, or more generally on energy storage systems configuration. Charging time is an essential parameter for scheduling the employment of machineries, assessing electric powertrain capabilities. For OHVs working in a restricted/planned area, charging infrastructure can be organized in a more efficient way.

Variety and Size of OH Applications

As we argued in the first chapter, OHVs are tailored and customizable according to their intended multi-uses. As a consequence, off-highway range of applications is much more diversified than automotive vehicles in terms of design variety.

Therefore, no generic powertrain layout will fit all off-highway vehicles because they require tailored powertrain system solutions according to their specific technical features. In this sense, the final paragraph of this chapter will detail the rate of electric powertrain adoption according to different values of two of the most important design variables: weight size and power ratings.

There is also an economic challenge arising from OHVs' variety: normally, they don't benefit from mass production. The huge diversity, combined with the overall lower volume of units compared to cars, might create a strong obstacle to electric transition.

It follows that total cost of ownership (TCO), rather than the mere upfront cost, can be a more important factor to assess economic viability and success of a powertrain.

2.1.3 Key Drivers and Enablers of electric adoption

It has been argued how electric cars diffusion has been strongly supported by environmental objectives and related incentivies. Although it is undoubetly relevant, emissions reduction is not the main driver for off-highway powertrain electrification.

The enhancement of energy efficiency (e.g. decreasing fuel consumption), the improvement in productivity and a long-term economic convenence are further factors driving alternative powetrains adoption.

The resulting key drivers for electrification of OHVs can be summarized as:

a. Emissions regulations
b. Enhanced Energy Efficiency
c. Technological Development of Components
d. Long-Term Economic Convenience
e. Improved Productivity
f. Corporate reputation and CSR

a) Emission regulations

Tight emission regulations are a pillar of preventive actions promoted by policy makers to fight climate change. Based on data from drive cycles' simulations described earlier, policy makers implement environmental protection regulations that impose limitations to vehicles' GHG emissions. The requirements affecting on-road vehicles also extend to off-road, which are sources of pollution during their operating time.

For OHVs, as for passenger cars, US and EU emission standards are the most widely referenced and applied regulations, with most other regions following them (Lajunen et al, 2018). The European Green Deal[8] (2019) has the ambitious objective of reducing greenhouse gas emissions in Europe by 80-95% the year 2050 compared to 1990 levels.

EU has proposed the world's toughest emission standards for non-road mobile machinery (NRMM[9]): Stage V regulation. The Stage V's updated standards extend the scope of the exhaust emission legislation to very small (< 19 kW) and very big engines (> 560 kW),

[8] EU Green Deal is a set of policy initiatives with the overarching aim of making the EU climate neutral in 2050
[9] In the EU classification, NRMM comprises: -small gardening and handheld equipment (lawn mowers, chainsaws, etc.), -construction machinery (excavators, loaders, bulldozers, etc.), -agricultural & farming machinery (harvesters, cultivators, etc.), -railcars, locomotives and inland waterway vessels.

reaching a complete coverage of power ratings. The direct impact of the new emission limits is the need to use more sophisticated emission control and exhaust gas treatment systems. OHVs vehicles compliant with Stage V can also enjoy tax subsidies.
The US Environmental Protection Agency (EPA) regulations have been almost identical to EU ones for over a decade, with US Tier 4 Final as the last standard implemented. Although it is unlikely that EPA will implement stricter Tier 5 standards anytime soon, legislators in regulatory strict states such as California and action by the new Biden administration could see this change in the coming years.

b) Enhanced Energy Efficiency

In general terms, energy efficiency refers to the amount of output that can be produced with a given input of energy. In a vehicle, energy efficiency is represented by the ratio of distance travelled per unit of fuel consumed (European Parliament, 2015).
Among available or potentially usable fuels, fossil fuels have been the most widely energy source to power the engine of different types of vehicles. However, the dominance of the fossil fuels is changing along with the stricter emission regulations and the evolution of alternative fuel options.
ICEs (mostly diesel-powered) have dominated also in mobile machinery, with hydraulic systems that complete the traditional powertrain layout of OHVs.
In this conventional powertrain layout, discussed in the first chapter for an excavator, the hydraulic systems convert mechanical power deriving from the engine to fluid power. The flow is then directed to machine actuators that use cylinders to convert fluid power back to mechanical power, fulfilling the task desired.
As hydraulic systems offer a good power density, they are well suitable for off-highway applications that operate at high torque capacity and low driving speeds.
Unfortunately, they have inherently lower energy efficiency compared to electric systems that could be potentially implemented. (Beltrami et al, 2021).
This important drawback is due to two factors. First, the pressure loss in hydraulic hoses: to control flow, pressure and direction of the fluid, hydraulic valves cause the pressure drop, which is loss of energy. The flow and pressure in the system have to be maintained even if the machine is not moving or working. Second, since the pump is mechanically coupled to the ICE, when actuators' cylinders require higher power load, the same increase has to occur in the engine speed.

The combined lack of efficiency of both ICE and hydraulic system implies that the net mechanical energy available is about 25% at best (Vukovic et al, 2017).

Beyond lower emissions, the most important advantage of electrification is the enhancement of energy efficiency through its inherent energy recovery[10] function.

The most known energy recovery strategy is *regenerative braking*, which recovers kinetic energy typically dissipated in the form of heat when the vehicle decelerates to brake. It's a specific property of EVs, that show the use of electric motors as generators: kinetic energy captured from the wheels is converted into electricity and stored in batteries to be used when needed (Ying Yong et al, 2015). The next chapter related to different powertrain will explain the different contribution on energy efficiency for each degree of electrification (i.e. hybrid, full electric, etc). Another potential electrification concerns actuators' systems. For example, it is possible to replace hydraulic actuators with electromechanical ones. These latter make actuators independent of one another by assigning an electric motor for each one, optimizing the speed range of each one, with those that are not needed even being turned off (Beltrami et al, 2021). Electromechanical actuators enhance fuel efficiency by reducing losses of conventional hydraulic systems (OEM Off-Highway, 2021-a)

c) *Technological Development of Components*

As investments in electrification and hybridization have been applied across all mobility markets, technology development in on-highway markets can bring confidence and drive down electric components costs. Batteries, in particular, are considered the most critical component of electric powertrains, both in terms of costs and power capacity. Technology improvements in power electronics and battery capacity maturated in other sectors, can be adapted to OHVs' requirements. Among the different types of batteries, *lithium-ion batteries* are recognized as the present state of the art, and also as the most interesting long-term solution, both from a technical and a cost-performance points of view. Indeed, from 2010 to 2016, specific cost per energy unit ($/kWh) decreased at a rate of almost 20% per year. Interact Analysis estimates that battery pack prices will fall to $200-100 per kWh by 2024 depending upon the application and chemistry.

[10] Energy recovery = any methods used to exchange energy in one sub-systems with another one, minimizing the energy input required by the overall system

Bloomberg[11] highlights an expected average battery pack price in 2030 of 53/kWh. Therefore, batteries will drop to a level that is very price competitive with ICEs, paving the way for full-electric solutions (Bloomberg NEF, 2021).
There is another technological aspect to consider in the energy storage system. Trends in energy generation and distribution are directed to renewable sources of energy such as wind and solar. The more available renewable energy can be exploited as electricity to recharge batteries, thus becoming an important factor when selecting a power source for OHVs (Porsche Consulting, 2020).

d) Improved Productivity

Electric motors do not require the service attention of engines, such as oil changes, filter changes, or hot and cold temperature fluid requirements. In this way, reduction of maintenance represents one of the major benefits of electrification, with positive effects in operating time and costs, as it will be argued soon.
Electric powertrains enable more accurate controllability and manoeuvrability, thanks to connectivity systems which in turn enhance user experience and precision by improving work monitoring (Semcon, 2017)
Finally, noise abatement is another great benefit that can be obtained from the electrification of a vehicle. Especially in urban contexts, zero-emissions area and indoor environments, noise reduction from the use of off-highway machines is very important for the productivity. Fewer vibrations are due to the lack of diesel engine and cooling fan, which guarantee a safer operation of the machine for workers (Big Rentz, 2021)

e) Long-term Economic Convenience

One of the major challenges for any electrification transition is cost estimation. The high costs of electric components, especially for batteries, have been a great obstacle for EVs, raising their purchase cost (i.e. up-front price).
The production volume for each off-highway machine type remains fairly low compared to passenger cars, which means any significant cost reductions in component level will be more challenging to realize for OHVs because they can't rely on mass production (Lajunen et al, 2018). For a fair cost evaluation of electric transitions, it is necessary to introduce

[11] Source: Hitting the EVs Inflection Point (BloombergNEF, 2021)

the concept of *total cost of ownership* (*TCO*). TCO[12] represents the best tool to evaluate long-term convenience of different investment options, over the entire assets' lifecycle. Despite it should be the first measure to assess any types of vehicles, it becomes even more important for OHVs, which by nature require more maintenance for their work-oriented purpose and longer lifespan.

Based on Argonne's Comprehensive Total Cost of Ownership quantification for vehicles with different size classes and powertrains (2021), cost components that should be included in the TCO calculations are depreciation, financing, fuel, insurance, maintenance, fees, etc. However, for the study's purpose it is sufficient to take into account fuel costs and maintenance, as main cost drivers in addition to up-front price.

According to Porsche Consulting (2020), the actual machine purchase price may represent an obstacle to electric powertrain (both HEV and BEV) choice, but looking at the other two main cost components, it is possible to realize that electric models will result economically convenient in the long-term (Fig. 2.6).

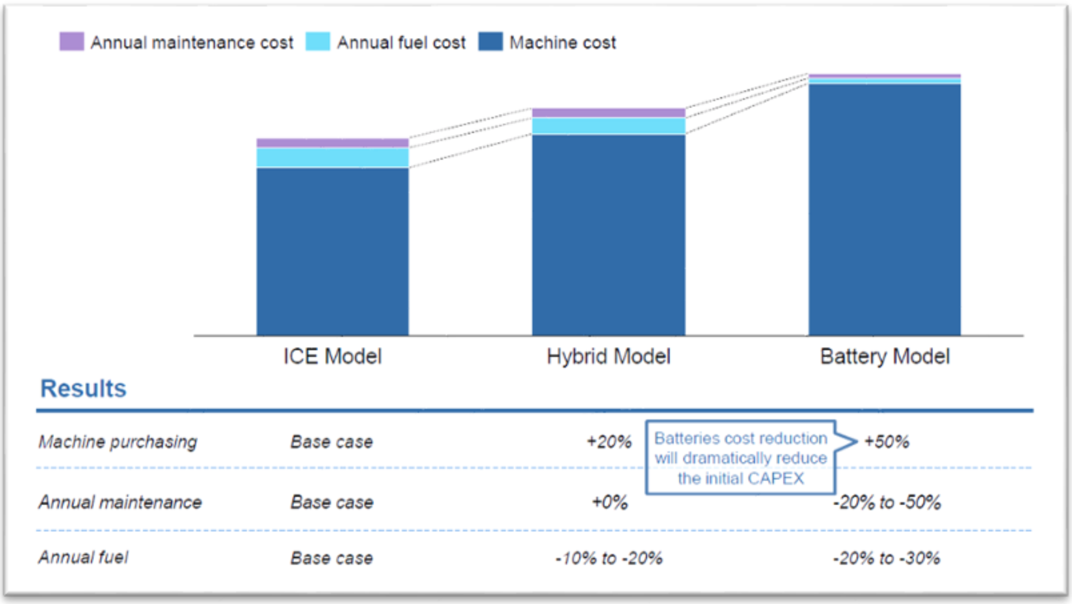


Fig. 2.6: Three main cost components of TCO by powertrain model
Source: The impact of New Mobility on the industrial sector in Emilia (Porsche Consulting, 2020)

[12] TCO = purchase price of an asset plus the costs of operation

Even if machine costs currently exceed economic benefits related to lower maintenance and higher fuel efficiency, in the lifecycle context the steady decrease of batteries' cost will dramatically reduce initial capital expenditures (indicated as CapEx in the figure) and in turn the total cost of ownership. Concluding, electric powertrain will become competitive with conventional models in terms of cost-efficiency.

f) Corporate reputation and CSR

Regardless of technological debates, moving towards cleaner powertrains means responding to climate change problems. The World Economic Forum (WEF) publishes annually the ranking of the Global Risks, which places permanently at the top several interrelated environmental issues, such as climate change and human environmental damages (WEF, 2021). For any type of company, it's important to demonstrate a commitment towards sustainability, as confirmed by the now essential Corporate Social Responsibility (CSR). In this way, suppliers that engage in the transition to greener powertrain solutions can enhance their brand and corporate reputation.

2.2 Alternative Powertrain Technologies

The driving factors presented earlier have been making electrified powertrains particularly attractive to OEMs and suppliers of off-highway industry.

Hybrid, full electric (e.g. battery-electric) and fuel-cell powertrains will be analysed. These configurations for OHVs are very similar to the automotive ones, with the essential difference that they don't have to power only the traction system, but also the actuators. Once again, excavators will serve as example of an off-highway machine electrification, even if it is important to remember how, depending on the specific application, duty cycles produce different power requirements.

Before going into the specifications of each technology, it is necessary to define what are the two main component of electric vehicles.

Energy Storage Systems

As ICE powertrains have a tank to contain sources of chemical energy (i.e. fossil fuels) to be transformed by combustion process into mechanical energy, electric powertrains use mainly batteries or supercapacitors as energy storage systems. Rechargeable batteries rely on chemical reactions to obtain electrical energy, while supercapacitors store electrostatic energy associated with an electrostatic field. It has been argued how lithium-ion batteries are the present state-of-the-art solution for electric energy storage. These batteries offer far higher energy density[13], while supercapacitors prevail in terms of power density[14]. In terms of costs, technology developments have made lithium-ion batteries the best cost-efficient choice. Due to these technical differences, batteries are the energy storage systems suited to battery-electric powertrains, while supercapacitors can be better employed in hybrid architectures, where the main energy source remains the ICE and the electrical energy is used only for power peaks and shorter duty cycles. However, some systems can combine two or more different energy storage devices. For example, by integrating high-power supercapacitors and high-energy batteries, the resulting energy storage system can take advantages of both technologies (Somà, 2017)

Electric motor

Electric motors convert electrical energy stored in batteries or supercapacitors into mechanical energy required to drive the vehicle. As it has been argued when discussing increase in energy efficiency due to electric powertrains, electric motors act as generators during regenerative braking. Electric generators carry out the reverse function, converting mechanical energy into electricity. In hybrid vehicles, the term motor-generator is frequently used to an electric system usable both as electric motor and generator. Electric motors use converters and inverter to shift from alternating current (AC) to direct current (DC) and viceversa (Wang et al, 2016).

[13] Energy density = amount of possible charge to be stored

[14] Power density = amount of time to charge and discharge energy

2.2.1 Hybrid powertrain (HEV)

Hybrid electric vehicles (HEVs) use a combination of an internal combustion engine and one or more electric motors for propulsion. The most common configurations for hybrid powertrain are series and parallel (Ying Yong et al, 2015).

For any type of vehicle type, series hybrid involves an ICE, battery packs or other energy storage devices such as supercapacitors, electric motors and generator. The ICE power a generator which in turn charges energy storage devices (e.g. batteries). Batteries provide energy to electric motors, which are the single source of propulsion.

Conversely, in parallel hybrid configurations, ICE and electric motors can drive the vehicle independently because they are both mechanically coupled to transmission. Thus, there are two alternative sources of propulsion, which can complement each other during different driving (or operating in case of OHVs' actuators) conditions.

Regardless the specific configuration, hybridization of excavators consists in an electric drive for the swing function, capable of recycling brake kinetic energy, while hydraulic actuators' system remains almost unchanged. ICE is smaller compared to traditional powertrain, but it is still the main power source. Batteries or/and supercapacitors are added to the traditional fuel tank, in order to store the energy recovered by regenerative braking (Imanishi et al, 2013).

A typical configuration for a series hybrid excavator designed by Kobelco[15], is portrayed in Fig. 2.7[16]. In this configuration, both a battery pack and a supercapacitor are employed to store energy. The system consists of an electric motor for each operating functions. Swing function is directly driven by an electric motor, while other actuators are powered by electric motors but still reliant on hydraulic pumps. Independent actuators with their own electric motor increase energy efficiency compared to conventional ICE-hydraulic configurations by reducing idle loss in fluid distribution, but production costs are higher.

[15] Kobelco is a leading construction machinery manufacturer

[16] The next three figures portraying hybrid configurations are all taken from "Trends and Hybridization Factor for Heavy-Duty Working Vehicles (Somà, 2017)

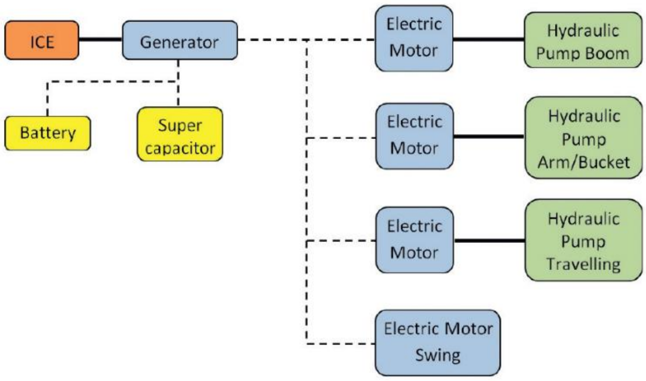


Fig. 2.7: Kobelco's series hybrid excavator configuration

Fig. 2.8 details the structure of one Hitachi's[17] parallel hybrid excavator.
The ICE power both hydraulic pumps and a generator. The hydraulic pumps drive the hydraulic circuit of the device, in a manner similar to conventional excavators, while the generator transforms the mechanical energy into electrical power and can operate the electric motor of swing rotation (Wang et al, 2016).

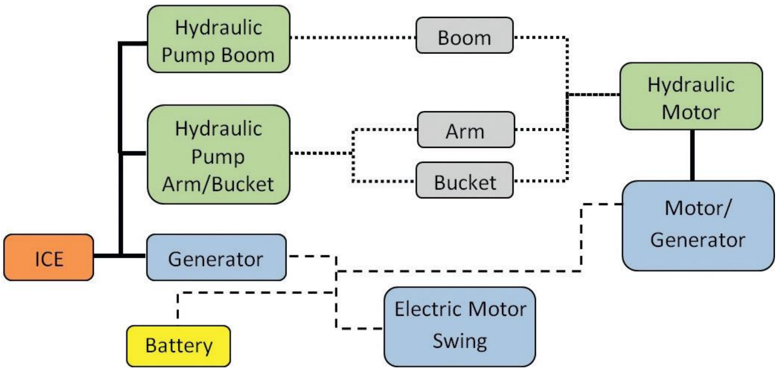


Fig. 2.8: Hitachi's parallel hybrid excavator configuration

Finally, a series-parallel configuration has been developed by Komatsu[18] (Fig. 2.9).
It is mixed architecture, also diffused in automotive vehicles, between series and parallel hybrid. Hydraulic pumps are powered by generator in series, and the swing electric motor is powered by both generator and energy storage system in parallel (in this case supercapacitors). This is considered the best solution among three configurations, as it offers the highest performance at lowest fuel consumption. (Wang et al, 2016). The drawback lies in its higher production costs required to mix two models in a single one.

[17] Hitachi is a multinational corporation operating in fields of electronics, robotics and industrial machinery
[18] Komatsu is the world's second largest manufacturer of construction and mining equipment

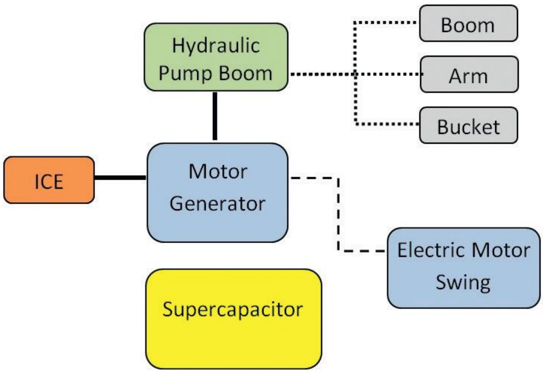


Fig. 2.9: Komatsu's series-parallel hybrid excavator configuration

HEVs' Strengths

Hybridization allows the use of electric power for lighter work and ICE for maximum power (Ying Yong et al, 2015). The energy storage systems, which retain energy recovered by regenerative braking, and the electric drives can better respond to the typical high fluctuating power flows and peak power demand of off-highway duty cycles. By decoupling systems, equipment such as hydraulics are no longer dependent on engine speed. All these factors offer the potential for engine downsizing (i.e. practice of using a smaller ICE providing the same power of a larger one), consequently leading to fuel savings (Wang et al, 2016). For example, Volvo CE[19] claims that its LX1 hybrid 20-ton loader is 50% more efficient than its 25-ton conventional diesel loader.

HEVs' Weaknesses

Hybrid OHVs are undoubtedly more efficient than traditional hydraulic-ICE powertrains. Inherent function of electric motors to recover energy and store it in batteries can be exploited, but there are still high emissions related to diesel engine, which remain the main source of power. Furthermore, although hybrid is considered as a way to manage and mitigate the possible technical and economic risks of battery technology, it still involves higher cost of electric components (Somà, 2017). With batteries technology becoming more mature and the cost dropping down significantly in recent years, hybrid technology can be a less attractive solution for OHVs.

[19] Volvo Construction Equipment (CE) is the off-highway machinery subsidiary of the homonymous group

Overall, hybrid technology appears more like a transition technology (Interact Analysis, 2021). Starting from hybrid machines equipped with small batteries, and then, mostly due to cost reductions in key technologies, a trend for higher capacity batteries being used in full electric technologies.

2.2.2 Battery / Full Electric Powertrain (BEV)

Battery electric powertrains consist of one or more electric motors for propulsion and derives its energy from a battery which is recharged using an external source of electrical power. The key difference compared to hybrid is the absence of ICE: this powertrain delivers net-zero carbon emissions, being fully driven by electric motors powered by rechargeable battery pack. Batteries used in BEVs have greater capacity than hybrids and can be recharged directly by power grid. They are the only source of energy for the whole machine, while in hybrid configuration they serve uniquely to store the energy recovered by braking (Ying Yang et al, 2015). Among all the current available technologies, Lithium-ion has become the dominating technology, thanks to the exponential cost reduction and the highest practical energy density.
Fig. 2.10 compare Komatsu's battery powered mini excavator PC30E-5 with the conventional ICE-powered model of the same Japanese manufacturer.

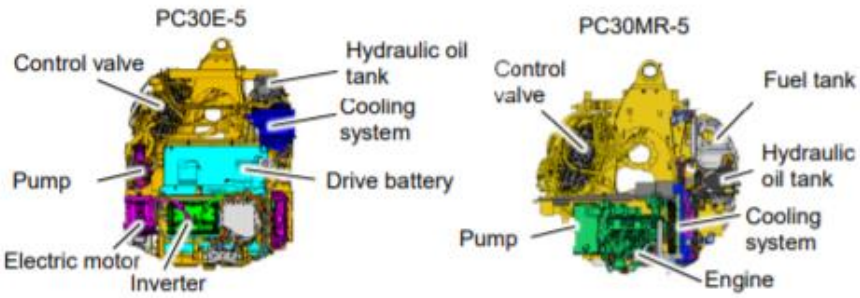


Fig. 2.10: Komatsu's battery electric PC30E-5 (a) ICE PC30MR-5 (b) configurations

However, the definition of full electric machine in off-highway industry is not obvious as in automotive. Even if there a no doubts about the absence of ICE, electric OHVs might lack the traditional hydraulic systems found in their conventional counterparts (OEM Off-highway, 2021-b). In the so-called *pure electric powertrain*[20], actuators' systems can be

[20] Pure Electric vehicles (PEVs) is a nomenclature that in cars, even if little used, embeds both BEVs and FCEVs.

electrified to prevent the typical energy loss of hydraulic pressure. More electrically advanced applications such as material handling machines are developing electromechanical actuators (EMA) to replace hydraulic ones (Interact Analysis, 2021). While conventional hydraulic actuators use fluid power to convey mechanical energy required by different loads, EMA convert electricity into mechanical energy through an electric motor for each implement. Therefore, they can guarantee the higher efficiency typically associated with electric systems. They also require less maintenance since they are oil-free compared to hydraulics and enhance controllability (Machine Design, 2018). However, when it comes to high-power applications such as construction applications, progress on electrification has been slow. Hydraulic actuators have always proved to be reliable mostly due to their great energy density provided. OEMs worried that they would not be able to find suitable electromechanical solutions for demanding tasks, or that electromechanical technology would be too expensive or too technically challenging (OEM Off-highway, 2021-a). For example, Volvo CE prototyped the first 100% pure electric compact excavator in 2017. It was equipped with two lithium-ion batteries in place of ICE, and hydraulics were replaced by electromechanical actuators to power the boom and implements. However, the prototype never became available in the market.

For the purpose of this thesis, the term full electric (or BEVs) will simply refer to the absence of the engine, replaced by electric motor and batteries as energy sources. Whether the term 'pure electric vehicle' should be used, it would mean that even machine actuators are managed by electric systems.

BEVs' Strengths

Advantages of full electric correspond to the electrification's ones previously described.

BEVs are less expensive to charge and require less maintenance compared to conventional powertrain. Full electric equipment not only eliminates fuel costs but also reduces overall operating costs thanks to its lower engine operating runtime, because they can be turned off as soon as the operator stops the machine, with no additional operating time accumulates. Furthermore, the development of BEVs in automotive creates more attractive options to fully electrify also OHVs, without passing through the intermediate stage of HEVs. As it has been said, the success in other vehicles' category not only help to drive cost down, but also spread confidence in the technology.

BEVs' Weaknesses

Current lithium-ion batteries still require a compromise between battery capacity, operation availability and charging solution. For heavy duty cycles and high-performance applications, it still seems to be challenging for Lithium-ion batteries to meet the power requirement reachable with ICEs (Beltrami et al, 2021).
Charging infrastructure must be leveraged to exploit the advantages offered by off-highway machine, which compared to passenger cars operate almost stationary.
Likely the major challenge towards the success of battery electric OHVs will be the lower overall vehicle volumes. They won't be able to rely on economies of scale. Rather, they will have to manage technology development timetables in limited volume markets.

Almost all the major OEMs of off-highway machines have launched or are planning to launch full electric models, such as Volvo CE, JCB, Caterpillar and Doosan (IDTechEx, 2020). As it will be detailed in the third paragraph of the chapter, these manufacturers are approaching full electrification starting from smaller machine, both in terms of weight size and power rating.

2.2.3 Hydrogen Powertrains (FCEV and HICEV)

The use of hydrogen as a power source can play an important role in the energy transition (EU, 2019). The main configurations in which hydrogen can be used are fuel-cell electric (FCEV) and hydrogen-ICE (HICEV) vehicles.
FCEVs powertrain technology follows the electrification trend being, as BEVs, composed of batteries and electric motors in place of conventional fuel tank and ICE. The difference is that FCEVs include hydrogen fuel cells as the main source of power (i.e. electricity), eventually combined with batteries or supercapacitors as auxiliary energy storage systems. Vehicles equipped with this powertrain derive energy from fuel cells, electrochemical cells that produce electricity through the chemical reactions between hydrogen contained in the fuel tank and oxygen in the air (Sorlei et al, 2020).
The only emission from the exhaust of this process is water. Electrical energy provided by this reaction is used to run electric motors which convert it into mechanical, as in the mechanism of BEVs.

FCEVs' Strengths

FCEVs ensure zero-emission free and low noise operation. The use of hydrogen fuel cells instead of batteries is primarily motivated by the higher energy density provided by the former. Furthermore, the power output can be maintained constant to ensure high intensity continuous operation and the refuelling is quicker than charging infrastructure for batteries. Indeed, the hydrogenation time of a vehicle is estimated in 1-3 minutes (BCG, 2021). For these advantages, fuel cells represent a valid power source for larger off-highway equipment with heavy loads, long utilization and high energy demands. The same is true for demanding long-haul transport vehicles, such as buses or heavy-duty trucks, whose manufacturers are exploring hydrogen opportunities more than passenger cars' ones.

FCEVs' Weakness

Even if it offers higher energy efficiency and zero emissions, hydrogen production has a great drawback: at present, the most common method to produce H2 involves using a fossil fuel to heat water into steam, mixing the steam with methane, and capturing the H2 released (BCG, 2021). This is a production process which release GHGs. The real benefit of hydrogen fuel would require the so-called "*green hydrogen*", i.e. hydrogen entirely produced from renewable energy sources. In addition, the limited adoption of fuel cell technology and hydrogen infrastructure keeps the production cost and transportation cost for hydrogen extremely high, making it difficult to adopt on a large scale. Hydrogen storage and distribution need to be developed much more to be a real competitor to diesel fuel or electrical energy storages.

Before the overall cost of hydrogen systems will decrease enough to become cost competitive and a more viable solution, full electric will be the main alternative powertrain technology adopted for use in electrified off highway vehicles. The technology delay in clean production and practical distribution of hydrogen fuel makes batteries more attractive, as they can use existing electric grid. However, different OHVs' manufacturers have presented prototypes of fuel cell electric machines. For example, Hyundai CE and JCB presented medium-large sized hydrogen excavators, while Sany proposed the first hydrogen-powered mixer truck. An opinion sustained by a leading engine manufacturer such as Cummins, is that BEVs and FCEVs are complementary technologies (OEM Off-Highway, 2021-c). If the first is more suited to small and urban equipment, the latter can be better employed in transportation and heavier machine. Fig 2.11 illustrates a possible market division for hydrogen-powered and batteries-powered technologies, according to energy demand and recharging time of the vehicle.

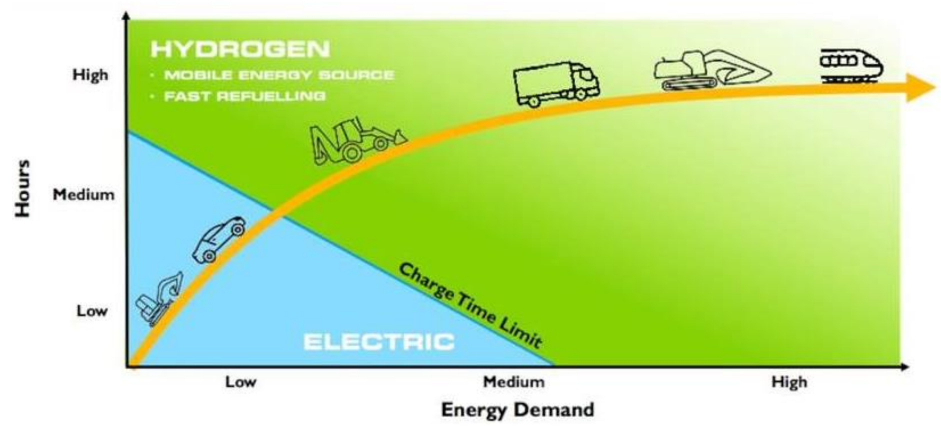


Fig. 2.11: FCEVs vs BEVs suitability for different vehicle's energy demand and recharging time

Another use of hydrogen has been experimented by some major OEMs: hydrogen ICE vehicles (HICEVs). In this particular configuration, hydrogen is burned just like conventional fossil fuels to provide mechanical energy to wheels and other implements (Fayaz et al, 2010). It's classified as hybrid technology since it mixes a green energy source which doesn't contain carbon, hydrogen, but it still produces nitrogen oxides[21] (NOx) as a result of combustion process: differently from FCEV powertrain, HICEV is not zero emissions (Mckinsey, 2021-b). An interesting consideration has been made by JCB, one of the major construction equipment manufacturers (Earthmovers, 2021). According to JCB's chairman, the long recharging time and not sufficient capacity make batteries and full electric powertrain unsuitable and unsustainable for heavy-duty vehicles. Fuel cells, instead, can offer quicker refuelling but they are still too expensive to be massively employed. These issues led the company to the hydrogen ICE concept for its OHVs.

JCB believes that battery electric powertrain can be used only for vehicles with low energy demand and short recharging time, while for heavier machine demanding higher energy and long refuelling, hydrogen-powered engine adapted to existing ICE could be the most suitable solution. Adaptation is exactly the driving force that can advantage HICEVs, as switching from diesel to hydrogen could be a straightforward way to decarbonize engines,

[21] Even if Nitrogen oxides (NOx) is not carbon-based, it is against emission regulations

with a relatively minor requirement for further technical innovation and capital expenditures (Fayaz et al, 2010). However, HICEVs presents the same problems of fuel cells in terms of production and distribution.

To conclude the paragraph, Table 2.1 summarizes the main aspects for each powertrain:

	Power Source	Strengths	Weaknesses
Hybrid Electric (HEVs)	*Main*: ICE + electric motor for swing function *Actuators:* Hydraulic (cylinders coordinated by a Main Control Valve)	▪ More efficient than ICE ▪ Lower emissions than ICE	▪ Issues of conventional powertrain is only partially solved ▪ Full electric architectures are more attractive
Full Electric (BEVs)	*Main*: Batteries + Electric motors *Actuators:* Hydraulic (cylinders coordinated by a Main Control Valve)	▪ High efficiency due to lack of ICE ▪ Zero emissions ▪ High productivity	▪ Still limited batteries' capability for higher power requirements ▪ Adequate charging infrastructure required
Fuel Cells Electric (FCEVs)	*Main:* Fuel cell (+ batteries) + Electric motors *Actuators:* Hydraulic (cylinders coordinated by a Main Control Valve)	▪ High efficiency due to lack of ICE ▪ Zero emissions ▪ High productivity	▪ Hydrogen production produce polluting emissions ▪ Delay in infrastructure development (hydrogen storage and transportation)
Pure Electric	*Main:* Batteries / Fuel Cells + Electric motors *Actuators:* Electro-mechanical (electric motors directly power actuators)	▪ Max efficiency due to lack of ICE and hydraulic systems ▪ Zero emissions	▪ Economic and technological obstacles for a wide EMAs adoption

Table 2.2: Strengths and Weaknesses of each powertrain technology

2.3 Market Outlook 2020-2030

Off-highway market outlook will mainly refer to the previously mentioned market research conducted by Interact Analysis. The company consider, for the electrification assessment, HEVs, BEVs and FCEVs[22], which have been defined later.

The global off highway vehicle market analysed by Interact Analysis highlighted total unit shipments of about 5.2 million in 2020, including excavators, loaders, bulldozers, dump truck, AWPs, telehandlers, forklifts, combines and tractors. The long-term growth rate (i.e. CAGR[23]) over the forecast period (from 2019 2029) is projected to be 3.6% in unit shipment terms, resulting in 7.1 million of units forecasted for 2029 (Fig. 2.12).

At 2029, e-powertrains are forecast to account for 36.8%, with a clear majority of BEVs (33.1%) followed by HEVs (2.23%) and FCEVs (1.45%), as expressed by Fig. 2.13.

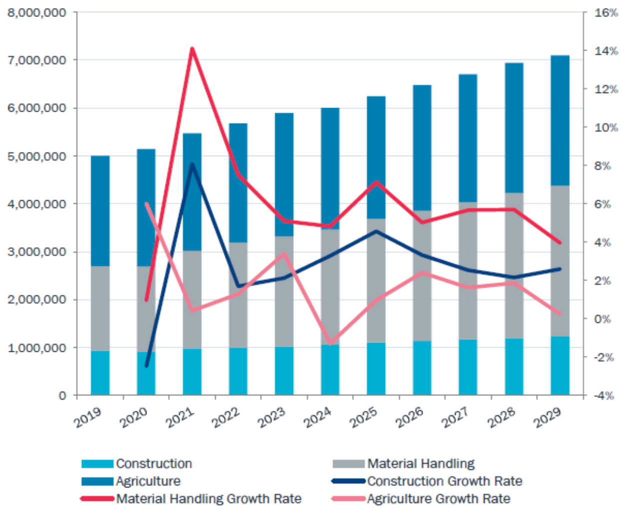


Fig. 2.12: Off-Highway Vehicle Market Forecast by Sector

	2020	2025	2029	CAGR
ICE	4,057,841	4,446,790	4,488,461	1.3%
Adoption Rate	*78.8%*	*71.1%*	*63.2%*	
Hybrid (HEV)	3,653	29,123	158,628	45.9%
Adoption Rate	*0.1%*	*0.5%*	*2%*	
Full Electric (BEV)	1,086,235	1,741,620	2,350,318	8.4%
Adoption Rate	*21.1%*	*27.8%*	*33.1%*	
Hydrogen (FCEV)	4,550	35,152	103,341	44.0%
Adoption Rate	*0.1%*	*0.6%*	*1.5%*	
Others	71	930	2,941	-
Adoption Rate	*0.0%*	*0.0%*	*0.0%*	
Total	5,152,350	6,253,616	7,103,688	3.6%

Fig, 2.13: Off-highway Vehicle Market Forecast by Powertrain

[22] Interact Analysis include also 'Others' as powertrain, defined as OHV using other power sources alongside an engine, could be tethered or cable electric systems. However, its rate is about 0.0% and it will be excluded.

[23] CAGR= compound annual growth rate (CAGR), is the rate of return that would be required for an investment to grow from its beginning balance to its ending balance, assuming the profits were reinvested at the end of each period of the investment's life span. It is used, as in this analysis, to make previsions.

As emerge from the graph, ICE powertrain will continue to be used in most applications for the foreseeable future. The exception is represented by material handling sector, which is currently extremely electrified, and the development of electric powertrains in its machinery will continue. Starting from the latter, all the three sectors' rate of electrification has to be reviewed, highlighting differences across applications within the same sector.

Material Handling

Material handling already has a long history of electrification. Its current electrification adoption rate is the highest among all three groups (more than 60% in 2020), and it is expected to reach 70% by 2029 (Fig. 2.14).The majority of equipment under this segment is compact equipment with power ratings under 75kW (99hp). These machines are more suited to adopt full battery electric solutions and are already seeing successful use cases and the associated economical sustainability benefits.

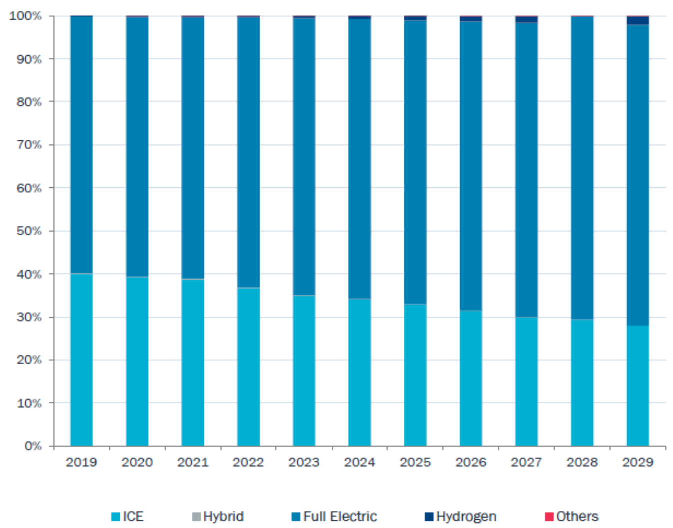


Fig. 2.14: Material Handling Market Forecast by Powertrain

For many of the environments where material handling typically works, such as airports, ports, large storage and logistics centres, there is higher demand for "greener" and cleaner equipment. It's easier to set up charging infrastructure or fuel cell stations around these places, and this imply an easier charging for material handling equipment and a decrease in overall operational costs. For example, port applications are a scenario that highly matches hydrogen energy. Coastal industrial areas can provide hydrogen sources and focus on the layout of hydrogenation infrastructure with cost advantages, forming a hydrogen energy system from hydrogen production, storage and transportation. There are already quite a few user cases of hydrogen fuel cell technologies in material handling applications where high intensity continuous operation is often required, but BEVs will be dominating. In particular, AWPs and forklifts have the highest electrification rate among all the applications. Conversely, the electric transition for telehandlers is more challenging as they generally are used continuously for longer periods of time and drive greater distances which can quickly drain battery power.

Construction

Construction electrification rate will grow up over the years, reaching a value of 10.2% for BEVs in 2029 (Fig. 2.15).

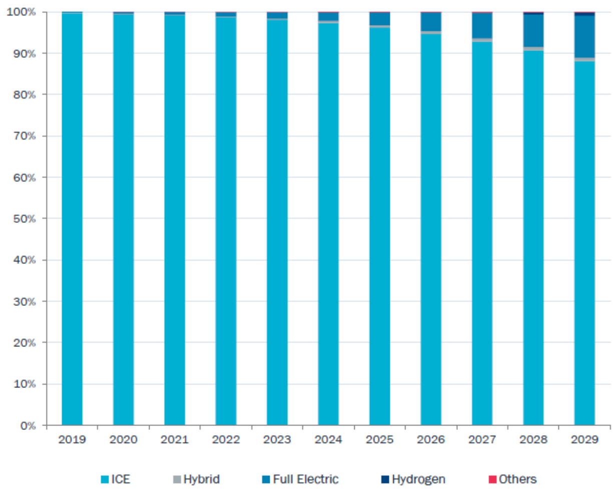


Fig. 2.15: Construction Market Forecast by Powertrain

Smaller equipment is where much of the initial focus is being placed for electrification of construction equipment, as well as hybrid powertrains which use electric power for lighter work and a combustion engine for maximum power. There is an increased interest and acceptance of electrified compact machine among users. This allows the equipment to be used in more environments including inside buildings, inner city work sites, and other noise sensitive areas. Battery technology suits better smaller machines due to the lower power demands.

However, there is also a development of electrification in medium sized construction equipment (e.g. excavator over 20 tons). In addition to reduction in fuel consumption and energy efficiency, which is one of a key consideration, lower operating costs as well as lower maintenance costs are the additional benefits electric construction equipment can provide. Excavator is the largest product group in the construction segment, accounting for over 50% of units shipped in 2020. Electrified excavators will achieve a penetration rate of 13% in 2029 of global excavator sales, with many more OEMs that are planning to produce with electric models. Fig. 2.16 details the electrification rate for different classes (weight size[24]) of excavator.

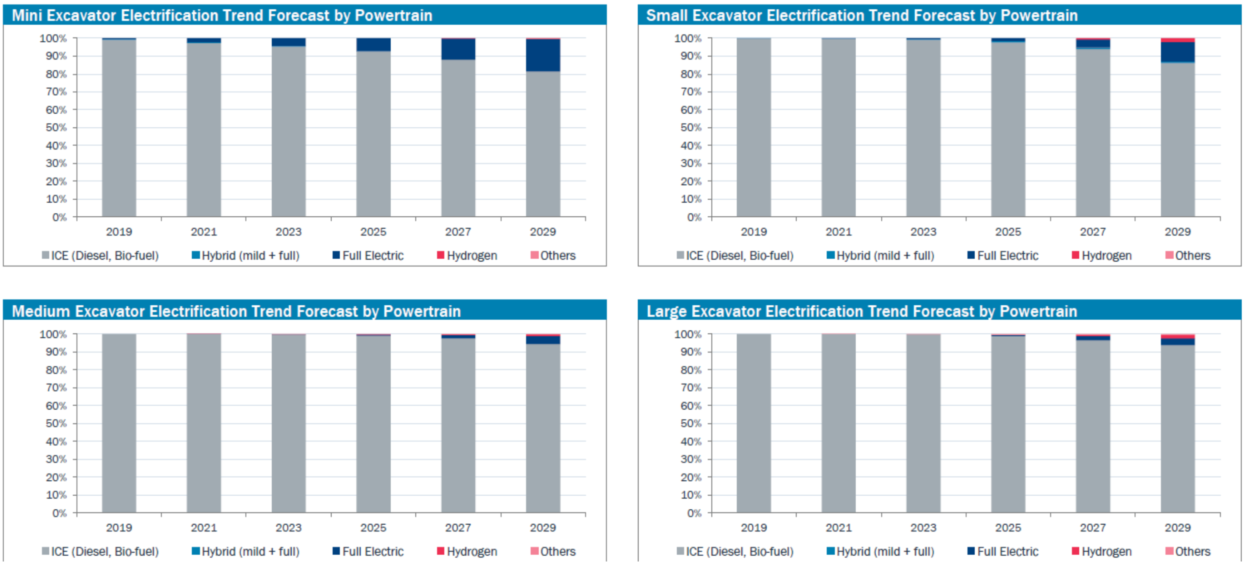


Fig. 2.16: Excavator Market Electrification Trend Forecast by size classes

As excavators have been used in many different applications and environments, covering a broad range of power ratings (e.g. from less than 37kW, to over 225kW) this category has experimented almost all the various electric options illustrated in the previous paragraph. It's impossible to have a generic solution that fits all excavators, but this is the segment that will get most attention from both OEM and component suppliers to prove technology. Mini excavators will be a prime candidate to be electrified. This category is forecast to have the highest penetration rate of 18.6% in 2029 with thousands of BEVs already available in the market. Indeed, the larger the excavator, the more challenges for electrification in terms of battery capacity, output and operating time per charge. Not to mention that large excavators are typically used in places where less strict emission

[24] Mini excavator (<6tons), Small (6-13tons), Medium (13-30tons), Large (>30tons)

standards are in place, so there is a less motivation to shift towards electrified vehicles. This category is forecast to have the lowest penetration rate of 6.2% in 2029. Concerning powertrain technology, in the past there was a big focus on hybrid configurations equipped with electric swing for energy saving, while now there is a trend moving to full battery electric, with leading suppliers like Volvo, Komatsu, XCMG looking into this option.

Agriculture

Agriculture machine sector forecasts for applications taken into considerario by Interact Analysis (tractors and combines) are portrayed in Fig. 2.17.

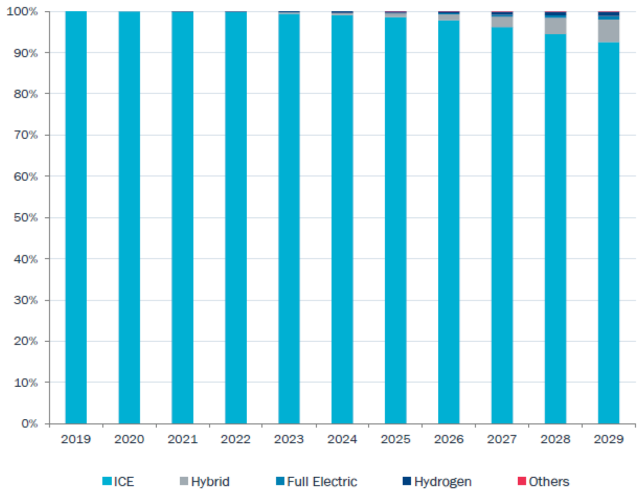


Fig. 2.17: Agricultural Market Forecast by Powertrain

As shown, it is the only sector in which hybrid powertrains are expected to be more than full electric. The reason lies in the fact that pushing for low or zero emission agricultural machinery would, in all probability, be more expensive that its polluting equivalent. Given the fact that most new tractors are sold into developing countries (embracing mechanization), pushing a high cost burden on to food producers may reduce crop production (less mechanization) and increase food prices, disproportionately affecting the poorest individuals. It may be better to focus, for example, on more efficient use of fertlisers which would simultaneously improve crop outputs, reduce farm costs and recue agricultural emissions. Despite this moral and social factor, some leading manufacturers such as as AGCO and John Deere are pushing ahead with battery electric tractors. In Western Europe and North America, the demand from sustainable farms/farmers for

more environmental-friendly equipment push for the replacement of diesel engines. However, demand will likely remain low because these types of farm remain relatively niche and the high price will deter many buyers.
Differently from tractors, combines probably represent the worst electrified opportunity. Not only do they typically have a high intensity duty cycle because they both move and require powered implements, but they are not used for a large period of time so there is very little benefit to be achieved through fuel savings either by moving electric or employing hybrid technology.

Power Rating

A final consideration must be undertaken on power ratings. Fig. 2.18 details power rating degrees for each off-highway application at 2019.

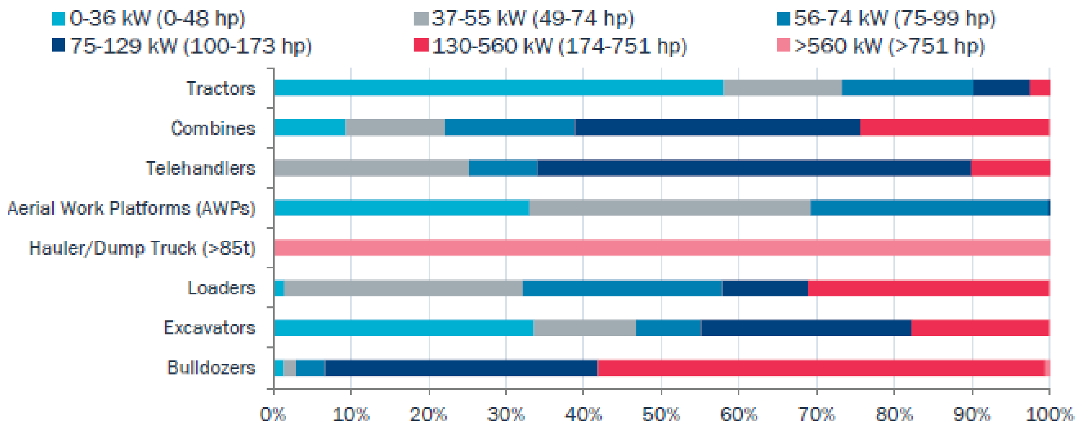


Fig. 2.18: Off-highway Power Rating by Application -2019

For the market analysed, low-power rating (considered as <55kW) types accounted for over 60% of the total volumes, with the majority of them being tractors, AWPs and mini excavators. Mid-power and high-power rating groups mainly consist of heavy duty construction equipment such as hydraulic excavators and wheel loaders (>80hp).
Although there is not necessarily a generic form for the development of electrification for each power rating group, they do follow some trends.
Low power rating fast mover to electrified powertrains, although tractors are exceptional as most users are price sensitive. Mini excavators will be in this sense the best and first example of electrification transition for OHVs, material handling applications excluded.

Mid and high-power rating classes comprise heavier vehicles that quite often require high peak power/torque to carry out their duty cycle. Energy efficiency and lower operational costs are even more important for high-power rating vehicles. However, electric technology must pass first from smaller weight and power sizes, because to electrify heavier applications, costs and power capacity make them still an unsustainable solution.

Concluding, market forecasts have confirmed how hybrid powertrains are just an intermediate passage from ICE to full electric. Considering the technological development resulting from other sectors, HEVs will never gain large share of diffusion in off-highway industry, while the powertrain transition will directly move from ICEs to BEVs.
Regarding FCEVs, they belong to the same field of BEVs, but delays in the infrastructure development for hydrogen keep its application to OHVs slow.

3. Innovation Management Framework

After having illustrated market scenarios and before analysing the specific effects on the case study, a theoretical step is required. A theoretical overview allows a greater understanding of the phenomenon and its business implications for companies involved. The first paragraph will report the innovation theories and the following classifications, with the aim of framing what kind of change is caused by a powertrain technology transition. The second section will describe the structure of the off-highway industry supply chain, highlighting the evolution of suppliers' role and the deriving sources of innovation. The third chapter will continue the innovative debate presenting potential open innovation strategies, considered a valuable way to carry out innovative processes.

3.1 Theoretical Overview on Innovation

The electric transition of OHVs has to be examined within the innovation management framework. Nowadays, globalization of the markets has created an international competitive arena which put pressure on companies to continuously innovate. Producing differentiated products and services is the only way to cope with a turbulent environment, characterized by saturated markets, shorter product lifecycles and high-price competition (Schilling, 2017). Thus, innovation is considered the main source of competitive advantage in many industries.

The common thread to deepen the innovation field has been the introduction, in the second chapter, of the *strategic inflection point* concept by Grove. As a CEO of Intel Corporation, he conceived this term based on academic theories which over the years have contributed to the study of innovation management.

Innovation derives from the Latin "*innovare*", which literally means "to make something new". While invention refers to the mere discovery or creation of something new, innovation apply and integrate the novelty at firm level in order to make it commercially available.

3.1.1 Technological Innovation patterns

Technology-driven innovations have always received great attention from scholars, because their impact can heavily alter the usual way to conduct business (Schilling, 2017). As expressed by Grove's strategic inflection point, technological changes have the power to revolutionize the competitive environment. Obviously, there are industries for which managing technology innovation is more crucial because they depend heavily on new technologies (Shane, 2008). Remaining in the computer industry, technological advances around the 70s led to the proliferation of personal computers, as opposed to traditional mainframes. This results in the repositioning of different companies in favour of emerging technology trends. For example, Andy Grove's Intel was forced to shift from its traditional core business of memory chips to microprocessors, due to Japanese semiconductor manufacturers' low-price competition and the window opportunity in PC diffusion. Thanks to its strong tie with IBM, one of the pioneers of the new personal computer technology, Intel was able to build a stable source of profit through the supply of microprocessors (Grove, 1996).

In the automotive industry, technological innovation is a crucial process through which companies create competitive advantage. Alternative powertrain technologies and, more in general, the process of electrification, are examples of innovations capable to disrupt the conventional technology paradigm on which OEMs rely. Regardless the type of vehicle (e.g. from passenger cars to OHVs), a change in powertrain technology have great implications for the entire supply chain (Mckinsey, 2021-a).

In management literature the diffusion of technologies in the market is commonly described through an S-shaped curve (Fig. 3.1).

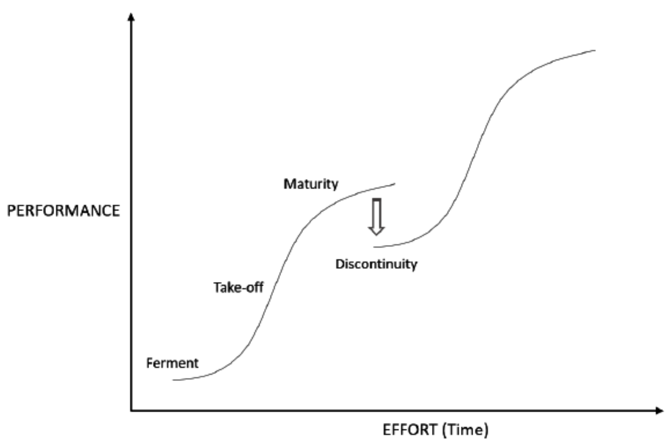


Fig. 3.1: S-curve of Technological discontinuity

Following the graph, a technology pass through the ferment stage, ruled by the typical uncertainty and risk associated with every innovation process, then it grows (i.e. take-off) when it's able to overcome investments' barrier, until it reaches a maturity level. Before the current technology reaches its limit, it might be replaced by new discontinuous ones (Shane, 2009). In the literature on innovation and technology development, technological discontinuities can lead to intensified technological competition or even to a complete breakdown of competitive dynamics (Abernathy and Clark, 1985). Later in the chapter concepts such as competence-destroying and disruptive innovations will be used to describe. When technological innovations have disruptive and competence-destroying characteristics, major challenges arise for established firms that want to survive.

Another graphical representation related to technological innovation has been introduced by Rogers. The innovation adaptation curve describes how a new technology is accepted by customers, by matching the total numbers of adopters and the range of time from the first introduction (Fig. 3.2).

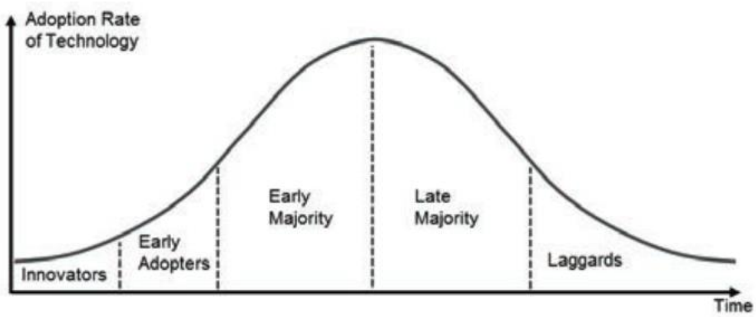


Fig. 3.2: Innovation Adoption curve for a new technology

The adoption rate measures the diffusion of a technology in the market (Rogers, 2003). This is exactly what it has been done in the previous chapter, collecting the different adoption rates to highlight powertrain technologies' forecasted diffusion. At the beginning, which corresponds to the ferment stage of Fig. 3.1, customers are still unfamiliar with the new technology, characterized by high financial requirements and unknown performances. From the producers' point of view, high investments and new organizational capabilities to manage the new technology are forces that slow the innovative process. When the technology starts to be more widely accepted, the adoption rate accelerates as it approaches the mass market. At the end, the market become saturated and the adoption rate declines.

According to many authors, the difficulties of early stages of technology diffusion derive from established companies' reluctance to switch to the new technology. Conversely, the new technology is more likely chosen by new players rather than incumbents (Schilling, 2017). Different academic contributions share the common assumption that industry incumbents are burdened with core rigidities and the legacy of old technology (Leonard-Barton, 1992). One of the most famous contributor of innovation theories, Joseph Schumpeter, recognized the revolutionary aspect of technological innovations with its concept "*creative destruction*". For the author, innovation has the force to destroy the old context and create a completely new one. The triggered dynamic brings to the birth of new companies offering innovative solution, but it also leads to collapse who fail to react to the novelty (Schumpeter, 1942). However, there are also authors who deny the threats produced by technological discontinuities against incumbents. They recognize that knowledge base and experience acquired over the years make established firms capable to capture the new technology innovation and to integrate it into its existing business (Bergek et al, 2013). The resulting reality is that there are no pre-announced winners in the uncertain world of technology innovations. What is important is understanding the relevance that these latter have on business dynamics. As Grove wanted to notice with his strategic inflection point, companies must be prepared to react to new technologies, analysing their progress through tools such as the two curves just mentioned. Market data illustrated in chapter two has shown that electric cars have reached the inflection point, meaning that OEMs and suppliers cannot rely anymore only on ICE-powered vehicles. Although full electric powertrain seems destined to become the major choice among alternative sources, managers (of both OEMs and suppliers) have to study the pattern of each technologies' diffusion.

3.1.2 Types of Innovation

In this paragraph different classification of innovation, often interrelated, will be detailed. The final goal, which will be part of the next chapter, lies in classifying the OHVs' electrification technology innovation according to academic concepts, in order to obtain a broader and more comprehensive vision of the phenomenon. The properties embedded in the resulting type of innovation, can offer guidelines on how to manage the shift from a business point of view.

Product vs Process Innovation

The classification by nature of innovation divides between product and process innovation (Schumpeter, 1934). A *product innovation* involves the development and subsequent commercialization of completely new or simply improved products and services. *Process innovation*, instead, involves new procedures and techniques implemented to improve the effectiveness of production process. While the former focuses on companies' outcome, the latter concerns how organizations operate for their business, including any improvements in functions such as manufacturing, delivery, marketing, etc (Vaughan, 2013). Product and process innovation may occur in tandem: sometimes a new process may bring new product development and, viceversa, a new product development may enable the design of a new production process.

Competence-Enhancing vs Competence-Destroying Innovation

Innovations can also be categorized according to the effects they imply on competences already in use by the company. *Competence-enhancing innovations* refine and improve internal competences. These types of innovations are built on firm's existing knowledge base, production processes, design capabilities, leveraging and reinforcing them (Tushman and Anderson, 1986). In contrast, *competence-destroying innovations* are based on skills different from companies' ones, which can become even obsolete.

As anticipated earlier, established firms have no problems in shifting to a new technology when that technology is competence-enhancing, but they may fail when it is competence-destroying. This debate is strictly connected with radical and disruptive innovation.

Radical vs Incremental Innovation

A fundamental classification is based on the breadth and intensity of the innovation: the degree of which a selected innovation is different from previous solutions or practices implemented by the company (Dewar and Dutton, 1986).

Incremental innovations introduce minor changes to existing products or processes, which don't bring great originality and don't require challenging investments. They involve sequential improvements that are considered to strengthen firm knowledge (i.e. competence-enhancing), simply responding to market-pull needs. On the other hand, *radical innovations* lead to very different solutions, which are often rooted in a different set of engineering and scientific principles, leading to a completely new knowledge base (i.e. competence-destroying). Radical innovations are risky for a company because they imply higher degree of uncertainty and additional costs to be undertaken. Anyway, they have the breadth to open up whole new markets and to irreversibly alter the competitive landscape of an industry. Taking up the previous discussion about the effects of technological discontinuities on established firms, radical innovations create major problems for incumbents. By allowing the foundation of new enters, displacing current products, creating new product category, or altering the supply relationships, radical innovations have the power to redefine a whole industry. This is what happened when industrial revolutions, a main example of radical innovation, occurred. However, the degree of radicalness obviously can change: an innovation emerged in the market as radical may become incremental with the flows of the time and as the knowledge base underlying this innovation becomes common (Schilling, 2017).

Architectural vs Modular Innovation

The debate about established firms' ability to manage the impact of different types of innovations, has been extended by Henderson and Clark (1990). Based on the idea that a product could be considered as a system composed of a certain number of components[25], they argued that there are two main types of innovation. *Architectural innovation* is a kind of innovation that changes the way in which components of the product are integrated[26], leaving the core design concept intact. This type of innovation destroys the usefulness of

[25] A component is a physically distinct portion of product that embodies a core design concept and perform a well-defined function (e.g. a motor of a vehicle is the component that delivers power to run it)

[26] A product architecture is the way in which components are integrated, the configuration of its functional elements

a company's architectural knowledge but preserves the knowledge of the core design concepts behind each single component (i.e. component knowledge). Instead, a *modular (or component) innovation* is a type of innovation that entails changes to one or more components, but it doesn't significantly affect the overall product architecture. However, these innovations often occur at the same time: the majority of architectural innovations not only imply changes in the system but also in the components underlying it. For the authors, a successful product development requires to know both the core design concepts and how they are applied in a particular component, and the product architecture in which different components are integrated. The distinction between architectural and component knowledge gives rise to the two innovations mentioned, which are added to incremental and radical types in the innovation matrix conceived by Henderson and Clark (Fig. 3.3):

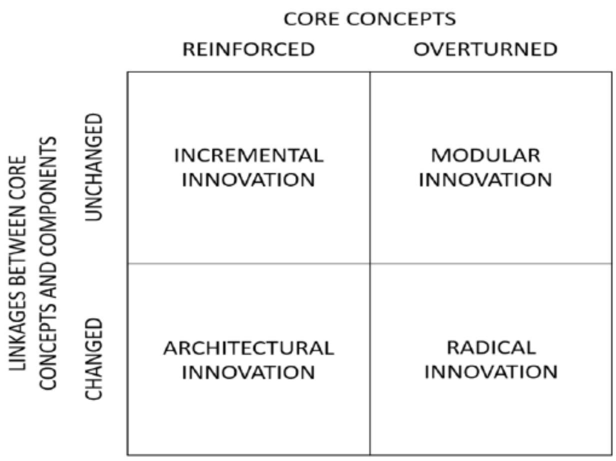


Fig. 3.3: The Innovation Matrix

The horizontal axis captures the impact on components, whose core design concepts are overturned in case of modular innovations. The vertical axis measures the impact on the linkages between the components to integrate, which are changed when an architectural innovation occurs. The matrix confirms the idea of other authors about the impact on incumbents' competencies of radical and incremental innovations, which are now investigated through the lens of product development knowledge. Incremental innovations strengthen the competitive positions of established firms by extending existing competencies, with components' core design and architecture unchanged. Radical innovations, instead, totally destroys both component and architectural knowledge, creating unmistakable challenges for established companies (Henderson and

Clark, 1990). Concluding, rather than highlighting the unquestionable destructive effect of radical innovation, the contribution of the authors is directed to warn managers of established firms about the challenges of architectural innovation. Since this latter tends to be embedded in the practices and procedures of industries, recognizing which resources, knowledge and skills are useful and which are not is a crucial battle for incumbents. Once again, new players find easier to build new architectural knowledge because they are no anchored to previous competencies which may handicap the innovation management, they have more organizational flexibility.

Disruptive and Sustaining Innovation

The distinction between disruptive and sustaining innovation is another dichotomy which describes how the degree of innovations impact the incumbents' stability.

Sustaining innovations reinforce the established companies' skills and processes, by giving customers something more or better in the performance attribute they already value. This type of innovation is normally introduced by leading companies to enlarge their traditional market (Christensen and Rosenbloom, 1995). At the other extreme, *disruptive innovations* imply a different package of performance attributes provided by mainstream technologies. As argued by Christensen (1997), disruptive technologies are innovations that might underperform with respect to the existing products, at least in the short term. When firstly introduced, these innovations target a market niche, having diversified features not intended to satisfy the needs of existing customer base. Over time disruptive innovations manage to expand throughout the overall market, ousting products or services that have occupied the leading role until then. Disruptive innovations are most often pioneered by new entrants and tend to be ignored initially by incumbents, for whom they are financially unattractive relative to existing business models (Christensen, 1997).

Indeed, it is reasonable to stress the fact that disruptive innovations, more than other extreme type of innovation such as radical and competence-destroying, are not referred just to a product / service or a technology. The disruption applies to the business model dimensions, resulting in innovative business models different from the ones adopted by incumbents (Christensen and Raynor, 2003). This brings to the last topic covered in this chapter.

3.1.3 Business Model Innovation

Innovation scholars agree that innovation often requires the company to adapt or redesign its business model (Christensen, 1997; Teece et al, 1997; Adner and Kapoor, 2010). Henry Chesbrough, who will be presented later in the chapter as the father of open innovation concept, claimed that "a mediocre technology pursued within a great business model may be more valuable that a great technology exploited via a mediocre business model" (Chesbrough, 2010). Before analysing the business model innovation phenomenon, it is necessary to have a clear comprehension of what is business model.
A business model describes the rationale of how an organization creates, delivers, and captures value (Osterwalder and Pigneur, 2009). Osterwalder proposed a strategic management template, called Business Model Canvas, to design and develop business models. The Business Model Canvas (Fig. 3.4) comprises nine building blocks:

- *Value Proposition*: bundle of products / services creating value for customers
- *Customer Segments*: from whom the company is creating value
- *Channels:* how the company delivers value to its customers
- *Customer Relationships*: type of relationship established with customers
- *Key Resources*: most important assets to implement the business model
- *Key Activities*: most important activities to implement the business model
- *Key Partnerships*: network of suppliers and partners to implement the business model
- *Revenue Streams*: the cash a company generates from each customer segments
- *Cost Structure*: all costs incurred to operate the business model

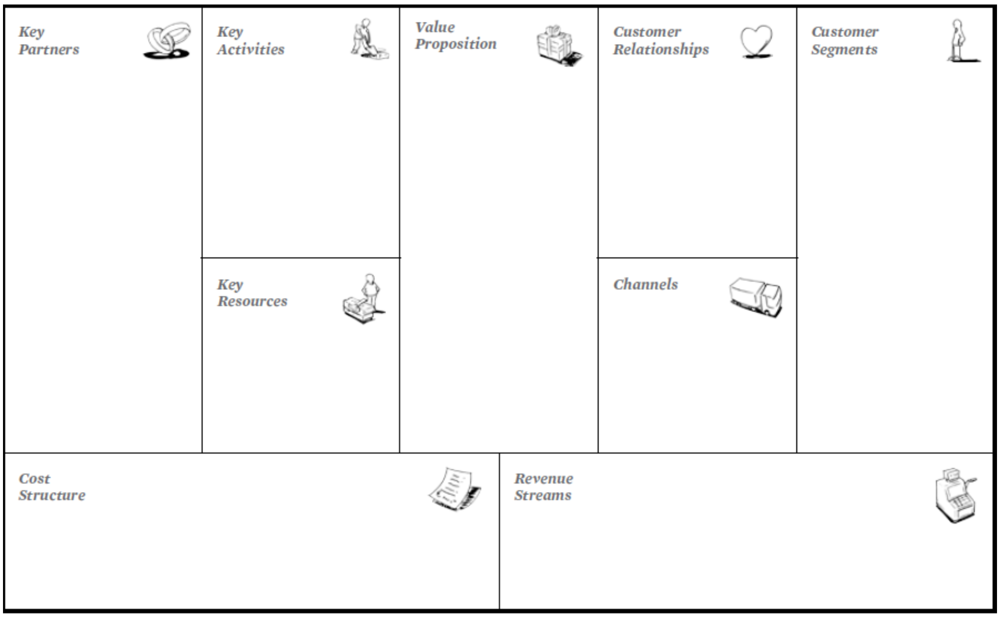


Fig. 3.4: The Business Model Canvas

The nine blocks are interdependent with each other. The value proposition expresses the reason why customers turn to one company over another. It satisfies the needs of customers, which are identified by the customer interface (i.e. customer segments, relationships and distributional channels to reach them). The so-called infrastructure management pillar includes the key activities, resources and partners. It represents the means by which companies can create and deliver the value proposition to customers. Companies can either rely on internal resources and operating activities by leveraging internal know-how, or they can establish collaborative partnerships to acquire new sources of competencies. The fourth pillar comprises the revenue streams and cost structure, which give information about the economic viability of the business model.

The comprehension of the business model concept is important because it offers a powerful tool for management to optimize decisions, for example on how to react to external pressures and innovative forces (Chesbrough and Rosenbloom, 2002).

It can help to identify how to innovate and serve as a guide in planning and implementing the change (Osterwalder et al, 2005). This is exactly what Chesbrough wanted to highlight in his quote: “a company has at least as much value to gain from developing an innovative new business model as from developing an innovative new technology” (Chesbrough, 2010). This idea acknowledges business model as a source of innovation. According to Boston Consulting Group (2018), *business model innovation* can deliver more lasting competitive advantage in disruptive times than innovations concerning products and services. Business model innovation is the process of enhancing advantage and value creation by making simultaneous changes to the organization's value proposition and to its underlying operating model. The innovation may bring to entirely new business models (e.g. start-up model), to the diversification through additional business models, to the acquisition (and integration) of new business models, or to the transformation from one business model to another (BCG, 2018). The object of the transformation process can be the whole system or just single building blocks. Both the academic and business world agree that frequent business model innovations allow companies to enhance their resistance to changes like technological discontinuities or disruptive innovation, adapting competencies to embrace new opportunities (Teece, 2017).

3.2 The Off-Highway Industry Supply Chain

The study of the supply chain is strategically determinant to understand the dynamics inside an industry, especially if the product is complex and constituted by several sub-components such as in automotive industry.

In this paragraph, a brief overview of off-highway vehicles' supply chain will be described, focusing on the evolution of suppliers – OEMs relationship and how this affects their role on innovation. Most of references and studies utilized in the following discussion belongs to automotive industry. However, supply chains of OHVs share the same characteristics of passenger cars' ones. Some main players, both from the OEMs and supplier' side, operate indistinctly on different categories of vehicles. For example, Volvo Group operates in off-highway market through its Volvo Construction Equipment division, the same for Hyundai, while Toyota is one of the world leading producer of forklifts. As for their customers, suppliers such as Bosch, ZF Friedrichshafen and Cummins are engaged on the manufacturing and supply of components not only for automotive vehicles, but also for OHVs.

3.2.1 Evolution of Suppliers' Role

The automotive industry is made of OEMs assembling the finished product and a multitude of suppliers, that can be classified in sequential tiers based on the level of provision they served. Tier 1 suppliers are those who are directly linked to the OEM, with whom they supply complex components or even integrated systems underlying specific functions of the vehicle (e.g. the brake system). Tier 2 suppliers are those companies that don't have a direct relationship with the OEM: they provide sub-components to tier 1 suppliers. Based on the product complexity and raw materials' requirement there can be other levels beyond second tier.

Suppliers' role has evolved along with the managerial and organizational principle that have characterized the history. Henry Ford introduced the Fordism phenomenon in 1913, providing a set of rules and techniques to enhance the manufacturing process, reaching the mass production. The emerging "*assembly line"* relied on the vertical integration of production: the product moves through various subsequent stations inside the plant, from the development to the final assembly. In this organization, everything is carried on inside the company, which own the whole supply chain.

A new production system was conceived by Toyota, driven by the pursuit of waste elimination (i.e. lean production). Through its "*just-in-time*" approach, the production process moved from a push attitude to a pull one: the whole production system is based exclusively on market needs in order to enhance organizational flexibility and efficiency. To respond quickly to changing market requests, companies must rely on external specialized suppliers, which hold specialized competencies. In the Japanese *keiretsu* systems, of which Toyota is the most famous example, OEMs and suppliers are tightly interrelated and integrated in a network system (Dyer, 1996). In these production systems, managing suppliers' relationships become a strategic source to improve competitive position of car manufacturers (Moretti and Zirpoli, 2017). Differently from vertical integration systems, part of responsibilities shift to the suppliers' side, and a mutual dependency exists between OEMs and their suppliers. As a consequence, nowadays suppliers are no longer considered as mere component manufacturers, but as strategic partner in the creation of innovative products (Wognum et al, 2002). The level of interaction between OEMs and their tier 1 supplier has increased significantly over time, blurring the lines between the two identities (Oliver Wyman, 2018)

Some of the tier 1 suppliers evolved into so-called mega-suppliers (tier 0.5), taking over full development and logistical integration of comprehensive modules for OEMs (i.e. system integration) (Wang 2014). This tier of suppliers is based on long-term strategic relationships which can be favoured by ownership links, such as Denso supply relationship with Toyota. Fig. 3.5 shows the pyramid of automotive supply chains' actors.

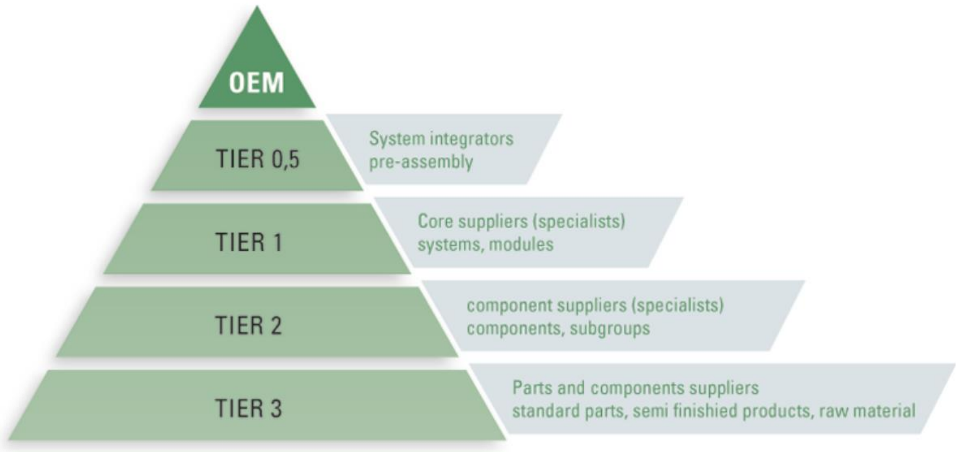


Fig. 3.5: Automotive Supply Chain pyramid

3.2.2 Modularity and Outsourcing

Japanese network systems have been essential for the shift in supply relationships, enabling suppliers to attain a great strategic relevance. Anyway, two trends affecting the whole production process, strictly interrelated each other, contributed to shape the automotive industry's supply chain: outsourcing and modularity.

Outsourcing

One of the most crucial point of a company's business strategy is the *make-or-buy decision*: manufacturing a product in-house or purchasing it from external supplier. The first alternative, the so-called *vertical integration* described earlier, guarantees a total control on the production process but requires a deep knowledge and huge financial and organizational capabilities. Indeed, recent evolutions of markets and the related implementation of new technologies, made risky or even not sustainable to concentrate the production totally in-house. *Outsourcing* refers to the second alternative, meaning a process through which components are commissioned to other companies to lower costs and reduce complexity (Schilling, 2017). The outsourcing trend follows the processes of de-verticalization and specialization of suppliers driven by Japanese production systems, with evident benefits to the supply-side which acquire a higher negotiation power. From the OEM-side the benefit assessment is harder. On one side, outsourcing activities allows the firm to concentrate the efforts in terms of investment, design and R&D on its core business. At the same time, it can exploit the technological expertise of its specialized suppliers. On the other side, by delegating specialistic part to third parties, companies may incur in competence loss in R&D and in the overall knowledge base (Takeishi, 2002). A long-run outsourcing weakens the firm's ability to understand the core designs underlying different components, besides the way these latter are integrated in the final product. Consequently, outsourcing can threaten both the component knowledge and the architectural knowledge, preventing a right learning-by-doing process that is relevant to assimilate new knowledge (Zirpoli and Becker, 2011). As it has been argued, the two mentioned types of knowledge are required to enable a proper product development, meaning that OEMs heavily reliant on outsourcing can struggle to design new products and to respond to innovation pressure.

Modularity

The concept of modularity starts from the assumption that complex products such as automobiles can be viewed as systems comprising a large number of components with many interactions among them (i.e. product architecture) (Ulrich, 1995).

Modularity refers to the way systems' components can be decomposed into different parts or modules (Cabigiosu et al, 2012). The benefits of modularity derive from the decomposition of the production process into simpler and standard units (modules) that can be managed independently by different companies, each one adding value to the final output (Baldwin and Clark, 1997). Every module carries out a specific function independently from other parts of the system. The independence can be obtained by defining *ex ante* the interfaces of each module, allowing an isolation of production and time saving on information coordination. Modular strategies in product development allows to exploit the efficiency and reliability of components' standardization, without giving up the flexibility to recombine the final product into customizable configurations

(Sanchez and Mahoney, 1996). Furthermore, since qualified suppliers handle a specific module, the production process is shortened and improved in terms of quality.
As reported by Baldwin and Clark, the computer industry has dramatically increased its rate of innovation through a widespread adoption of modular designs. By breaking up a product into subsystems, companies reduce complexity in the production process and gain the flexibility required to cope with change. Especially in industry characterized by high degree of technology discontinuity and consequent sophisticated products, such as computer and automotive industry, modularity offers an invaluable weapon to follow up the pace of innovation. In the automotive industry, OEMs usually organize the manufacturing in different modules for each component of the car, which in the end are assembled together to realize the final product. Apart from its advantages, modularity has also potential drawbacks, which are the same resulting from outsourcing practices. The potentially high dependency on external resources (e.g. modules in this case) may enhance the vulnerability of OEMs in negotiations (Clark and Fujimoto, 1991). Furthermore, as argued for outsourcing, if the modular knowledge and its related competencies are delegated to third parties, the overall architecture knowledge would decrease. The loss of competencies can make harder the comprehension of the way components are integrated.

Outsourcing and modularization represent two sides of the same coin representing the de-verticalization and suppliers' specialization process that have affected the automotive industry. These two trends are mutually reinforcing: once managers decide to allocate in outsourcing the production, the degree of modularity of vehicle's components becomes of growing importance. Modularity is believed to help firms in managing outsourcing efficiently and effectively, thus facilitating the integration of external sources of innovation. An optimal solution to solve the potential drawbacks of these two trends lies in establishing in-depth cooperative relationships with ever stronger suppliers, involving them not only in production process but also in the product development phase.
Strategic collaborations, that will be treated in the next paragraph, represent a suitable way to share knowledge and divide the efforts of innovation processes between suppliers and OEMs.

3.3 Open Innovation across Supply Chain

In the previous paragraph it has been described how the evolution of production systems towards networks of companies (i.e. Japanese *keiretsu*), alongside the correlated modularity and outsourcing trends, led to a new role of suppliers. They moved from merely producing parts to also developing them, since they are often involved in new product development projects already during the design phase (Wognum et al, 2002). However, for the mutual dependency relationship to be successful, it might be necessary to establish an open innovation system. Through inter-firm collaborations it is possible to avoid the potential competencies' loss incurring when production processes are outsourced to specialized third parties. For this reason, this paragraph will review the concept of open innovation and its benefits. Within open innovation domain, the main strategies of collaborations will be detailed, together with the effect caused on companies involved.

3.3.1 Open Innovation: benefits and strategies

In the face of increasing global competition, shortening product lifecycles and the pressure of constantly evolving technologies, companies realized that innovation cannot result only from leveraging internal competencies (Chesbrough, 2003). A closed innovation system in which new product development arise only from a centralized R&D function embedded in a vertically integrated production system, is not capable to respond to the dynamic environment. This forces organizations to consider both internal and external sources of innovation. As a result, collaborating with those who possess external sources of knowledge is decisive to access the competencies required to boost innovation processes (Chesbrough, 2003).
Henry Chesbrough, considered the father of open innovation, defined the concept as "the use of purposive inflows and outflows of knowledge to accelerate internal innovation, and expand the markets for external use of innovation, respectively" (Chesbrough, 2006). This definition assumes that open innovation encompasses both the internal use of the acquired external knowledge (i.e. inbound open innovation) and the inside-out shift of internal unused capabilities in favour of the whole market (i.e. outbound open

innovation). However, the second interpretation is still less explored and riskier compared to the outside-in knowledge shift of inbound open innovation. Inbound open innovation strategies, instead, are universally considered as an easier and profitable way to innovate.

Benefits of open innovation adoption

The benefits that open innovation strategies can offer are summarized as follows:

- R&D costs decrease due to the access to external knowledge, which allows to focus on core competencies while filling gaps with the new knowledge absorbed through the collaboration
- Investments and risks related to manufacturing and financial efforts, which are normally high for uncertain innovation processes, can be shared among parties
- The incorporation of specialized third companies early in the product development process imply a reduced time-to-market[27] and more differentiated products, must-have factors in turbulent competitive environments
- Quicker adoption of new emerging technologies
- Potential to enter new markets, alternative or substitute of current ones, that may otherwise have been inaccessible

The overall advantage of deploying an open innovation strategy lies in the greater innovation capabilities resulting from internal and external sources of knowledge, which in turn entails the several benefits listed (Laursen and Salter, 2006).

Inbound open innovation strategies comprise different form of collaboration networks. The most used criteria to classify them is based on the partners' position in the value chain, which determines a horizontal, vertical or lateral direction of collaboration (Solaimani and Van der Veen, 2021). *Horizontal* networks involve firms belonging to the same industry on the same level of the value. This is the case of collaborations between two or more OEMs, or between suppliers of the same tier. The *horizontal* direction means that participating firms are direct competitors, increasing the danger of conflicts of interest. *Lateral* networks, the most extreme direction of collaboration, comprise firms which are neither part of the same industry nor on the same value chain level. Despite the

[27] The time-to-market refers the time from which the company conceive a product to its availability for sale in the market

distance, this type of collaborations may be strongly useful for innovation purpose by exploiting knowledge complementary to business purposes. This can be the case of companies in the electronics industry providing batteries to major automotive OEMs for the electric vehicles' transition. Panasonic, for example, is a major partner of Tesla for the development of its innovative EVs. Notwithstanding, the most popular and easier form of collaboration is the *vertical* network. In the automotive value chain, in particular, the vertical collaborations between OEMs and tier 1 suppliers are quite diffuse because compared to other sub-tier suppliers they have a great innovativeness. OEMs identify and select innovative suppliers, effectively integrate them into their product development process, and then collaborate with them to develop and commercialize an innovation. As argued when dealing with the suppliers' role evolution, the relationship is not one-side. The relationship concerning OEM's pull-innovation and suppliers' passive fulfilment doesn't work anymore: specialized supplier can rely on push-innovation capabilities which guarantee them a greater market power in the selection about which customers to cooperate with. Ultimately, suppliers' innovativeness enhances OEMs total innovation performance and is an essential source of both product and process innovations (Kurpjuweit et al, 2018).

Open Innovation Strategies

For the purpose of this thesis, the forms of collaboration among companies taken into consideration are licensing, joint ventures and co-development activities. Collaborative relationships become even more important in high-tech industries. In these industries, as for automotive, it is more difficult to realize innovations using only internal resources (Hagedoorn, 2002).

Through *licensing*, for example, a party (i.e. licensee) can obtain the legal right to use a certain intellectual knowledge (e.g. a copyright, a brand name, a patented invention) from the granter (i.e. licensor). In this way the licensee can acquire quickly a proven technology, or a competence which it doesn't have, avoiding the cost of time, resources and investments required to develop it internally. Frequently, the licensed technology is disseminated to several other parties, so it is unlikely to constitute a competitive advantage for the single license (Schilling, 2017).

A longer and more structured form collaboration is represented by *joint ventures*. Joint ventures are temporary strategic alliances which imply the creation of separated business entity. They are established for the purpose of carrying out a project, to access new emerging markets or simply to share knowledge and investments. It is generally characterized by shared ownership and governance, which may arise conflicts far superior to other collaborations strategies (Schilling, 2017)

Authors are used to include *outsourcing* as a way to collaborate. However, since this thesis refers to automotive supply chain, the outsourcing activity is something inherent in the industry. Outsourcing has already been treated as a major trend characterizing OEM-supplier relationship. What is different, instead, is a *co-development partnership* between these two actors within a supply chain. Collaboration partnerships perfectly match the open innovation field, concerning the use of external skilled companies to enhance the product development performance. The collaboration goes from the conceptualization to the market entry of a product, service or technology. Rather than relying only on internal R&D efforts, by adopting co-developing partnerships is possible to leverage the capabilities of partner firms (Chesbrough and Schwartz, 2007).

3.3.2 Organization Alignment towards Open Innovation

While several literature contributions have stressed the advantages arising from the adoption of open innovation strategies, companies involved may benefit disproportionately or even not benefit at all from the collaboration (Saebi and Foss, 2015). When deciding to carry on these strategies, there are must-have features necessary to reap the benefits of the collaboration. Innovation literature has evidenced two major factors required to accommodate and take advantage of open innovation: absorptive capacity and business model adaptation. These two aspects are enclosed in a wider organizational realignment, characterized by increased flexibility and permeability.

Absorptive Capacity

During this theoretical overview it has been repeatedly highlighted how competencies have a key role in affecting innovation capabilities. It follows that managing knowledge, whether deriving from in-house R&D activities or from external sources such as in open innovation strategies, is a crucial prerequisite for companies.

Management scholars defined the ability to identify the value of new external knowledge, to assimilate it and to apply it commercially as "*absorptive capacity*" (Cohen and Levinthal, 1990). A company's absorptive capacity is able to boost innovation processes by integrating external competencies with the prior knowledge already possessed by the company itself. The more the more the preliminary knowledge is correlated to that to be absorbed, the more the learning process will be facilitated. In this way, absorptive capacity can be interpreted as a learning ability with a key mediating role between eternal knowledge and innovation (Zahra and George, 2002).

The absorption process is divided into four phases: knowledge acquisition, assimilation, transformation, exploitation. In the first step the external knowledge desired to be absorbed is identified based on the existing gap. Through assimilation and transformation, the external knowledge is integrated and eventually adapted with the internal one. The final exploitation guarantees to implement new products, processes or strategies with the new resulting knowledge base (Zahra and George, 2002).

The absorptive capacity is a fundamental factor affecting the performance of open innovation strategies. Even if the companies involved in the collaboration had great competencies, maybe even complementary to each other, the inability to absorb them would jeopardize the final outcome (Zahra and Nielsen, 2002)

Business Model Adaptation

Earlier in the chapter the business model innovation has been stated as important as technology innovation. Many authors agree that a possible explanation of under-performing or unsuccessful innovation activities lies in an unsuitable business model. Business models, which should reflect the strategic choices of the company, need to be adapted to match the open innovation strategies. The adoption of these latter require that the involved companies define the ways to create, deliver and capture value in conjunction with external partners (Hienerth et al, 2011). This implies an openness of the business model itself towards a transparent sharing information among partners, to gain a cumulative knowledge. Chesbrough states that the main barrier of business model innovations lies in the potential conflict between traditional configurations of firm assets and the new entering technologies. (Chesbrough, 2010). Managers are reluctant to modify business models, because they are scared to lose the competitive advantage established over the years. Chesbrough' contribution suggests to spread experimentation within the organization: compared to established business models, business models aligned for open innovation strategies require a high degree of experimentation. Furthermore, business models for innovation can be interpreted as supplementary to current ones, at least in the short term. They are not supposed to replace the current business models but to be developed in parallel with them.

As argued during the business model innovation explanation, the realignment may involve just one of the nine blocks conceived by Osterwalder. For example, from open innovation strategies can arise new revenue streams, such as in the case of business models for *mobility-as-a-service* (*MaaS*) which are considered profitable opportunities for both suppliers and OEMs of the automotive industry. Open innovation strategies may give access to new markets and customer segments, along with new distribution channels.

4. Company's Strategy towards Electrification

This chapter will present a case-study arising from a real working experience of the author in Bonfiglioli Riduttori SPA, that made possible to be directly involved in the company e-mobility project. The company has to manage the technological innovation derived from the electrification process by deploying a tailored strategy to capture the opportunities deriving.

A clear detail of methodologies employed to conduct the analysis will be given.

Then, the results emerging from the insights collected will be analysed also in the light of the theoretical references addressed in the previous chapter.

The final paragraphs will describe the new positioning and, according to this latter, the business model canvas highlighting the change.

The business case can be taken as an example of the way and the extent to which off-highway industry's actors are affected by the electrified transition.

Suppliers can be impacted even harder than their clients by the growth of electrification at the expense of current leading powertrains.

4.1 Impact of the Transition on Bonfiglioli

In this first paragraph the analysis of case-study analysis will be implemented.

After a presentation of methodologies used during this work, the results will be detailed to assess the impact that the electric transition implies for a supplier as Bonfiglioli.

In order to contextualize the electrification process into the innovation management framework, the phenomenon and its effects for the company business will be classified based on the innovation types reviewed in the previous chapter.

The paragraph will also carry out an overview of the experience on electric systems gained by the company over the years, in order to assess the knowledge base with which it begins the transition challenge.

4.1.1 Methodology

The e-mobility transition is the most innovative project within the Bonfiglioli's business nowadays. Managers from different company functions, such as R&D, manufacturing, purchasing, product marketing and sales, are jointly committed to define the proper strategy for the technological transition. Once this latter is defined, the following innovative solutions may be implemented accordingly.

Many interviews have been undertaken with the purpose of responding to the main research question:

What is the impact of the electric technology transition for a leading supplier?
What are the resulting strategies to be adopted in order to react to this change?

These main questions have been broken down into several bullet points directed to specific managers. The interviews have been conducted between November 2021 and January 2022. One-one meetings with the selected manager have been scheduled, in which it has been decided to adopt a *semi-structured interview* methodology.

This choice lies in the high uncertainty regarding the adoption of new alternative technologies, which requires to maintain the debate as open as possible.

A semi-structured interview has the flexibility suited to collect opinions and comments for a qualitative research without imposing a rigid direction on the conversation.

A list of sub-topics and possible questions has been prepared, in order to submit to the interviewee insights on which to argue the discussion.

Every interview lasted between 30 minutes and one hour. Table 4.1 summarizes the interviewees carried out with the interviewee's business role, the number and the total duration in hours and the main objects treated:

Company Role	N° interviews / tot h	Object of the Interview
Bonfiglioli Mobility & Wind's CEO[28]	3 / 3h	a) Likeliness of alternative technologies diffusion within the industry b) Impact of electric technology adoption for the company business (opportunity or threat?) c) Innovative solutions for e-mobility
E-mobility Sales Manager – Off-Highway	4 / 4h	a) Impact of electric technology adoption for the company's core markets (i.e. OHVs) b) Strategy to be deployed to follow electrification trend c) Experience gained with electrical systems (which competencies can it rely on and which would be lacking?)
E-mobility Sales Manager – On-Highway	2 / 1.5 h	a) New markets that would become addressable with electrified powertrains b) Potential impact of a broader electrification adoption
Segment Sales Manager – Construction	2 / 1h	a) Clients (OEMs) reactions towards electrification
Product Marketing Manager	4 / 4h	a) Strategy to be deployed to follow electrification trend b) Innovative solutions for e-mobility
R&D Manager	2 / 2h	a) Experience gained with electrical systems over the years (which competencies can it rely on and which would be lacking?)
Purchasing Manager	1 / 1h	a) Emerging sub-suppliers of electric powertrain components

Table 4.1: Case-study's Interviews

[28] Bonfiglioli has a CEO for each business units. As it has been clarified in the first chapter, this thesis concerns the Mobile & Wind BU. All managers interviewed belong to this BU.

To integrate the internal interviews' findings, it has been interviewed also a client (OEM) which as will be described later, responds to the research of a partner for co-development partnerships: *Sampierana Group*. A member of Sampierana's purchasing department has been contacted with the aim of depicting the buyer-supplier relationship within this technological transition, understanding their issues and how a supplier like Bonfiglioli could sustain their electrification process.
The insights emerged from the interviews have been documented and reported in a descriptive form. The following part of the chapter will present the results of this qualitative research.

4.1.2 Effects on the Supply Chain

As a supplier of components for OEMs' vehicles, Bonfiglioli has to monitor and follow technological trends. The whole company is interested on the reports and analyses highlighting the electrification trend. As argued in the second chapter, the main alternative powertrain technologies with respect to the traditional ICE are hybrid electric, full electric and fuel-cell electric[29]. The company agrees with the market forecasts previously presented, which point out the higher adoption rate for BEVs over the decade, while HEVs and FCEVs are expected to reach a very limited diffusion. Notwithstanding, the company's core markets (i.e. off-highway applications) are characterized by two interrelated systems. To the usual powertrain system for the central energy generation, present in any vehicle propulsion (i.e. traction power), it's added an auxiliary system composed by the different actuators based on the machine.
So, it's important to clarify what part of the vehicle is foreseen to become electrified. According to the second chapter's argumentations, the definition of full electric, and more in general the electrification process, would involve only the *central energy generation system*. An off-highway battery-electric vehicle would result to be equipped with electric motors replacing ICEs, with batteries playing the role of energy storage in place of fuel tanks. The hydraulic systems (i.e. pumps, main control valve, hydraulic motors, etc) are

[29] As argued in the second chapter, FCEVs can be grouped into the electrified powertrains as they include electric motors and, eventually, batteries in place of ICE.

expected to remain unchanged, at least until 2030. This is the reason why a so-called pure electrification would not happen in the OHVs.
The first chapter has briefly described what is the business of Bonfiglioli, in which sectors it is engaged and what is its current positioning towards these latter.
As noted in the first chapter, the stable market share acquired over the years by Bonfiglioli mostly derives from products devoted to the traditional hydraulic-ICE powertrain technology dominating OHVs. Following the debate about technologies, it seems that the core business of the company, i.e. drive applications such as track, wheel, slew, winch, etc for hydraulic actuators, would be safe for now, untouched by the electric transition.
However, the central[30] electrification affecting OHVs would lead to important implications within the off-highway supply chain:

a) new *sub-suppliers* specialized in electric systems' components would appear as relevant actors to deal with into the supply chain dynamics for the development and correct functioning of the final vehicle
b) actual and potential *clients* (i.e. *OEMs*) would shift their business priorities from auxiliary systems' efficiency to the electrification of the whole machine
c) *competitors* historically committed also to automotive industry, can leverage the knowledge acquired in markets where electrified powertrains are more mature to expand into the world of OHVs

All these implications, that need to be treated in detail, force the company to react to the electrification process, even if it doesn't directly affect its core business.

a) New sub-supplier for electrified powertrains

From the point of view of a supplier which has traditionally produced components for ICE powertrain (or hydraulic-ICE in case of OHVs), the electrification process can be seen a technology transition primarily leading to an *architecture innovation*.
After all, a powertrain system represents the architecture of a vehicle, i.e. the way components are integrated to operate it. Even if batteries and electric motors are simply a different energy source to power the hydraulic systems, they encompass new set of

[30] Another technical term used to indicate the electrification of the energy generation

competencies: from mechanics to electric engineering.

Furthermore, the functioning of electric motors requires the involvement of new components within the vehicle architecture. Inverters, converters, on-board charger and electronic control units (ECUs), belonging to the electronics field, are complementary products that characterize any electrified powertrains. They are designed differently based on the vehicle type. In the OHVs' configuration that is standing out in the market, *on-board chargers* convert alternate current (AC) to direct current (DC), which then continues its electric circuit across power electronics devices (i.e. inverter and DC-DC converters). While the role of *inverters* have already been explained (i.e. converting DC to AC), the *DC-DC converter* plays the relevant function of converting a source of direct current (i.e. the battery pack) from one voltage level to another, by storing the input energy temporarily and then releasing that energy to the output at a different voltage. This allows the distribution of energy to different auxiliary systems which have different power requirements. The *electronic control units*, finally, are software programs integrated within the powertrain components to help data exchange and processing.

In a nutshell, electrifying OHVs would bring to an innovation on both the vehicle architecture and the components within this latter.

The introduction of these new components suited for electric vehicles, in turn would imply the entry of new categories of *specialized suppliers*. Producers of electric motors, batteries and power electronics would become new actors playing a relevant role into the OHVs' supply chain. They can rely on specialized knowledge and competencies to gain a high contractual weight within supply chain dynamics. Both OEMs and current suppliers of hydraulic components would be affected by the emerging players, because they are not familiar with their innovative products and they would suffer the technological dependence on these latter.

b) OEMs' electrification plans for OHVs

As the OEMs of passenger cars have been experiencing the transition to electric powertrains, the same is occurring for OHVs' ones. Beyond the already mentioned particular case of material handling, even electric agriculture and construction applications are expected to grow up in terms of electrification. Construction, which is the most important market for Bonfiglioli, appears as the most difficult off-highway sector to electrify according to the market forecasts. Nevertheless, some major OEMs of this sector are leading the transition with new electric models. It is the case of Volvo CE with its ECR25 electric compact excavator, equipped with lithium-ion batteries and an electric motor powering the unchanged hydraulic system. Caterpillar, Komatsu, Hyundai CE and JCB (Fig. 4.3) have followed the same innovative path and the same technologies of the Swedish company by introducing two electric mini excavators. Even if mini excavators are definitely the construction application most likely to be electrified due to lower size and power requirement, Volvo CE has launched also a battery electric wheel loader.

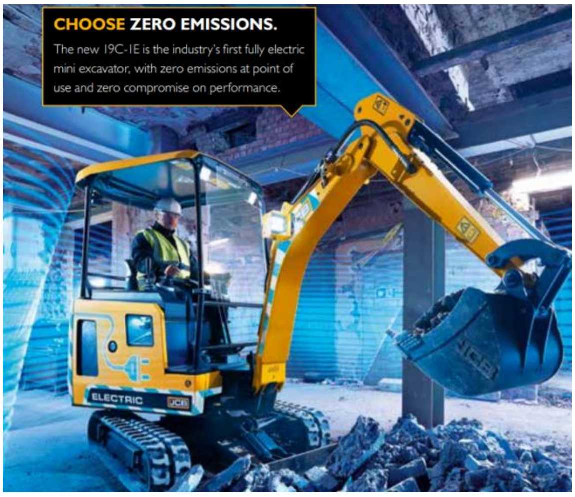


Fig. 4.1: JCB's 19C-IE electric mini excavator

The electrification of the central energy generation is considered a priority for OEMs. However, they are so confused about the technology to bet on and how to implement.

In a situation of such great technological uncertainty, suppliers must play an even more strategic role in assisting their clients. In the previous chapter it has been stressed out how over the years the responsibility for specific competencies and the following manufacturing skills have shifted to suppliers. As technological complexities and competition evolve, OEMs are forced to rely on specialized suppliers. The outsourcing practices embedded in the off-highway industry, just like in automotive, makes OEMs dealing with a technological innovation even more dependent on the innovativeness of their suppliers. The market entry of new actors producing components for electric systems will further enhance the chaos into the supply chain dynamics. In order to fit the new electrified vehicle architectures and related products, OEMs have to establish strong relationship with suppliers capable to react to the innovation process.

At the same time, suppliers have to respond to OEMs' current priorities, even if these are not usually part of their core business.

c) Competitors enlarging their products and markets

As in any well-defined business strategy, it is necessary to carry out a competitors' analysis. ZF, Dana, Bosch Rexroth, Nabtesco and Doosan are some of the main competitors for Bonfiglioli. Unfortunately, many of them are engaged in more sectors (e.g. automobiles) compared to Bonfiglioli, which currently contribute almost only to off-highway sectors. In addition, they are not limited to the auxiliary systems' applications, but provide to their clients the complete powertrain (central energy system included).

ZF and Bosch Rexroth, for example, can derive components and systems for the electrified powertrain of OHVs from their product portfolio for automotive. They can benefit from the success of their products in markets which are more mature in terms of electrification. It is an extreme case because these two players are the market leaders, with a total 2020's turnover of 32.6 and 5.2 billions respectively. Their electrified products have to be considered as examples paving the way for the electrification also in the off-highway industry. The company's innovative solution that will be presented later in the chapter is inspired by them. However, also other smaller competitors closer to Bonfiglioli's dimension and business, are pushing electric solutions into the market.

As argued in the previous point, suppliers have to follow the changing priorities of their clients. From the supplier-side, the risk lies in being replaced by these latter in favour of emerging and more innovative competitors. As other suppliers, Bonfiglioli have to sustain their current OEMs involved in the transition to avoid ceasing the relationship with them, which would also entail an erosion of the market shares acquired in the established business (i.e. hydraulic-ICE powertrain components).

4.1.3 Company's experience on Electric systems

Until now the discussion has focused on the implications that the electrification process might create for the supply chain, such as the entry of new actors and the re-alignment of incumbents' businesses (both OEMs and suppliers) to follow the technological trend.

The central issue that these aspects have in common lies in the knowledge of electrified systems.

In the last chapter it has been pointed out the relationship between radicalness of innovation and the impact of that innovation on actual competencies. The transition

towards electrified powertrain technologies fits the definition of *radical innovation*, as it brings to new set of competencies that destroys the acquired knowledge base of established companies (i.e. *competence-destroying innovation*).
As it has been argued, the competencies would shift from mechanics (required for ICE powertrains) to electric and electronic engineering (which rules electric systems). Another correlated shift is from hardware to software relevance for electronic modules.
Therefore, the point is the following: *what are the experience and competencies in electric systems that Bonfiglioli can rely on?*
The company approached electrification in other markets different from the main ones over the years. For example, some years ago it joined the business of *material handling* applications, by developing electrified solutions for forklifts and aerial working platforms (AWPs). As stressed in the second chapter, this off-highway sector is by nature easily to electrify, since they are used mainly indoor and they don't have the power requirements characterizing many construction applications. Nowadays, the majority of forklifts are powered by electric motors and equipped with rechargeable batteries. These secondary markets were used by Bonfiglioli to experiment new technologies, giving rise to new product lines for them, such as tailored electric wheel drive and electric traction systems for forklifts. The former product line implied the design of its gearboxes to be coupled with electric motors instead of hydraulic ones.
The electric traction systems, instead, marked the first contribute of Bonfiglioli to the central energy generation system for OHVs. They refer to company's gearboxes associated with electric traction motors that are mostly derived from outside, because the actual capacity of internal electric motors for forklifts is too limited. The *experimentation* has been allowed by the lower power requirements of forklifts compared to other off-highway applications. However, these electric solutions can be applied only to limited volumes. As we argued in the first chapter, the company has penetrated other mobile markets outside the off-highway corner. This is the case of light commercial vehicles (LCVs) which represents the so-called *e-mobility sector* of the company. It is another case of experimentation made possible by the adaptation of gearboxes to the wheel drives of these electric vehicles. For example, the company has been engaged on the Fiat E-Ducato's wheel drives business, the electric version of the famous LCV.
All these initiatives can be seen as steps towards the new technology, with the consequent reconversion of product lines.

The company’s 2020 turnover deriving from material handling and e-mobility vehicles, representing the only electrified sectors so far, is illustrated in Tab. 4.2.

SECTOR	APPLICATION	€ ICE powertrain	€ Full Electric powertrain
Material Handling	**Forklifts** 	1,622,336	13,766,406
	AEWs 	5,333,481	826,601
E-Mobility	**LCVs** 	0	1,712,898

Table 4.2: Bonfiglioli’s turnover in electrified sectors

As showed, the material handling applications served by Bonfiglioli, forklifts and aerial working platforms (AEWs), are both ICE and electric-powered. In electric forklifts, the company is able to provide both electric traction systems and the usual drive solutions for auxiliary systems, which in these cases are electrified (i.e. forklifts are the only case of pure electric OHV). AEWs, instead, are a material handling application still more suitable to ICE powering the traditional hydraulic actuators.

Regarding e-mobility sector, LCVs are the only vehicle type served and the low revenues generated makes it almost irrelevant compared to core business[31].

However, these experiences made with these applications makes possible to respond to the hype of e-mobility affecting core sectors (e.g. construction[32]) with an increasing knowledge base. Through the learning-by-doing approach adopted towards secondary sectors such as material handling and LCVs, Bonfiglioli can leverage the competencies acquired by experimentation to lead the electrification of other OHVs more difficult to electrify. In this way, it would be able to counteract the barriers of the competence-destroying transition, starting with some advantages over competitors that have never experienced electric systems.

[31] As highlighted in the first chapter, the turnover generated by e-mobility sector was only 0.30 % of the total 2020.

[32] Construction equipment accounted for the 50 % of total turnover generated in 2020

4.2 New Company Positioning

In the previous paragraph it has been claimed how suppliers should be prepared when the electrification occurs, in order to manage the effects that it implies.
There are some possible strategies for the off-highway industry's suppliers to transform the potential threats of the electric transition into opportunities:

- Shift investments from ICE components to batteries, charging infrastructure and electronics through a capital re-allocation (i.e. *from expenditures on established technologies to invest on experimentation directed to new technologies*)
- *Boost collaboration within the supply chain* rather than developing technologies separately, by forming partnerships, alliances and joint ventures.
- *Capture more of the value within the vehicle powertrain*. OEMs or their joint ventures have mostly produced ICEs in-house, while with electrified powertrains they could lose a part of the value chain in favour of new range of tier suppliers providing integrated systems.
- *Engage in mergers and acquisitions (M&A)* activities to acquire external capabilities and integrate them vertically (e.g. tier 1 suppliers acquiring sub-suppliers)

These alternatives have been taken into consideration by Bonfiglioli to define the right positioning to tackle the electrification process.
The resulting strategy is directed to capture more value from the value chain.
Bonfiglioli would re-position itself towards a different part of the vehicle, *from auxiliary systems to the main energy generation busines*s. This strategic passage must be seen as a way to match the electrification process at a previous step (i.e. electrification of the whole vehicle architecture) compared to the traditional business (i.e. auxiliary systems). The hypothetic final drives' electrification will be a next step. Nowadays, the off-highway industry's actors have to deal with the replacement of diesel engine with electric motors and batteries. As argued, the central vehicle electrification is the current OEMs' priority. The market trends analysed and the necessity to follow the clients in the technological transition, have brought Bonfiglioli to conceive its new positioning: *from component supplier to system integrator* (Fig. 4.2).

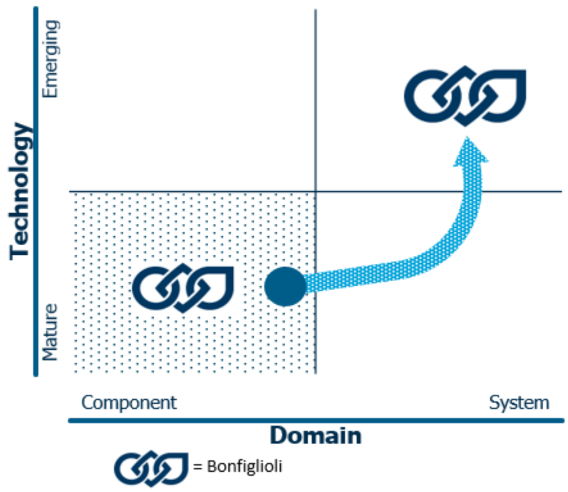


Fig. 4.2: New Company Positioning – From component supplier to system integrator

The new company positioning determines the entry of the company into the business of the main energy generation, exploiting the turbulence due to the technology discontinuity and the rise of electrification. By integrating different components of electrified powertrain into one single system, Bonfiglioli would interface with disparate sub-suppliers in place of OEMs. This would allow from the OEM-side to save time and costs for coordinating activities, while for the company would enhance the competencies in electric systems and enlarge its business by offering innovative solutions in addition to the traditional hydraulic drive applications. The system integration is the proper role to play into a new supply chain populated by different actors with specialized competences. In this way, OEMs would interface only with their former tier 1 supplier Bonfiglioli (now tier 0.5, i.e. system integrator), while this latter could rely on the coordination of disparate sub-suppliers.

The introduction of these new electrified system solutions will in turn open up new business opportunities in adjacent electric vehicle markets.

This paragraph will describe all these points arising from the new positioning, from the design of innovative solutions to the potential markets to penetrate with these latter, together with a focus on co-development partnerships within the supply chain necessary to implement the strategy.

4.2.1 Innovative Solutions for Electrified powertrain

Bonfiglioli is dealing with the creation of a product portfolio suitable for the electrification of OHVs. By approaching a system integration approach as new strategic positioning, the company has conceived an integrated and complete solution for electric powertrains.
The innovative system has been identified in an *electric drive system (EDS)* including 5 components in one single solution, illustrated in Fig. 4.3.

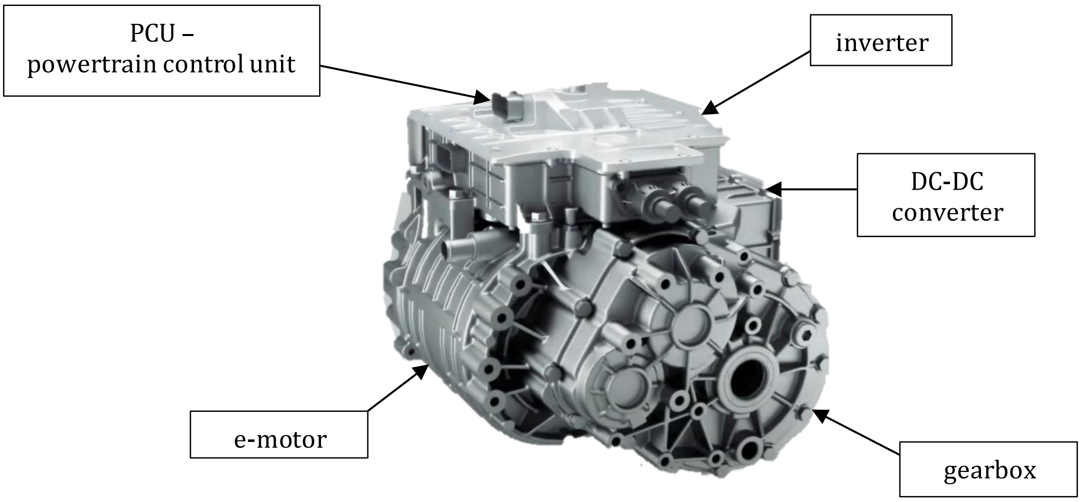


Fig. 4.3: Bonfiglioli's new 5-in-1 Electric Drive System

The electric system is the result of the integration of five components.
Bonfiglioli's *gearboxes* coupled with *electric traction motors*[33] which are expected to be produced in-house based on the competencies learned through material handling experimentation. However, at this stage the company would opt for outsourcing the e-motors, establishing strategic partnerships with sub-suppliers to co-design products. This is due to a limited production capacity of its own electric motors.
DC-DC converters are completely delegated to external sources which develop them according to the specification provided by Bonfiglioli. The same occurs for *inverters* and *PCU*, which are outsourced for the hardware part, while the software is managed and designed by Bonfiglioli's R&D to control the system's logics.

[33] Electric traction motors are the denomination for electric motors used for propulsion (i.e. traction power) of a vehicle, useful to distinguish them from e-motors of OHVs' drives (e.g. swing e-motor)

The integration of different components into one system guarantees a great modularity and a wide range of power rating. As it will be discussed, this would allow to adapt the EDS to different power requirements within OHVs, and also to penetrate new electrified vehicle markets.
The final accomplishment to provide a real complete integrated powertrain would imply to add *batteries* in the system. Batteries encompass the most complex technologies among electric powertrain components. The company is currently looking for partners to co-develop this critical component and complete the offer.
As it appears, it is unavoidable to resort to outsourcing practices in the face of a new knowledge base which have to be acquired over the years. The long-term objective for the company is to build a proper know-how to manufacture internally all the components.
At the moment, however, some suppliers specialized in the field of electronics are able to rely on cutting-edge technologies which cannot be equalized by leveraging internal competencies. They have a competitive advantage in the business of electric motors and inverters, due to both a greater cost-efficiency in the product development and specialized competencies which have already been tested in automotive EVs. This is the case of Chinese actors with whom Bonfiglioli have established *co-design strategic partnerships* to receive customized components according to the specifications indicated. In this way, the final electric powertrain of the vehicle can rely on specific sources of innovation, which are integrated by Bonfiglioli in its EDS. This latter is the result of the synergy between internal and external competencies and products.
In an innovation process which is increasingly based on deep collaborations across companies, as will be argued in the next paragraph, Bonfiglioli acts as a link across supply chain actors.

4.2.2 Co-Development Partnerships

In the previous paragraph it has been pointed out how much is necessary a co-design partnership with the emerging sub-suppliers providing the electrified components of the alternative vehicle architecture. Through the new positioning, Bonfiglioli places itself as the direct (and only) interlocutor of these actors within the supply chain.
It specifies its requirements and then exploits their competencies to design the integrated

system. Bonfiglioli can leverage on the previous experiences with these actors, maturated in the field of material handling and light commercial electric applications. In this way, it is well prepared to satisfy its clients' request of system integration of the several sub-components. Regarding the co-development strategies with OEMs, they have to be seen as a common *modus operandi* embedded in the industry, just like for automotive.

As argued in the third chapter, co-engineering practices are one of the main aspects characterizing the OEM-supplier relationship. Each client has his own requests based on the specific application. The pursuit of customization is the main reason for the increasing use of *modular configuration*, which allows to save time and costs in product development. During a process of technological transition, the relevance of these collaborations is even emphasized by the high degree of uncertainty.

Co-development partnerships encompass the whole product development process, from preliminary feasibility study to the final design validation test. Their main objective lies in the *mutual experimentation* towards new innovative solutions, a prerequisite in an innovation process of this breadth. By co-developing products, the companies involved can share costs (e.g. R&D, infrastructure, etc), risks (e.g. investment) and above all, competencies. It follows that Bonfiglioli has to find an OEM which is willing to share its time, knowledge and technical information (e.g. regarding specific duty cycles and performances of its applications), experimenting together. Duty cycles, for example, are key points for the electrification design process, since knowing the power and torque request profiles for each vehicle allows the correct selection and sizing of the on-board power sources, powertrain layout and energy storage systems (Beltrami et al, 2021).

Finding people willing to share information is not easy, especially in an industry such the one of OHVs where technological details play such an important role that brings a great deal of confidentiality in leaking information and knowledge. Even if the partnership should be arranged, the issue of communicating strategic information might remain a strong challenge for the success of the collaboration.

Anyway, Bonfiglioli has identified a potential good partner in *Sampierana Group*.

Sampierana is an Italian company recently acquired by the industrial giant CNH Industrial. The company is engaged in the construction sector, manufacturing mini excavators, skid loader and tracked undercarriages. It is an established client of Bonfiglioli, that generated revenues of almost 1.7 millions in 2020 by selling Sampierana its traditional drive applications.

The purchase manager has been interviewed, as its role is directly involved in the relationships with suppliers like Bonfiglioli.
There are some factors that have led to the selection of Sampierana among other OEMs:

- it has the greater *flexibility* associated with smaller companies, which may enhance its aversion to risk and experimentation, preventing the organizational rigidities of bigger OEMs
- as mentioned before, its *assortment is limited* to only three applications, so it can focus the efforts specifically to them
- it has already planned to launch a first version of an *electric mini excavator* (1.3 tons) equipped with lithium-ion batteries and an electric motor with peak power of 16 kW, suitable for indoor and domestic use.

The OEM has currently planned to acquire each component from different suppliers. However, this means dealing with several actors for new products, so it's looking for a single supplier capable of providing the complete package. The system integration promised by Bonfiglioli would guarantee the saving of coordination and purchasing efforts, in addition to the modularity offered by EDS. The two companies expect to merge their knowledge to solve the electrification priority, building a long-term partnership that could lead to further projects in the future (e.g. the electrification of heavier applications and the potential future electrification of final drives).
Everything will depend on the absorptive capacity of both companies, a necessity for the efficient implementation of the collaboration.
The case of Sampierana may be taken as an example of the *partner identikit* needed at these initial steps, while the further goal is to establish profitable collaborations with as many OEMs as possible.

4.2.3 On-Highway Electric Vehicles' penetration

The opportunities brought by the electrification process are not limited to the core markets of OHVs. Thanks to the system integration approach and the resulting EDS, Bonfiglioli would be able to penetrate new markets with the same modular and customizable product line. The on-highway markets opened by the electrification refer to the category of commercial vehicles, described in the first chapter. As it has been argued, they are divided in classes of weight size. Light commercial vehicles (LCVs), the smallest class, represent the current e-mobility sector for Bonfiglioli, which is at the early stages. The objective of the company, in parallel with the progress on off-highway vehicles, is to penetrate the commercial vehicles' sector through its EDS. Indeed, the wide power range of the integrated system makes it suitable for different applications. In commercial vehicles, the EDS would be able to replace ICE on front and rear traction. This would be the response to the growth of electrified powertrains for this vehicle category, which is a few steps ahead of OHVs. Indeed, they are affected by the same environmental regulations of other on-road vehicles (e.g. passenger cars)

The Fig. 4.4 illustrates the Interact Analysis' (2020)[34] market forecasts for commercial vehicles by powertrain, in terms of variation between 2020 and 2030.

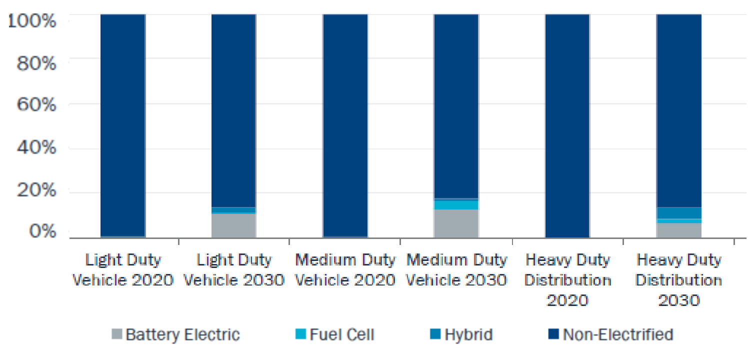


Fig. 4.4: Commercial vehicles Market Forecast by Powertrain

As highlighted, the smallest the vehicle size, the highest electrified adoption. Heavy-duty commercial vehicles (called in the analysis distribution truck) are expected to reach the lowest electrification, while LCVs and medium-duty vehicles would reach respectively the 15% and 20% of the total units delivered in 2030.

[34] Source: The HEV and Electrified Truck and Bus Market - 2020 Edition (2021)

Following these optimistic forecasts, Bonfiglioli is ready to customize its innovative electric products to these two sizes of commercial vehicles by providing adequate power range configurations of its integrated system. While the light-duty class had already been served, the company acted as a sub-supplier of gearbox for other tier 1 suppliers. With the introduction of a complete system, Bonfiglioli would scale the supply chain pyramid, establishing itself as a system integrator supplier dialoguing directly with final LCVs' OEMs. The same would be possible for medium-duty classes.

In this way, Bonfiglioli could its share of revenues deriving from on-highway markets.

Once the product has reached a certain acceptance in the on-highway vehicles' world, for the company various opportunities will open up in the new business of electric energy generation. After all, it has been argued how the components of the EDS derive from automotive industry. This latter might be the final destination of Bonfiglioli' business enlargement following the electrification trends.

Following this path, the company is currently investigating other electrified on-highway markets to tackle, such as buses and particular urban vehicles like city cars characterized by low power requirements.

4.3 Business Model Canvas for Electrification

Whatever the enlargement of the integrated system's configuration (e.g. with batteries) and/or the markets covered by this solution, a new strategy emerges for Bonfiglioli.

This represents an innovation at the business model level (i.e. *business model innovation*), which is added to the established business and is not intended to replace it, at least not now. Rather, it has to be interpreted as a *complementary positioning* compared to the traditional positioning of Bonfiglioli as supplier of drive applications for auxiliary systems. In case of a future pure electrification of OHVs (i.e. the hydraulic auxiliary systems turn electrified), the company would be able to provide the whole vehicle architecture by merging the established positioning and the new one.

The new company positioning has different interrelated meanings:

- it determines the *entry of the company into the business of the main energy generation*, exploiting the turbulence due to the technology discontinuity with the rise of electrification
- it guarantees the possibility to offer *innovative electrified solutions* in addition to the traditional commoditized hydraulic drive applications
- it highlights the passage *from a pure market-pull approach to the combination of pull and push innovation approaches* able to solve the specific needs that the clients demand at this stage of the transition (i.e. prioritization of central electrification)
- it allows OEMs to avoid interfacing with disparate suppliers for the different new components of electrified powertrain, relying only on their partner *Bonfiglioli as system integrator*

In order to highlight the strategy to be deployed, it is useful to detail the business model canvas for electrification, which follows the nine building blocks set out by Osterwalder and explained in the third chapter:

- *Value Proposition:* The new positioning as system integrator supplier to tackle the electrification process aims to provide an integrated electric drive system which guarantees modularity, customization and efficiency to lead the technological transition.

- *Customer Segments:* Established and new off-highway applications' OEMs but also others engaged in the electric commercial vehicles' business

- *Channels:* The increasingly more popular events and webinars related to e-mobility might be relevant touchpoints to negotiate with clients

- *Customer Relationships:* Even if the collaboration is embedded in the industry's buyer-supplier relationships, within the electrification process the co-development partnerships become crucial for innovation. Bonfiglioli wants to offer to their clients a reliable support to implement the transition.

- *Key Partners:* In addition to the OEMs, co-design activities with sub-suppliers manufacturing components for electrified powertrains are necessary because these latter have specialized competencies which cannot be imitated

- *Key Activities:* System Integration becomes the most important activity to develop the EDS, together with the usual manufacturing and negotiation (e.g. with sub-suppliers)

- *Key Resources*: To approach electrification are needed both the internal R&D know-how and the external knowledge that has to be absorbed and integrated (i.e. absorptive capacity)

- *Revenue Streams and Costs:* The company expects to generate revenues by the central energy generation business, as it is a priority for clients with respect to the final drives. The modularity allows to save costs and apply the EDS to different applications, offsetting costs related to the outsourcing and coordination of different components.

The business model canvas has been detailed in Fig. 4.5.

<table>
<tr><th colspan="5">BUSINESS MODEL CANVAS for ELECTRIFICATION</th></tr>
<tr><th>Key Partners</th><th>Key Activities</th><th>Value Proposition</th><th>Customer Relationship</th><th>Customer Segments</th></tr>
<tr><td rowspan="3">• Sub-suppliers manufacturing components for electrified powertrain (e.g. e-motors, inverter, etc)

• OEMs looking for assistance in the technological transition (current and new)</td><td>• System Integration
• Innovation & Design
• Negotation</td><td rowspan="3">The new positioning as system integrator supplier aims to provide an integrated electric drive system which guarantees modularity, customization and efficiency to lead the technological transition</td><td>• Co-development Partnerships
• Intellectual and technical support for the transition</td><td rowspan="3">• Off-highway's OEMs
• New vehicle markets' OEMs</td></tr>
<tr><th>Key Resources</th><th>Channels</th></tr>
<tr><td>• R&D know-how
• Absorptive Capacity</td><td>• Events
• Webinars</td></tr>
<tr><th colspan="2">Cost Structure</th><th colspan="3">Revenue Streams</th></tr>
<tr><td colspan="2">• Costs for managing and coordinating sub-suppliers' components
• R&D costs</td><td colspan="3">• Revenues from product (EDS) sales
• Revenues from consultancy in applications' development and aftersales</td></tr>
</table>

Fig. 4.5: Business Model Canvas for Electrification

Conclusion

The case-study has proved how a supplier is impacted by the electrification process of the vehicles for which it provides powertrain components. Even if this can be extended to every vehicle category, the thesis has focused on *industrial vehicles* (commercial vehicles and off-highway vehicles). In this sense, the research offers an analysis of the electrification processes from a different and original reference market, often overlooked compared to automotive.

The OHVs' powertrain differ from the most common automobiles, as it comprises two distinct but interrelated systems which respond to different function. The *central energy generation system* refers to the propulsion function, i.e. traction power, and it's present in any type of vehicle, from on-highway to off-highway machines. This latter, in addition, have the so-called *auxiliary systems*, composed by final drives (i.e. actuators) for the several operating duties that these have to perform. So far, OHVs have been dominated by the ICE technology, which in turn power the hydraulic systems of actuators: the so-called hydraulic-ICE powertrain. However, the market forecasts highlight a growth of electrification adoption rate, including hybrid, full-electric and fuel-cell architectures.

Bonfiglioli Riduttori SPA has built over time a leading position within the off-highway industry, ensuring quality solutions for the vehicles of the world's major OEMs.

The company product portfolio has mainly comprised final drive solutions to be coupled with hydraulic motors, while its experience on electric systems has been limited to secondary markets. The stability of the industry and consequently of its business made up of commoditized products, has slowed down both the company's innovativeness and the research of new businesses. As the technological innovation brought by the electric transition is expected to modify the usual way to conduct businesses within the industry, this is the moment for Bonfiglioli to take strategic decisions.

Through these lenses it has been carried out the *qualitative research*.

The OHVs' electrification trends emerging from the market forecasts, in line with what is occurring in the automotive industry, has been the starting point for the analysis.

All the powertrain technologies have been studied. Full-electric architecture (BEVs) emerged as the most likely electrified powertrain to be employed over the next decade.

The discussion has then moved to the literature review on technological innovation and the different innovation classifications, useful to understand the electric transition and its implications in terms of key success factors such as competencies. In the same chapter it has been treated the role of suppliers and its evolution into the innovation processes, together with the relevance of inter-company collaborations, grouped in the field of open innovation. Finally, the study has come to the specific company case.

Several Bonfiglioli's managers have been interviewed with the purpose of collecting insight firstly about the impact of the transition on the company's business and then regarding the strategy to deploy.

The interviews revealed some findings concerning supply chain dynamics, which in turn have implications for Bonfiglioli:

1) OEMs' priorities shift towards the electrification of the central energy generation system; even if the final drives business would be untouched, Bonfiglioli has to support its clients, which are even more dependent of suppliers, in the technological transition to avoid losing the relationship with them
2) New sub-supplier specialized in cutting edge technologies related to electronics and other components for electrified systems, become relevant actors that Bonfiglioli has to consider for its electrification path, interfacing and establishing collaborative activities with them
3) Competitors engaged in automotive sectors can rely on solutions which have been already tested in more mature electrified markets; Bonfiglioli must move quickly to fill the gap with them, taking inspiration by their examples for designing innovative solutions

The research has addressed the actual company's knowledge base about electrified systems, stressing the importance of experimentation when approaching new technologies. The final discussion has led to the new company positioning to tackle the electrification process: *from component supplier to system integrator*.

This latter lies to innovative solutions (the electric drive system – EDS) directed to the central energy generation business, made possible by the collaborations established or to establish with sub-supplier and OEMs. The co-development partnerships are essential to share risks and costs of the innovative projects, using the time needed to experiment, and creating a cumulative set of competencies to lead the transition.

The new positioning open up new markets, new categories of vehicle which become addressable thanks to the adoption of electrified powertrains. The electrification, in this sense, has given to the company the possibility to move towards a new business of the vehicle, taking advantage of the reset of hierarchies that a technological innovation is able to bring. Bonfiglioli wants to anticipate the market forecasts, anticipating possible next electrified adoption such as in its core business of OHVs' auxiliary systems and establishing itself as a reliable partner for the transition.

Furthermore, over the next years some of the mentioned electrified technologies now limited by delays in infrastructure, such as fuel-cell electric powertrains, might become competitive, decreasing the tradition ICE adoption rate even more.

Following the expected growth of electric industrial vehicles, suppliers' long-term objective might imply being able to provide a more complete service to the vehicle, in key aspects such as charging infrastructure and batteries.

This is the demonstration of how the advent of a technological transition can lead to endless business opportunities which have to be captured.

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Figures and Tables