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How Electrification is Changing Off-Highway Industry

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Executive Summary

Off-Highway Equipment such as construction, mining, and agricultural machinery are an essential part of modern industry and agriculture. However, these equipments are known for their high fuel consumption, emissions, and noise levels. As a result, there is an increasing interest in the electrification of Off-Highway Equipment which can reduce their environmental impact and operational costs. This whitepaper explores the benefits and challenges associated with the electrification of off-highway equipment.

Electrification of Off-Highway Equipment involves replacing the conventional internal combustion engine (ICE) with an electric motor and battery system. The battery system can be charged from the grid or onboard generators. The primary benefits of electrification are environmental, economic, and operational. By using electric power, off-highway equipment can reduce greenhouse gas emissions, improve air quality, and reduce noise pollution. Additionally, electric equipment is generally more energy efficient than conventional equipment, resulting in lower fuel consumption and lower operating costs. Finally, electric equipment can offer better performance, including increased torque and better response time. However, there are also challenges associated with the electrification of off-highway equipment.

The primary challenge is the lack of infrastructure, including charging stations and battery storage facilities i.e., battery systems size, weight, and cost. Another challenge is the initial cost of electrification which can be higher than conventional equipment. Furthermore, electric equipment requires specialized maintenance and training which can be expensive.



Despite these challenges, the benefits of electrification are too significant to ignore. Governments and industry stakeholders are working together to build the necessary infrastructure, provide financial incentives, and promote research and development in electrification. With proper investment and support, the electrification of off-highway equipment can lead to a more sustainable and efficient future for the agriculture, construction, and mining industries.

In conclusion, electrification of off-highway equipment is a promising solution to reduce their environmental impact and operational costs. However, the size, weight, and cost of the battery system are critical challenges. BMS can be the solution to tackle most of the challenges. An efficient BMS can be used to optimize the battery system's performance by managing its charging and discharging processes, monitoring its condition, and protecting it from overcharging and overheating.

Introduction

Off-highway equipment, also known as non-road mobility machinery, heavy machinery or earth-moving machinery refers to a broad range of vehicles that are primarily used for construction, mining, and farming purposes. These equipments include excavators, bulldozers, loaders, graders, tractors, and more. The off-highway equipment industry has long depended on diesel power for heavy machinery, large vehicles, and specialized transportation systems. Consequently, the farming, mining, and construction sectors encounter numerous obstacles and risks.

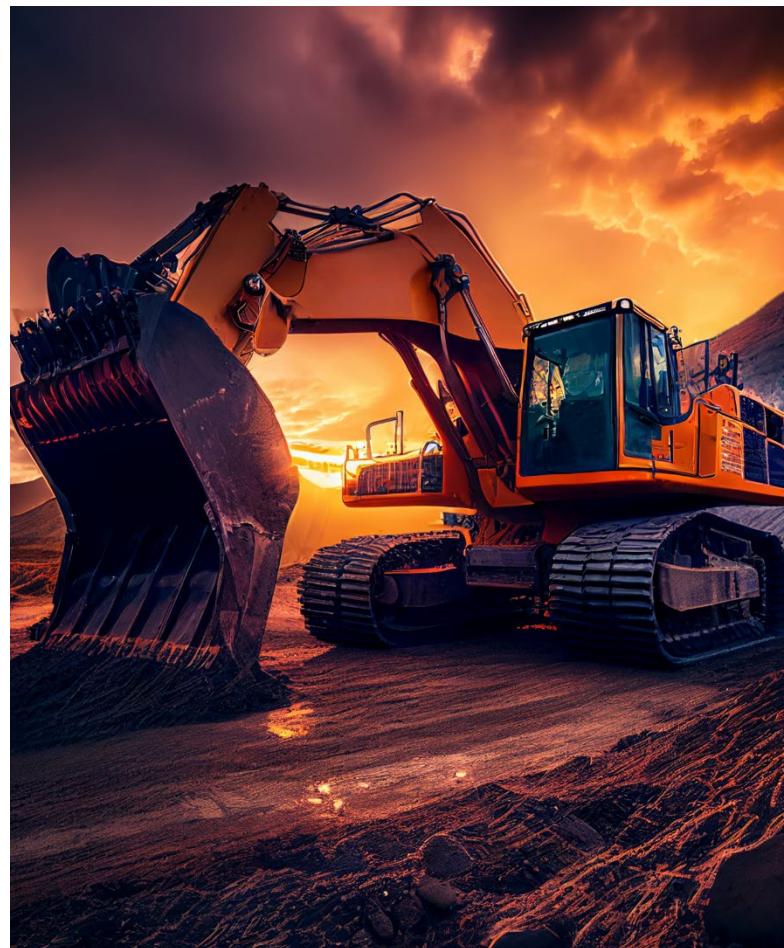
Excess heat and exhaust fumes from powerful diesel engines necessitate the installation of sophisticated ventilation systems in subterranean mines. Noise and vibration protection is also essential for tunnel and shaft structural integrity, mechanical wear of parts and vehicles, and worker health and safety.

Diesel engines are large and big; therefore, equipment and machinery must be built to accommodate them. As a result, tunnels must be larger, making excavation more difficult and costlier. The mine's infrastructure and seamless operation are additionally hampered by refueling requirements. All these difficulties are compounded by the costs of fueling and maintaining heavy-duty diesel engines and mining equipment. The return on investment of a mine is determined by fuel costs that are beyond the operator's control, and expenditures for maintenance and replacement of bespoke parts cut into earnings.

The problems brought on by employing heavy diesel engines in off-highway equipment are solved by electrifying fleets of transit vehicles, haulage trucks, and mining equipment. This electrification of equipment is far safer to operate under underground conditions than diesel-powered counterparts since they produce no exhausts, significantly less surplus heat, and significantly less noise and vibration.

The electrification of off-highway equipment is becoming increasingly important as we strive towards a more sustainable future. The use of these equipments contributes significantly to greenhouse emissions and air pollution, which is a growing concern for the environment and human health.

The objective of this whitepaper is to provide an in-depth analysis of the benefits and challenges of electrification for off-highway equipment. It will also explore the latest technologies, case studies, and future trends in the market. The goal is to help stakeholders make informed decisions on how to incorporate electrification into their operations to reduce their environmental impact and improve their bottom line.



Market Overview

The market for off-highway vehicle engines is valued at USD 37.21 billion and is anticipated to grow to USD 58.53 billion over the next five years, registering a CAGR of 7.92%. The surging utilization in the use of off-highway vehicle engines is linked to the positive sales performance of agricultural and construction equipment. This trend is propelled by swift urbanization and increased infrastructure development in both residential and commercial sectors, which in turn boosts the demand for construction machinery. Additionally, governmental efforts, particularly in developing nations, to advance agricultural mechanization are spurring the need for farming equipment, including medium and heavy-duty tractors. Consequently, as the uptake of construction and agricultural machinery escalates, so does the global requirement for off-highway vehicle engines.

The rise of the construction and agricultural machinery industries affects the development of off-highway vehicle engines. Agricultural and construction machinery markets are being driven by rising agricultural mechanization trends in developing nations and an increase in residential and commercial construction projects worldwide.

The off-highway engine market is expected to grow during the estimated period due to an increase in the demand for and manufacturing of off-highway vehicles. Additionally, the use of off-highway vehicles has expanded in several industries, including farming, construction, mining, infrastructure, and others, due to an increase in automation.

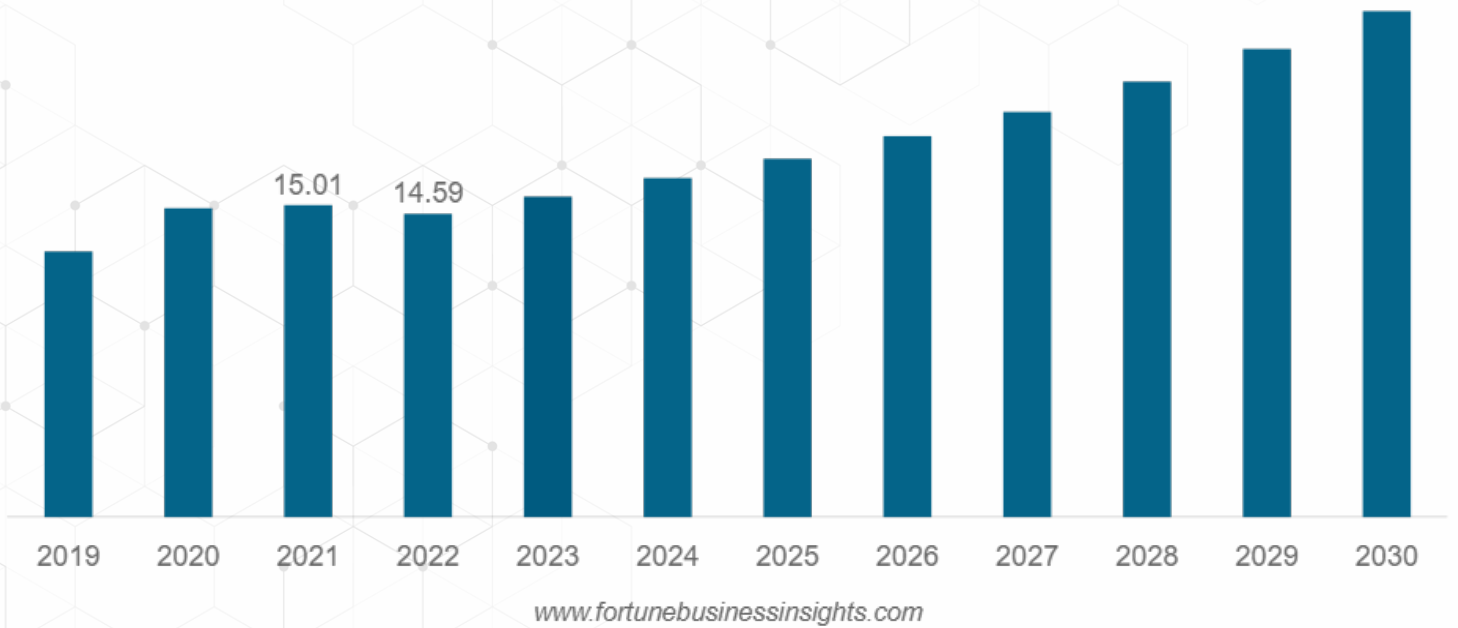
The off-highway engine industry, however, is expected to be severely constrained by high cost and maintenance expenses. Globally, regulatory organizations are enforcing strict standards to lower automobile carbon emissions. Vehicles' carbon emissions can be decreased by modifying their off-highway engines. The demand for off-highway engines is expected to be driven by this.

Over the next ten years, construction is expected to rank among the most lucrative industries on a global scale. The mining and quarrying industries saw an increase in activity as a result of the Asia-Pacific construction sector's recovery, and further market investment is likely to be stimulated by the current favorable economic climate and low lending rates. The demand for off-highway engines in the Asia-Pacific region will be primarily driven by the extensive modernization of agriculture through the incorporation of mechanized agricultural practices over the forecast period.

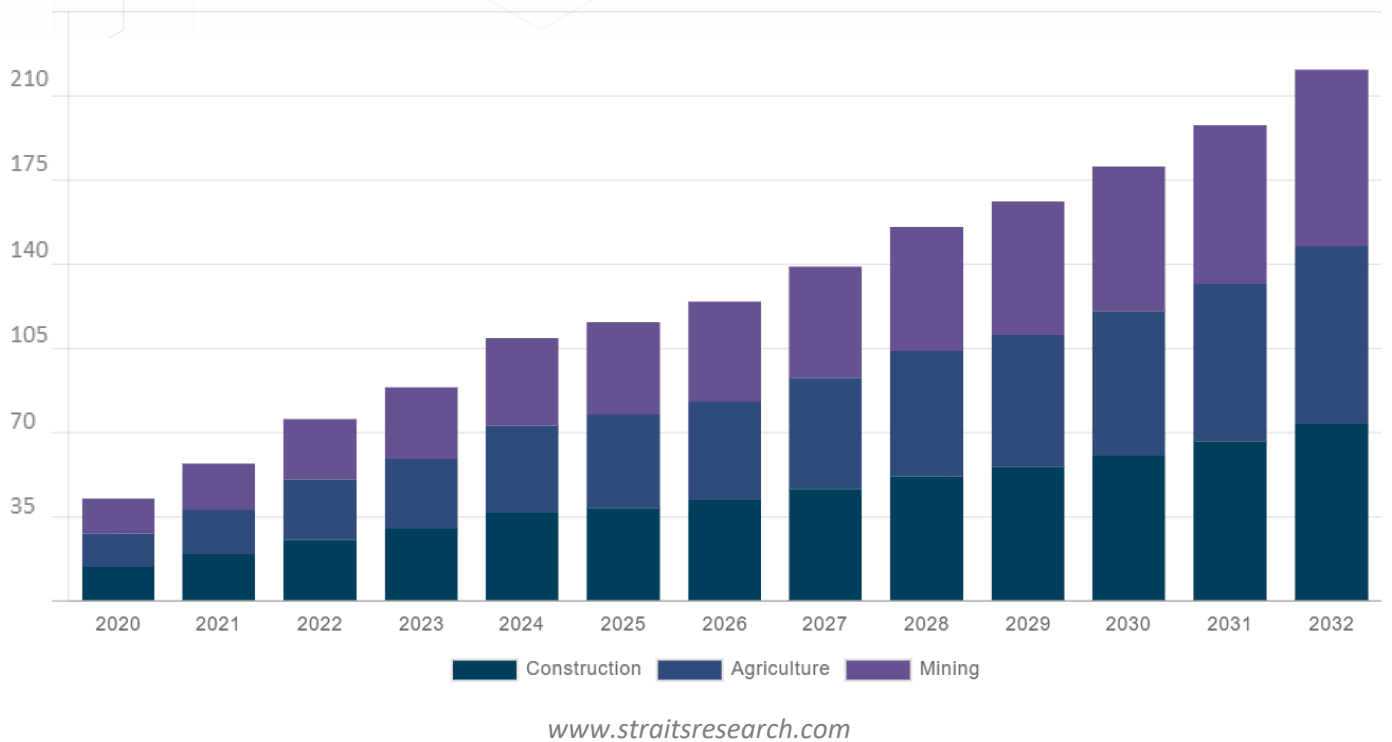
Few of the key players in the market include Caterpillar, CNH Industrial, Hitachi Construction Machinery, JCB, John Deere, Komatsu, and Volvo Construction Equipment. These companies are investing steadily in the R&D of electrification technology to stay competitive in the market. Other notable players include AGCO, Doosan Bobcat, Epiroc, Liebherr, Terex, Sany and Sandvik among others. The market is highly competitive with companies aiming to gain a comparative advantage through innovation and technological advancements.

Overall, the market is expected to grow as the demand for off-highway vehicles continues to rise and more companies adopt electrification due to various factors such as environmental regulations, economic benefits, improved productivity, brand image and to stay ahead of competitors in the market.

Asia Pacific Off Highway Vehicle Engine Market Size - 2019 to 2020 (USD Billion)



Potential Market for Off Highway Vehicle Electrification



Electrification Technology Overview

The electrification of off-highway equipment involves the integration of electric powertrains, battery technology, and charging infrastructure. Companies and governments are increasingly adopting electrification of off-highway equipment due to various factors such as, approximately 59% to 62% of the electrical energy from the grid is converted by Electric vehicles to power at the wheels, according to the US Department of Energy's Office of Energy Efficiency and Renewable Energy, while gasoline engines can only convert approximately 17% to 21% of the energy used by conventional gasoline counterparts and diesel engines can convert at least double of energy used by conventional diesel counterparts to drive the wheels, but still they are less efficient compared to Electric operated vehicles. The electrical motor of an Electric operated equipment is thought to utilize between 85% and 90% of the electricity given to it and store it in the battery. In other words, the vehicle uses up to 90% of the energy produced for work, which shows its high efficiency. According to Roland Berger, the biggest players in manufacturing of off-highway equipment are expecting anything between 20-50% in fuel cost savings and 20-50% less time for refueling and maintenance for these Electric off-highway vehicles compared to their conventional counterparts.

Electric Powertrains

Electric powertrains for off-highway equipment can come in various forms, including:

- **Fully electric Powertrains:** Fully electric Off-Highway equipment are powered by battery-electric powertrains. These powertrains convert electrical energy stored in batteries to mechanical energy to propel the vehicle. Electric motors are used instead of internal combustion engines to generate torque and power. Battery technology has seen advancements significantly in recent years, which has made it possible for electric off-highway vehicles to have a good range on a single charge.
 - **Hybrid Electric Powertrains:** Hybrid electric powertrains are a combination of electric and internal combustion engines. In this system, the internal combustion engine charges the batteries while driving or during idle time. The electric motor is used for propulsion at low speeds, while the internal combustion engine kicks in when more power is required.
- Electrification offers several advantages over conventional powertrains including:
- **Reduced Operating Costs:** Electric off-highway equipment has lower operating costs than conventional off-highway equipment because electricity is less expensive than diesel or gasoline. Additionally, electric powertrains require less maintenance resulting in reduced maintenance costs.
 - **Lower Environmental Impact:** Electric off-highway equipment emits zero tailpipe emissions, resulting in lower greenhouse gas emissions and improved air quality. They also emit less noise than conventional off-highway vehicles reducing noise pollution.
 - **Improved Performance:** Electric powertrains provide instant torque, resulting in faster acceleration and improved performance compared to conventional off-highway equipment.
 - **Improved Safety:** Electric off-highway equipment has fewer moving parts, resulting in reduced risk of mechanical failure. Additionally, the absence of exhaust fumes reduces the risk of operator exposure to harmful emissions.

Battery Technology

Batteries are a critical component of off-highway equipment electrification. The most prevalent battery type used in off-highway equipment is lithium-ion because of its great energy density and good long cycle life. However, research is ongoing to develop next-generation battery technologies that offer even higher energy density and improved performance.

Charging Infrastructure

The development of charging infrastructure is crucial for the widespread adoption of electric off-highway vehicles. Companies are investing in establishing charging stations at job sites and other locations to support the increased use of electric equipment. The charging infrastructure for off-highway vehicles depends on the type of powertrain used. Fully electric off-highway vehicles require charging stations with high power output. The future of charging off-highway machinery lies in private charging stations, especially mobile transportable ones that can be connected by an electrician on the site, can be temporarily installed until the job is finished on the job site and then moved to another location. These chargers will be tailored to meet the unique requirements of off-highway equipment, considering factors such as charging speed, power demands, environmental conditions, and integration with onboard telematics systems. By providing specialized charging solutions, these dedicated chargers can optimize the charging process and enhance the overall performance of off-highway vehicles. These charging stations offer the robustness and safety necessary for today's job site.

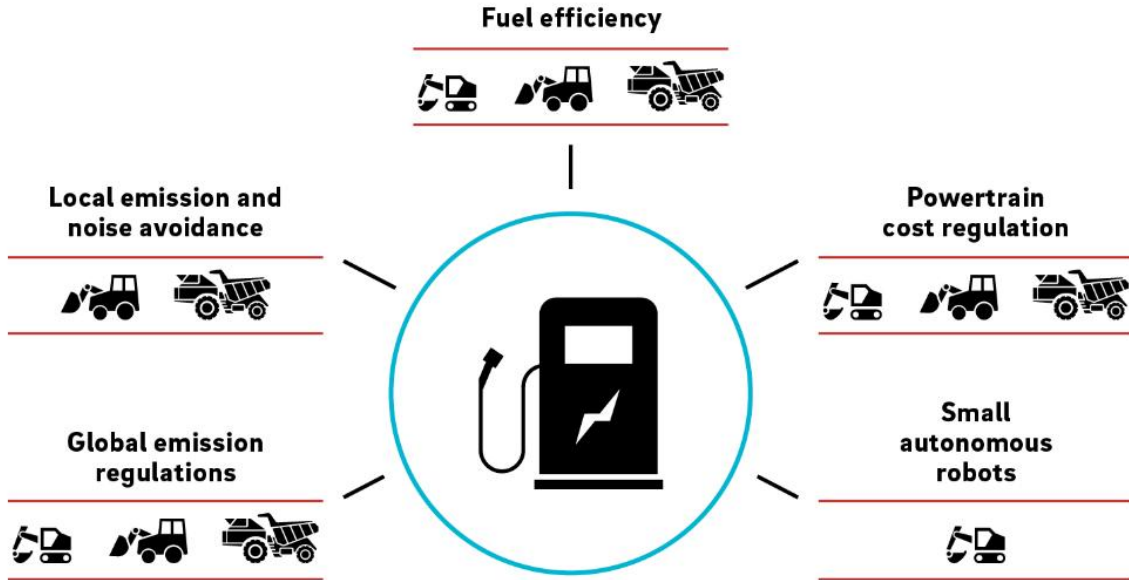
Overall electrification technology is a promising solution for reducing the environmental impact of off-highway vehicles. It offers various benefits including reduced emissions, improved efficiency, and lower operating costs. As technology advancements come up we can expect to see more electrified off-highway vehicles in various applications. As the industry is rapidly evolving and with the help of advancements in battery technology and charging infrastructure, electrification will soon become increasingly viable for off-highway vehicles.



Benefits of Electrification for Off-Highway Equipment

The electrification of off-highway equipment offers several benefits that can make them attractive for businesses to adopt. Here are the benefits:

Overview drivers for off-highway electrification



 Mining trucks  Compact wheel loader  Mini Excavators

Source Gamma Technologies, Roland Berger



- 1. Reduced operating costs:** Electric vehicles are generally more efficient than their diesel counterparts, resulting in lower operating costs over time. They also require less maintenance as they have fewer moving parts
- 2. Improved environmental sustainability:** Off-highway equipment such as construction equipment, mining trucks, and farming machinery are notable contributors to air pollution and greenhouse gas emissions. Electrification can significantly reduce these emissions and improve the environmental sustainability of these operations.
- 3. Improved Efficiency:** Electric off-highway equipment is more efficient than diesel-powered off-highway equipment. Electric motors convert a higher percentage of energy into motion compared to internal combustion engines which have a much lower efficiency. This translates to lower energy consumption and longer operating times for electric off-highway equipment.
- 4. Improved Performance:** Electric off-highway equipment offer improved performance over traditional diesel-powered off-highway equipment. Electric motors provide instant torque and faster acceleration, making them ideal for heavy-duty applications. Additionally, electric motors offer better control and precision resulting in improved productivity and safety
- 5. Reduced Noise:** Electric off-highway equipment operates with very less noise or no noise whatsoever thereby reducing noise pollution in construction and mining sites This is particularly important in residential areas, where noise levels are regulated

6. **Enhanced Operator Safety:** Electric vehicles produce less noise, vibration, and exhaust emissions than diesel vehicles, making them safer and more comfortable for operators.
7. **Increased productivity:** Electric off-highway equipment offers instant torque and greater flexibility in terms of power output, allowing them to operate at maximum power without experiencing power loss due to altitude or temperature changes. This can improve productivity and reduce downtime.
8. **Reduced dependence on fossil fuels:** Electrification reduces the reliance on fossil fuels which can be subject to price fluctuations and supply disruptions. Electric vehicles can be charged from renewable and non-conventional energy sources such as solar and wind which can improve the resilience of off-highway operations

9. **Improved regulatory compliance:** Many countries are introducing regulations to reduce emissions from off-highway vehicles. Electrification can help operators comply with these regulations and avoid penalties.

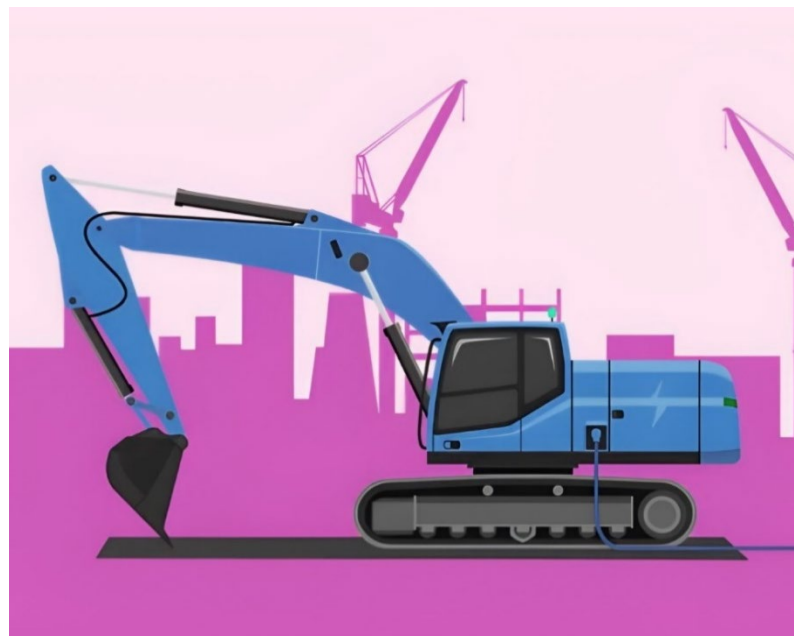
In conclusion, the electrification of off-highway equipment offers significant benefits over traditional diesel-powered ones. Reduced emissions, lower operating costs, improved efficiency and performance, reduced noise, increased productivity, regulatory compliance, and improved safety are just some of the many benefits of electrification.



Challenges for Electrification of Off-highway Equipment

The electrification of Off-Highway equipment presents unique challenges due to their demanding operational requirements. The considerable challenges in the way of electrification are:

1. **Energy Storage:** Off-Highway equipment especially vehicles require large amounts of energy to perform their tasks. The energy storage systems need to be durable, efficient, and capable of handling high voltage and high current requirements. Additionally, the energy storage system should be able to withstand the rugged conditions of Off-Highway vehicle environments, including temperature variations, dust, and vibrations.
2. **Range and Battery Technology:** Range is a significant challenge in electrifying off-highway vehicles. Off-Highway vehicles require large amounts of power for extended periods, which can quickly drain batteries. The limited range and capacity of batteries along with their size and weight, can significantly increase the weight and reduce the payload capacity of vehicles.
3. **Durability and Ruggedness:** Off-Highway equipment is often used in harsh and rugged environments such as mining sites or construction sites which can cause wear and tear on the vehicle. Electrified off-highway equipment needs to be designed to withstand these tough conditions, including vibration, impact, and extreme temperatures.
4. **Charging Infrastructure:** Off-Highway Equipment is often used in remote locations, making it challenging to establish a reliable charging infrastructure. The charging infrastructure for off-highway equipment is currently limited and not widely available. The lack of charging infrastructure can limit the range and flexibility of electrified off-highway equipment making them less practical for certain applications.
5. **Weight:** The weight of electric Off-highway equipment can be a challenge. These equipments require significant battery packs which add to the weight of the equipment. This additional weight can impact the vehicle's performance and limit its range making it difficult to operate effectively.
6. **Cost:** The cost of electrified Off-highway equipment is currently higher than their diesel counterparts primarily because of the high cost of batteries and other components. While the cost of batteries is expected to decrease over time, it will still take some time for electrified Off-highway equipment to become cost-competitive with diesel-powered vehicles.
7. **Performance:** Off-Highway Equipment is often required to perform at high levels of power and torque. Electric motors can deliver high levels of torque, but they might not deliver the same level of power as diesel engines, which could limit their performance in certain applications.
8. **Safety:** Safety is a critical challenge for electric Off-Highway equipment. High Voltages and currents are present in electric off-highway equipment which can be dangerous to operators and maintenance personnel. Therefore, electric off-highway equipment needs to be designed with appropriate safety features, including high-voltage interlocks, insulation, and grounding systems.



An Efficient Battery Management System is the Need for the Situation

The electrification of off-highway vehicles is gaining momentum as a large number of companies seek to reduce their carbon footprint and comply with increasingly stringent emission standards. However, one of the main challenges in achieving widespread adoption of electric off-highway equipment is the need for a reliable and efficient battery management system. A BMS is a critical component that monitors and controls the performance and safety of the battery pack and is essential to ensuring the long-term viability of electric OHVs.

Importance of BMS in the Electrification of Off-highway Equipment

The role of a BMS in electric Off-highway equipment is to monitor and manage the battery pack to ensure optimal performance, safety, and longevity. A BMS performs a range of functions, including monitoring the state of charge (SOC) and state of health (SoH) of the battery, controlling the charging and discharging of the battery, and protecting the battery from overcharging, over-discharging, and overheating. A well-designed BMS can extend the life of the battery pack, increase the efficiency of the off-highway equipment and enhance the safety of the vehicle.

The Role of BMS in the Electrification of Off-Highway Equipment:

The adoption of electrification of off-highway equipment depends on the availability of reliable and efficient battery systems. BMS plays a critical role in ensuring that the batteries are used safely and efficiently maximizing their lifespan and performance. BMS provides several benefits that are essential for the electrification of off-highway equipment as follows:

- **Improved Safety:** BMS ensures the safety of the operator and the vehicle by preventing battery failures caused by overcharging, over-discharging, or overheating. By monitoring the battery's state, the BMS can detect any anomalies and take corrective actions to prevent safety hazards.

- **Increased Efficiency:** BMS optimizes the battery's performance by managing its charge and discharge cycles, reducing energy losses, and maximizing the battery's capacity utilization. This ensures that the Off-Highway Equipment's power requirements are met efficiently, reducing the vehicle's energy consumption and extending the battery's lifespan.
- **Enhanced Battery Life:** BMS monitors the battery's state of health and provides real-time information on its performance. This allows the operator to take proactive measures to maintain the battery's health and prevent any potential failures that may affect the battery's lifespan
- **Reduced Downtime:** BMS can predict the battery's remaining capacity and estimate its runtime, allowing the operator to plan the vehicle's operations efficiently. This reduces unplanned downtime due to battery failure, ensuring that the Off-Highway Equipment operates efficiently and effectively
- **Cost Savings:** BMS optimizes the battery's performance, reducing energy consumption and extending its lifespan. This leads to cost savings in battery replacement and maintenance, reducing the overall operational costs of the Off-Highway Equipment

Challenges in developing a Robust BMS for Off-Highway Vehicles

Developing a BMS for Off-Highway Vehicles presents numerous challenges that necessarily need to be taken care of to ensure the long-term viability of electric Off-Highway Vehicles. Some of the key challenges include:

- **Harsh Operating Environments:** Off-Highway Vehicles are often used in harsh operating environments, such as mining sites, construction sites, and agricultural fields. These environments expose the BMS to extreme temperatures, vibrations, and shock which can affect the performance and reliability of the system.

- **High Power and Energy Requirements:** Off-Highway Vehicles require high power and energy to perform their tasks, which places significant demands on the Battery pack and BMS. The BMS must be designed to handle these high power and energy requirements while ensuring the safety and longevity of the battery.
- **Cost:** Developing a robust BMS for Off-Highway Vehicles can be expensive and the cost involved of the BMS can significantly impact the overall cost of the vehicle. To ensure the widespread adoption of electric Off-Highway Vehicles, the cost of the BMS must be minimized without sacrificing performance and safety



Case Studies showing successful implementation of Electrification in Off-Highway Vehicles and components

There are several successful case studies of the implementation of electrification in off-highway vehicles across various industries. Here are some examples:

1. **Volvo Construction Equipment:** Volvo CE has been a leader in the adoption of electrification in the construction industry. They have developed several electric machines including the ECR25 Electric compact excavator and the L25 Electric compact wheel loader. These machines have demonstrated significant improvements in energy efficiency and reduced emissions, making them ideal for urban construction sites with strict environmental regulations.
2. **Komatsu:** Komatsu has also been a significant player in the electrification of off-highway vehicles. They have developed several hybrid machines, including the HB365LC-3 Hybrid excavator and the D475A-5EO Bulldozer. These machines have demonstrated improvements in fuel efficiency and reduced emissions making them ideal for use in the mining industry
3. **John Deere:** John Deere has developed several electric and hybrid machines, including the 944K Electric Wheel Loader and the 644K Hybrid Wheel Loader. These machines have demonstrated improvements in fuel efficiency and reduced emissions making them ideal for use in the agricultural industry.
4. **JCB:** JCB has developed several electric machines including the 19c-1E Electric mini excavator and the 220x Electric excavator. These machines have demonstrated significant improvements in energy efficiency and reduced emissions, making them ideal for use in urban construction sites

Overall, these case studies demonstrate the successful implementation of electrification in off-highway vehicles across various industries. The adoption of electrification has led to significant improvements in energy efficiency, reduced emissions, and improved performance, making them an attractive option for businesses looking to bring down their carbon footprint and improve their bottom line.

Case Studies where efficient Battery Management System ensured longer life of Electric Off-Highway Vehicle

1. One such case study is the Komatsu 830E Electric off-highway truck which utilizes an efficient battery management system to ensure a longer life of the vehicle. The battery management system ensures that the batteries are charged optimally, reducing the risk of overcharging or undercharging which can lead to premature battery failure. The system incorporated also monitors the health of the batteries and alerts the operator if any issues arise. The usage of this system has resulted in increased uptime and reduced maintenance costs for the Komatsu 830E.
2. Another example is the Caterpillar 794 AC Electric drive truck which also utilizes an efficient battery management system. The system helps to maximize optimal charging levels and monitor battery health. Additionally, the truck is equipped with a regenerative braking system, which helps to recharge the batteries during operation. This system has resulted in increased uptime and reduced maintenance cost for the Caterpillar 794 AC.

Future of Electrification in Off-Highway Equipment Industry



The electric off-highway equipment market is estimated to show remarkable growth in the coming years. The increasing demand for environmentally sustainable and cost-efficient solutions is driving the adoption of electric off-highway equipment. The mining and construction industries are estimated to be the largest adopters of electric Highway Vehicles due to the high operating costs and emissions associated with traditional internal combustion engine vehicles.

Advances in battery technology and charging infrastructure are expected to improve the range and performance of electric off-highway equipment. The development of solid-state batteries is expected to address some of the current limitations of lithium-ion batteries such as range, charging time, and lifespan.

Future Trends

1. **Electrification of heavy-duty vehicles:** The electrification of heavy-duty vehicles such as dump trucks and bulldozers is expected to be a major trend in the future of off-highway vehicles. The high operating costs and emissions associated with these vehicles make them ideal candidates for electrification.
2. **Electric Autonomous off-highway vehicles:** Electric Autonomous off-highway vehicles may become more prevalent in the future as they can improve efficiency and reduce operating costs. Autonomous technology may also improve safety by reducing the risk of accidents caused due to operator error.
3. **Integration of renewable energy:** Integrating renewable energy sources such as wind turbines and solar panels into off-highway vehicle charging infrastructure may provide a more sustainable and cost-efficient solution for powering electric off-highway vehicles.
4. **Fuel Cell Technology:** Fuel cell technology may become a viable alternative to batteries for powering electric off-highway vehicles in the future. Fuel cells offer high power density and longer range compared to batteries making them suitable for heavy-duty applications.

Conclusion

The electrification of off-highway equipment presents a promising future for businesses seeking to reduce their environmental impact and improve their bottom line. The benefits of electrification are clear, including reduced emissions, decreased maintenance costs, improved energy efficiency, and increased productivity. While there are certainly challenges associated with electrification such as upfront costs of equipment and the need for charging infrastructure, these can be mitigated by careful planning and investment.

As outlined in this whitepaper, there are several key factors that businesses should consider when evaluating the electrification of their off-highway equipment including the equipment's duty cycle, power requirements, and operational constraints. By carefully analyzing these factors, businesses can identify the best electrification solutions for their needs and maximize the benefits of electrification.

Moreover, it is important to recognize that electrification is not a one-size-fits-all solution. Each business will have unique requirements and constraints that must be considered when designing an electrification strategy. Therefore, it is recommended that businesses work closely with equipment manufacturers, energy providers, and other stakeholders to develop customized solutions that meet their specific needs.

Finally, it is important to note that the electrification of off-highway equipment is not just a trend but a necessity for sustainable business practices in the 21st century. As countries around the world continue to adapt to more stringent emissions standards and consumers become more environmentally conscious, businesses that fail to embrace electrification risk falling behind their competitors and losing market share.

References

1. Off-highway Vehicle Engine Market Size & Share Analysis - Industry Research Report - Growth Trends (mordorintelligence.com)
2. Off-Highway Electrified Equipment Market (nbmcw.com)
3. Electrification of construction equipment set to continue - Highways Today
4. Electrifying heavy machinery and equipment | McKinsey
5. Electrification – Analysis – IEA
6. Off-highway Vehicle Market Size, Share, Growth Analysis 2031 (transparencymarketresearch.com)
7. Global Heavy Duty Truck Electrification Market to 2027 - Analysis and Forecast by Components & Powertrain Type | Markets Insider (businessinsider.com)
8. How electrification is changing mining | New Scientist
9. Off-highway Electric Vehicle Market Size & Share Report, 2030 (grandviewresearch.com)
10. Electric Construction Equipment Market Size, Share, and Forecast Report by 2030 (marketsandmarkets.com)
11. Electrification Trends in Off-Highway Equipment | OEM Off-Highway (oemoffhighway.com)
12. How Innovation in Battery Management Systems is Increasing EV Adoption
13. (PDF) Battery Management Systems (BMS) for EV: Electric Vehicles and the Future of Energy-Efficient Transportation (researchgate.net)
14. Electric Vehicles in Construction, Agriculture and Mining 2020-2030: IDTechEx

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