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POWERTRAIN

THEMES & TRENDS

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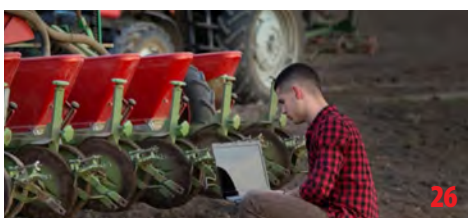
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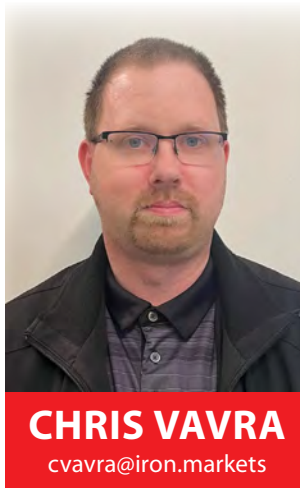
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The general feeling these days, it seems, is “cautious optimism” and it has reached the point of cliché. It doesn’t invalidate or diminish what many are feeling. The 2020s have been a turbulent time. We’re officially in the second half of the decade and who’s to say the next five years will be any different? It might not come in the form of a pandemic or a major conflict, but anxiety remains.

The good news is we haven't let these events get us down. People are resilient and they bring new and great ideas to work every day and collaborate with like-minded individuals. In the 2024 State of the Industry, while the respondents acknowledged how tough it's been the last few years, they are hopeful for the future. They see the potential of digital transformation, the industrial Internet of Things (IIoT) and the technological developments for off-highway vehicles. They're excited for what lies ahead.

The stories in this issue are representative of that optimism through innovation and pushing forward. During my travels this year, I hope to hear the same from many of you during my visits to booths, attending press events and listening to presentations about what people in the off-highway industry are doing and how they're embracing the future.

Stay tuned for recaps and write-ups throughout 2025 highlighting the best of what's happening on the ground from your colleagues and contemporaries in the off-highway industry. 



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CEMA President Elects Stefan Top as President

Stefan Top elected president of CEMA, the European Agricultural Machinery Association.

The CEMA Board of Directors and the CEMA General Assembly unanimously elected Mr. Top for a two-year term during their respective meetings in Strasbourg, France. Thierry Krier, Carlo Lambro, Alessandro Malavolti and Christoph Wigger have been elected vice presidents.

The engagement of senior company leaders with CEMA highlights the growing significance of the European

Union for the agricultural machinery industry.

Stefan Top is the managing director of AVR and has been the representative of the Belgian Federation Agoria in the CEMA Board of Directors since 2011. A seasoned professional with more than three decades of experience in the agricultural machinery sector, Mr. Top brings significant industry knowledge, expertise, and leadership to the role.

Top holds a master's degree in electromechanical engineering and a master's degree in industrial management from KU Leuven. His career began in 1993 as a design engineer at AVR. He has held numerous roles within AVR, including product manager sales director and board member before being named managing director in 2011. Top also has served as president of the business group for agricultural and horticultural machinery within Agoria since 2019.

Top succeeds Thierry Krier, president and CEO of Kuhn Group, who has led CEMA for four years. Reflecting on this transition, Top said in a statement: "I would like to express my gratitude to our outgoing president, Thierry, for his exceptional leadership over the past two terms. Thierry has guided our organization with great dedication and skill, steering CEMA through unprecedented challenges, including the COVID crisis. Under his leadership, we have successfully held impactful CEMA summits, welcomed a new Secretary General, and strengthened the voice of our industry in Europe. Thank you, Thierry, for your unwavering commitment and for leaving CEMA stronger and more resilient than ever." ■



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Motion Agrees to Purchase Conveyance Company

Motion signed a definitive purchase agreement to acquire the operating assets of U.S.-based

International Conveyor and Rubber (ICR). The transaction is expected to close at the end of December 2024.

ICR services commercial and industrial customers in the eastern United States. Headquartered in Blairsville, Penn., the company has seven locations that offer sales, installation, repair and maintenance of conveyor belt. They also provide engineering and design services for custom solutions.

ICR serves many industries, including mining and aggregates, power generation, oil and gas, construction,

steel, building materials manufacturing, package handling and distribution, wood/pulp/paper and more..

"ICR is highly complementary to Motion, adding seven strategic locations that expand our reach," said James Howe, President of Motion. "We are thrilled to welcome the highly talented ICR employees to the Motion team, including Kory and the other owner-operators, who will continue to play an integral role in the business." ■



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CEAT Acquires Camso Brand Off-Highway Tires, Tracks Business From Michelin

CEAT and Michelin announced they have entered into a definitive agreement for CEAT to acquire Camso brand's off-highway construction equipment in an all-cash deal of around \$225 million.. Camso is involved in construction equipment tire and tracks with strong equity and market position in EU and North American aftermarket and OE segments.

This will expand CEAT's product portfolio in the OHT and tracks segments related to compact tires and construction tracks.



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Turntide Expands, Integrates European and Asian Operations

Turntide Technologies integrated its three U.K. facilities into a centralized engineering campus and the production launch of its class leading power electronics in India to meet the growing demand for electrification solutions globally.

Enhancing collaboration, efficiency in the UK

Turntide is integrating its Sunderland

site, focused on energy storage (batteries/battery management systems), and its Cramlington site, specializing in thermals (fans, motors, and pumps), into its head office and engineering campus at Team Valley Gateshead. This move will streamline operations, enhance collaboration across teams, and further improve product quality.

The Sunderland and Cramlington facilities will remain operational for additional storage and engineering testing capacity. The phased relocation ensures minimal disruption. Current operators, equipment and processes will

transition to Gateshead, supported by a robust change management process. A unified integrated management system also will cover all relevant certifications (ISO9001, IATF16949, ISO14001 and ISO45001), simplifying compliance and maintaining the highest quality standards.

Expansion into India

Turntide is making inroads in India and the Asia-Pacific region — the world's most rapidly evolving markets for electric light duty vehicles, including two-wheelers, three-wheelers, and four-wheeler light commercial vehicles, with its low-voltage inverters specially configured for the unique requirements of this region. ■



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Class 8 Truck Orders End 2024 on High Note

FTR reported preliminary North American Class 8 net orders in December totaled 31,900 units, down 7% month-over-month (m/m). However, there was a 23% increase year-over-year (y/y). This figure slightly outperformed seasonal expectations, surpassing the seven-year December average of 29,716 net orders. Despite a sluggish truck freight environment, the 2025 order season (September through December 2024) has seen cumulative net orders up 6% y/y, signaling positive momentum as we enter the new year.

Full-year 2024 total Class 8 net orders were up 11% y/y, a performance slightly surpassing replacement demand levels at an average of 23,323 net orders per month. Class 8 orders for full-year 2024 totaled 279,872 units. ■



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Uncertainty, CHALLENGES AHEAD for Agriculture Industry

The state of the agriculture industry faces uncertain economic headwinds due to weather and tariff worries. See additional insights about the construction and mining industries.

by Chris Vavra, Eli Lustgarten

This series examines the state of the off-highway industry and analyzes the trends happening and what it might mean in the short- and long-term for the industry. Each installment also will dive deeper into one of the three key industries that are crucial to the off-highway industry: Agricultural, construction and mining.

The information used in this article has been prepared by Eli Lustgarten, president at ESL Consultants. He is an expert in the manufacturing and off-highway industries with more than 40 years of experience and has spoken at many events on manufacturing topics.

December 2024 Manufacturing Status

The industrial sector and most heavy equipment markets are facing uncertainty and have slowed things down due to weak macroeconomic fundamentals both here and abroad. Softer demand, slow declining interest rates and global conflicts has resulted in significant inventory reduction and have left many companies

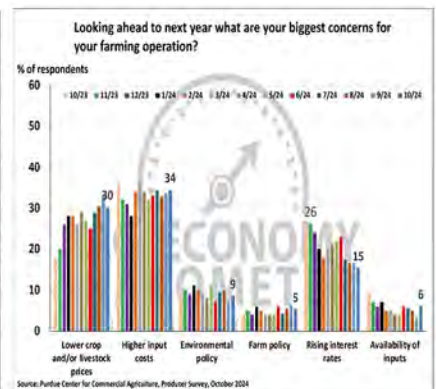
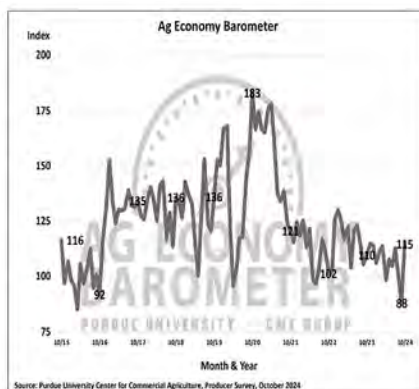
and industries in a holding pattern, particularly in Europe. This will likely continue through the first half of 2025.

The state of U.S. manufacturing remains in contraction according to the Institute for Supply Management (ISM), which monitors the industry's strength with their Purchasing Manufacturers' Index (PMI). It registered at 48.4% in November, which means the industry

has been below the threshold (50) for 24 of the last 25 months.

Some of this isn't unexpected because there had been issues with supply chain bottlenecks, inflation and overheated demand due to the COVID-19 pandemic. It was inevitable there would be a pendulum swing in the other direction.

The global economy also has been in a general holding pattern due to factors



The sentiment for the agricultural industry has rebounded from a 10-year low, but concerns about input costs and prices remain high.

outside their control and manufacturing, while holding steady, hasn't been able to break through the fog.

The next six months are likely to reflect continued uncertainty. In the U.S., it depends on what happens with the new administration and their actions toward government spending, especially the Inflation Reduction Act, The Chip Act and the Infrastructure Act. Will tariffs be imposed on countries like Mexico, Europe and China? If so, how will they respond and what will the effect be on the United States? Will imports and exports decline to these countries? Is inflation going to be a major problem again? What will that do?

It's very much like a game of Dominoes, but the problem is, it's hard to predict where the next domino will fall because of all the geo-political variables hanging in the balance.

Hopefully, 2025 will be the mirror image of 2024 with demand and production recovering after a slow start and showing some strength in the second half of the year. Many companies and industries were in a holding pattern, particularly in the U.S., due to the election. Now that it's over, maybe they'll be able to breathe again.

State Of The Key Off-Highway Industries

This will examine the three key off-highway industries: Agriculture, construction and mining in a general sense to see what's happening and what the key players in these industries are doing, as well.

State of the agricultural industry

Farmer outlook remains very cautious with capital investment plans remaining weak. The decline in sales in 2023 and 2024 has brought sales down to more normal levels after the sugar rush from 2020, 2021 and 2022 due to the COVID-19 pandemic. That's something many industries endured, but agriculture, in particular, has been affected by. It's also problematic because the industry is being affected by rising carryovers and declining commodity prices. It also is highly dependent on good weather, particularly in milder climates. The crystal ball only goes so far. Market weakness is expected to continue in at least the first half of 2025 and it could be exacerbated by tariffs and other factors beyond the farmers' control.

State of the construction industry

Construction spending has slowed throughout 2024, particularly in the commercial sector. Equipment sales also will decline into 2025 as inventories are liquidated, which is a continuing theme as spending continues to be an issue. The architectural index has been soft since 2022 and not showing any basis for improvement. If tariffs are imposed, the AGC believes higher tariffs will raise costs and could result in supply chain issues if other countries retaliate. Construction equipment sales decline in 2024 of 5 to 15% will likely continue into 2025.

The softer construction industry is reflected by Caterpillar. In their earnings release, 4th-quarter results in 2024 are down compared to the same period in 2023 with lower machine sales and inventory from their key suppliers and dealers. This is expected to continue into 2025.

There may be some hope for construction sectors such as infrastructure, power and data centers, but that is somewhat dependent on what happens with the new administration.



Industrial Production: Manufacturing (NAICS)



NAICS, HCOB, S&P GLOBAL PMI

Manufacturing production has remained steady since the COVID-19 pandemic, but political and economic concerns remain.

State of the mining industry

Mining markets are expected to be softer as global economic conditions remain sluggish and the slow decline in interest rates. Commodity prices also are expected to be soft and there's great uncertainty about what the future holds. There's been a greater push for sustainability and green energy in the mining industry, which is known for heavy CO₂ emissions. While the big players are dedicated to improving their bottom line toward saving energy and lowering costs, it's a question of how far and how hard to push, especially given the economy's turbulence the last few years. The future is uncertain for power, green energy and electrification, particularly in automobiles, and it has had a negative effect on spending and new project development all over the world. This uncertainty has been exacerbated by government changes in France, Germany and Canada.

“

Many companies and industries were in a holding pattern, particularly in the U.S., due to the election. Now that it's over, maybe they'll be able to breathe again.”

A Closer Look At The Agricultural Industry

North American farm equipment fundamentals entering 2025 remain weak, plagued by large crops rising carryovers and higher interest rates for longer causing declining commodity prices to levels driving farmers to unprofitability. Farm equipment sales have continued declining through the second half of 2024.

Original equipment manufacturers (OEMs) have sharply lowered production, and undertaken a significant inventory reduction which will continue into the first half of 2025.

Significant layoffs continue to be announced by all producers including a new recent job reduction by John Deere for January 2025.

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Despite the troubled outlook, farm sentiment has improved post-election as the change in administration brought optimism to the farm belt to the highest level since May 2021. The improved optimism reflects the likelihood of a more favorable regulation and tax environment for agriculture as the new administration implements its growth objectives.

The first two weeks of 2025 has contained several surprises. John Deere has announced more layoffs due to weak demand. However, the most recent WASDE report from the U.S. Department of Agriculture showed some significant revisions in the forecast for the 2024-25 crop projections. The projected corn yield was dropped 3.8 bushels to 179.3 bushels per acre, which had the effect of reducing the U.S. projected corn carryover from 1.74 billion to 1.54

billion bushels, which is only modestly above normal.

The projected average price of corn rose \$0.15 to \$4.25. Soybean projected crop also was reduced. For now, holding back better prices are record crops projected in South America. These revised suggestions suggest that the first half of 2025 could quite possibly be the bottom for the Farm Equipment industry.

For now, the farm sector has to work through the current weak fundamentals, inventory reduction and manage the possibility and impact of a tariff-induced trade war. The industry faces another year of potential double-digit sales decline, particularly in the first half of 2025. The longer-term outlook is improving and is aided by significant new technology being introduced.

For example, John Deere is in the process of introducing its largest new product program including new HHP tractors, fuel-efficient combines smart sprayers, new engines, new hydraulic pumps and automation and guidance systems. New electrical variable transmission, including hybrid, which can use diesel engine to provide electricity to drive attachments and/or drivetrains. Artificial intelligence (AI) also is being implemented by manufacturers in its technology stations. ■

Chris Vavra is editor of OEM Off-Highway; Eli Lustgarten is president of ESL Consultants.



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POWERING MACHINERY PROGRESS with Electrification

OEMs in the off-highway industry are facing challenges as the industry moves toward electrification, but this can be an opportunity with the right approach.

by Rod Dayrit

As the global drive toward electrification continues reshaping industries, original equipment manufacturers (OEMs) in the off-highway sector face growing regulatory pressures. These challenges demand innovation, but they also present a chance to leverage solutions from parallel sectors.

There are several ways the off-highway industry overcome obstacles in achieving electrification and build toward a thriving future.

A Generational Model for Electrification

Historical breakthroughs often guide future innovations. Similarly, the evolution of electrification in adjacent sectors indicates a clear trajectory for off-highway machinery.



Figure 1: Decarbonization and adherence to environmental over time and vehicle.

Electric forklifts and indoor machinery serve as prime examples of early electrification efforts. While industries often credit the automotive sector with pioneering electrification, few recognize the material handling

sector laid the foundational groundwork for this innovation.

These machines demonstrated early success with emissions-free solutions in demanding environments, paving the way for modern passenger electric vehicles (EVs).

With stricter CO₂ emission regulations driving change, the same pattern repeats today. Off-highway electrification now benefits from mature electric technologies — such as advanced charging solutions — developed in parallel industries.

With future growth anticipated in higher-powered, industrial applications, OEMs can utilize established markets as case studies for developing electric and hybrid solutions.

Figure 2: Example of electric powertrain system integration.



This progression a three-part “generational model” of electrification, comprising:

- **Generation 1** – Early proof-of-concept designs using standard parts from other industries to create an electric drivetrain.
- **Generation 1.5** – A phase of iterative refinement, with design decisions focused on enhancing performance, reducing costs, and delegating more tasks to suppliers.
- **Generation 2** – Full maturity, where third-party integrators manage optimized subsystems, allowing OEMs to focus on market-specific customization and seamless integration.

Fully integrated drivetrains mark the ultimate goal. By replacing systems composed of disparate parts with cohesive designs, each component works in harmony for maximum efficiency.

Chargers: The Centerpiece of Integration?

Achieving this integrated future in electrified machinery starts with the right charging solution. An OEM's charger selection is not an afterthought, but the backbone of next-generation drivetrains. Two factors support this statement:

- A charger tailored to the machine's application improves the battery's efficiency, safety, and lifespan. Since the battery is often the most expensive component, it makes sense to protect this investment and maximize its value with the right charger.
- Charging an electric or hybrid machine is far more complex than refueling an internal combustion engine counterpart. An on-board charging solution is non-negotiable in bridging the gap between the machine's battery and varied charging infrastructures.

The second point is particularly crucial given the significant growth in EV charging infrastructure — a market

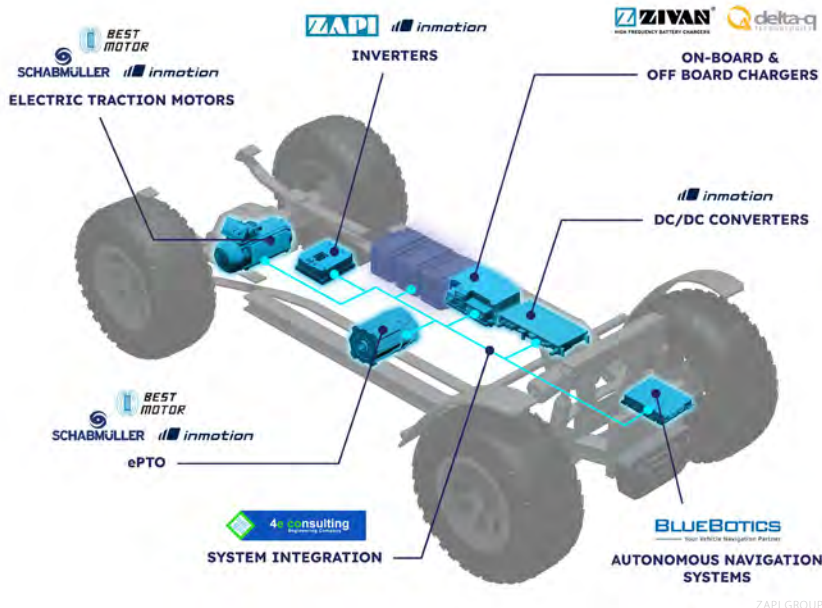


Figure 3: On-board and off-board charging solutions.

anticipated to be worth \$12.1 billion by 2030.

This circles back to the charging solution. On-board chargers simplify logistics and broaden recharging options for OEM machinery across various settings, from public EV stations to basic ac wall plugs.

Unlocking these efficiencies — such as opportunity charging for heavy construction equipment — requires chargers designed to meet the specific challenges of off-highway applications. Without them, the vision of seamless electrification remains incomplete.

Real-World Developments and Applications

Besides meeting sustainability goals, emerging technologies continue to redefine the electrification landscape and fuel new OEM designs. Consider these four examples:

- Gallium Nitride (GaN) and Silicon Carbide (SiC) drive new efficiencies in power electronics, reducing losses and improving performance.
- Lithium batteries deliver greater energy density and smarter integration capabilities, meeting the increasing power demands of industrial machinery.
- Battery management systems (BMS)

enhance operational safety, provide predictive maintenance insights, and adapt charging profiles for maximum battery performance.

- CANbus protocols facilitate remote fleet monitoring and management, streamlining operations and reducing machine downtime.

Real-world applications exemplify the possibilities of these technologies in off-highway applications, expanding options for OEMs and end-users alike.

For instance, Delta-Q Technologies operates an automated battery charger test lab for applications ranging from golf carts to construction. By calibrating custom charging profiles and algorithms to match the application, the facility ensures every charger maximizes battery cost performance.

ZIVAN leverages advanced communication protocols to empower fleet managers with real-time analytics and charge control. These “battery rooms” extend battery life by implementing strategies like first-in-first-out rotation and automated recharge management. Such tools allow managers to predict maintenance and replacement needs, regardless of fleet size or complexity.

Both case studies underscore a crucial point: OEMs must cultivate strategic

partnerships to navigate electrification efficiently and at scale.

Overcoming Integrated Solution Challenges

While internal combustion engines rely on discrete components working together to generate motion, an integrated electric drivetrain operates differently — each component enhances the performance of the others.

This interconnectedness requires OEMs to navigate certain trade-offs — particularly between flexibility and cost efficiency.

For example, consider two potential scenarios when upgrading an electric drivetrain:

- Upgrades for non-integrated setups are a simple process. Each component can simply be replaced as needed. Although this approach incurs a higher upfront cost due to varied parts and design complexity, it provides significant flexibility for future modifications.
- A fully integrated solution presents a greater challenge given its interconnected design architecture. Though optimized for cost and performance, such a solution lacks the flexibility to swap or upgrade components independently.

These examples aren't intended to discourage a fully integrated future. Rather, it showcases the considerations OEMs must address when electrifying. Even partially integrated systems face similar trade-offs, requiring design teams to balance performance, cost, and flexibility for their specific applications.

Rather than transactional supplier relationships, OEMs must prioritize strategic partnerships with electrification experts to develop electrified solutions tailored to meet evolving demands.

Developing Electrification Partnerships Are Key for The Future

Cross-industry expertise has always been the engine of innovation, and today's off-highway machinery sector is no different.

The only difference is electrification is no longer optional — it's a regulatory and operational necessity.

As the industry moves toward fully integrated solutions, partnering with electrification experts from the initial design stage is crucial. Such a proactive approach will allow OEMs to avoid expensive backtracking and ensure a seamless transition to an all-electric future.

Electrification isn't just about powering machinery. It's about powering progress — and OEMs who embrace these technologies will lead the way. ■

Rod Dayrit is the global director of business development for ZAPI GROUP charging solutions.



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MAXIMIZING Machine Efficiency with Hybrid Valve Technology

Hybrid valve technologies can help off-highway OEMs realize their equipment's potential by mixing modularity, precision and adaptability.

by Scott Parker, Ross Johannes

The increasing complexity of off-highway machinery and the evolving landscape demand hydraulic systems that deliver optimal performance, energy efficiency and precision. Hybrid valve technology represents a revolutionary advancement for original equipment manufacturers (OEMs) looking to optimize their equipment's potential. By blending the modularity of cartridge valves with the precision and adaptability of sectional valves, hybrid valves provide unmatched precision, energy savings and operational versatility.

Design Synergy: Function vs. Application

Across multiple industries, each machine has unique hydraulic requirements, and hybrid valves offer greater versatility to meet those demands compared to traditional valves.

Cartridge valves offer significant flexibility in hydraulic system design due to their modular nature. Their modular design allows users to customize systems by adding or replacing individual valves without needing to modify the entire valve assembly.

This makes cartridge valves especially valuable in mobile equipment like excavators and plow trucks, where uptime is critical. Their compact design and easy serviceability also make them ideal for lower-flow applications, such as downforce control in seed planters to ensure consistent planting depth and improve crop yields, as well as in 3-way solutions for compact machines requiring precise control and space-efficient designs.

Sectional valves are comprised of several interconnected sections or "modules," each controlling a specific hydraulic function. Their biggest advantage is users can pack all this functionality into a compact package. Sections can be bolted together in a modular fashion, allowing customization and expansion. Sectional valves are designed to handle higher flow rates and higher pressures, making them well-suited for demanding applications where advanced functionality is required, such as controlling high flow steering circuits in mobile equipment like wheel loaders, where precision is crucial for safe operation.

Cartridge valves and sectional valves

are primarily hydraulic based, lacking the direct integration of electronic control. While they can provide high flow and reliable control, it can be challenging for them to adapt to changing system conditions in real time without external sensors or control units.

Hybrid Valve Solutions: Bringing The Best Of Both Worlds

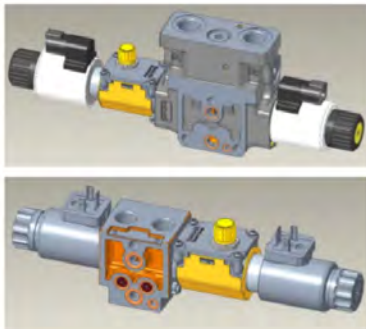
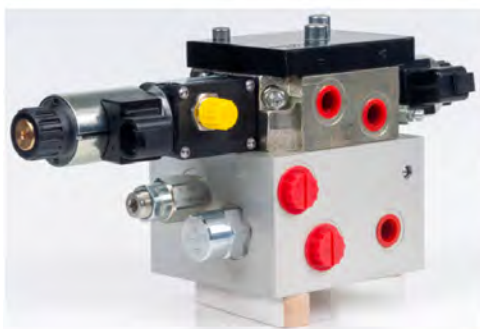
Hybrid valve solutions combine the best core functions of cartridge valves with sectional valves and integrate multiple hydraulic functions and electronic controls into a single valve assembly. Fewer components and simplified integration reduce the complexity of the hydraulic systems, leading to easier installation and troubleshooting and less potential for system failure. Hybrid valve solutions also optimize space utilization in compact equipment, enabling high functionality without increasing the system's footprint.

While cartridge valves and sectional valves are effective for specific applications, hybrid valve solutions provide the best of both worlds, offering improved functionality, efficiency and adaptability for complex hydraulic systems in mobile equipment. In industries like construction or agriculture, where machine designs can vary greatly based on the specific task, hybrid valves can be designed to optimize performance, such as dynamically controlling fan speed based on engine temperature and reducing fuel consumption.

By combining the capabilities of hydraulic valves and advanced electronic control into one solution, hybrid valves maximize the benefits of cartridge and sectional valve designs to improve energy efficiency and performance in mobile and industrial applications.

Hybrid Valve Design Innovations

Hybrid valve technology addresses the unique requirements of various applications by combining distinct advantages of different valve designs. These systems feature an integrated electro-hydraulic architecture that enables seamless interaction between



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Hybrid valve technology combines distinct advantages of different valve designs for off-highway OEMs.

the mechanical and electronic components, offering OEMs the opportunity to optimize machine performance while reducing complexity. (See Figure 1).

Hybrid valve technology has seen significant design innovations, particularly in response to the growing demand for more efficient, compact and flexible hydraulic control systems. Modern hybrid valves are being manufactured using lightweight and durable materials to reduce energy consumption and increase functionality, all while minimizing the overall system footprint.

Hybrid valves incorporate electronic proportional control, allowing for more precise adjustments of flow and pressure based on sensor inputs. These valves use feedback loops to adjust fluid flow continuously, improving the system's ability to react to dynamic operating conditions. Their modular design allows OEMs to customize and scale systems based on application needs.

The symmetrical slice valve design can be an important component in hybrid valve solutions, particularly in systems that require hydraulic and electronic control by enhancing the performance of these valves, especially in high-flow, high-efficiency applications. Actuators and solenoids are positioned on both sides of the valve slice, improving system stability and reducing pressure fluctuations in high-demand applications like hydraulic cranes.

Sensors can also be embedded in hybrid valves to enable real-time

data collection on flow, pressure and temperature to allow predictive maintenance and reduce unplanned downtime.

Load-sensing technology has evolved a lot. When combined with post-compensation mechanisms, it provides even more dynamic control of hydraulic systems. Hybrid valves now feature advanced load-sensing capabilities, where the valve adjusts its operation based on real-time load feedback. This means the valve can sense changes in pressure and adjust the flow accordingly, reducing energy consumption and ensuring the system operates optimally under varying loads.

Post-compensated systems dynamically adjust flow and pressure after the initial command is made, accounting for changes in load or external factors. This allows for greater precision in maintaining consistent hydraulic force, improving machine performance even in highly variable conditions. For example, in telehandlers, hybrid valves manage hydraulic flow between lifting and steering functions, optimizing machine performance.

The latest design advancements in hybrid valves have transformed hydraulic control systems, offering enhanced functionality, reduced maintenance and the ability to meet the increasingly complex demands of modern hydraulic systems.

Hydraulic Valve Applications

Hybrid valves are making an impact in many ways such as improving cycle times in excavators and loaders. They also are enabling precision planting and harvesting solutions with reduced soil

compaction and enhancing control in forklifts and cranes for safer operation.

For example, hybrid valves illustrate their versatility in vehicles with multiple and diverse functions like plow trucks with integrated salt spreaders. Different trucks require different functions and valve configurations, in addition to the standard functions. Hybrid solutions allow for precise material application while ensuring efficient hydraulic flow to auxiliary systems. They can monitor and control the speed of the salt-spreading mechanism, adjusting the amount of salt dispensed based on the motor load. This is achieved through operator interfaces, joysticks, controllers, and the hydraulic system controller.

For example, the truck's two-way spreader functions can be managed with proportional control cartridges in the valve inlet while its four-way plow and dump bed functions can be managed with on/off slice valves. Modular PO-check valves, counterbalance valves and cross-port relief can also be integrated with plow sectional valves, depending on the specific plow truck configuration

Improving Off-Highway Machinery Precision And Sustainability

Hybrid valve technology marks a significant advancement in hydraulic systems for off-highway machinery, offering a range of new capabilities for industries requiring precision, adaptability and energy efficiency.

By combining cartridge and sectional valve benefits, OEMs can overcome traditional challenges and achieve new levels of productivity and sustainability in their operations. As advancements in materials, control systems and connectivity continue to evolve and drive market innovation, hybrid valves are poised to play a pivotal role in shaping the future of hydraulic innovation. ■

Scott Parker is a senior application engineer and Ross Johannes is the application tech services team leader at HydraForce.

Pump and Motor Considerations in Off-Highway Vehicle Electrification

Electrification is on the rise for off-highway vehicles in the construction industry and companies must take care pumps, motors and other equipment can operate effectively regardless of the situation or condition.

by Mattia Buscherini

The construction industry's transition toward electrification demands careful evaluation of motor technologies, cooling systems and integration strategies. This examination of key technical considerations helps guide successful off-highway application implementation.

The Rise Of Permanent Magnet Motors

Permanent magnet motors (PMMs) are becoming a preferred choice for electric construction equipment due to their high-power density, efficiency and compact design. Compared to the more traditional induction motors, PMMs provide several advantages such as:

- **High torque-to-weight ratio:** This makes them ideal for demanding applications such as construction.
- **Improved efficiency:** Operates efficiently across a wide speed range.
- **Compact design:** This enables flexible integration into existing machinery designs.

Application Considerations For Motors In Off-Highway Vehicles

When selecting electric motors for off-highway vehicles, engineers must consider operating conditions. Digging a little deeper, this includes knowing about specific operational demands, application-based load profiles and requirements specific to the industry. Performance demands such as peak load management, maximum torque requirements and continuous operation parameters are also important.

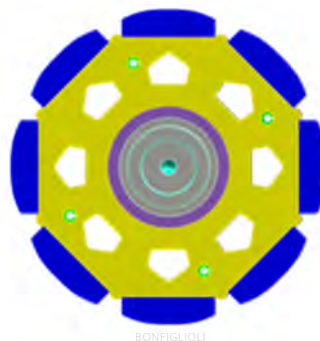
Environmental factors such as environment tolerance, thermal management needs and operational capabilities also need to be addressed, particularly in construction and mining, which can have hazardous areas for workers as well as the vehicles they're operating.

When it comes to system optimization, there are a few things to consider. Operators can ensure performance validation with an efficiency map analysis, torque curve evaluation and power delivery optimization.

Energy efficiency shouldn't be forgotten, either. Look for ways to reduce consumption while ensuring optimal operation and system efficiency.

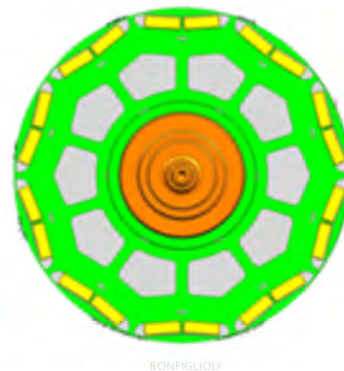
Choosing The Right Magnet Motor

Permanent magnet motors can be designed with either surface-mounted or internally embedded magnets, classifying them as surface permanent magnet (SPM) or internal permanent magnet (IPM) motors. Each technology offers unique advantages and is suited for different applications:



Example of a surface permanent magnet (SPM) rotor.

SPM motors excel in hydraulic pump drive applications and provide consistent performance at lower speeds. They also optimize efficiency in constant torque applications and deliver superior low-speed torque characteristics.



Example of an internal permanent magnet (IPM) rotor.

IPM motors support higher power density applications and can perform efficiently at higher speeds. They also offer extended speed ranges through field weakening.

Two Thermal Management Approaches

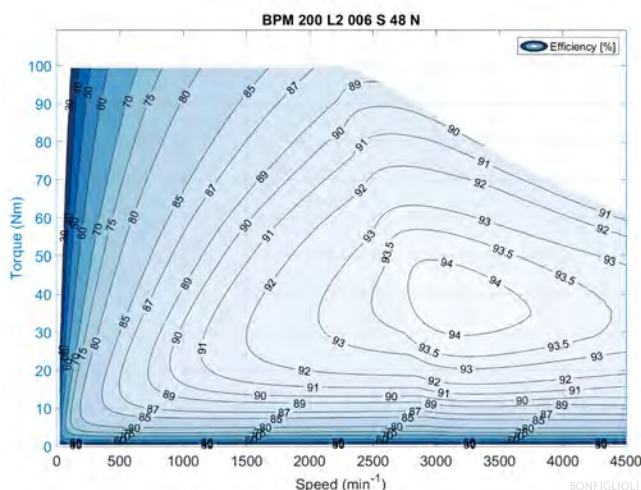
Effective thermal management is crucial for ensuring optimal performance and longevity of electric motors, especially in demanding off-highway applications. The two most common methods are natural ventilation and liquid cooling.

Natural ventilation benefits include:

- Eliminates the need for additional cooling circuits
- Reduced system complexity
- Enables more radial compact installations.

Liquid cooling benefits include:

- Enabling operation in confined spaces, which reduces motor length while keeping the output power constant
- Provides consistent performance in harsh environments
- Offers the choice between oil or glycol cooling.



Efficiency maps provide crucial visual representation of motor performance across operating conditions.

Electric Motor Performance Optimization

Understanding the performance characteristics of electric motors is vital for optimal system design in off-highway applications. Maximizing the efficiency can lead to a saving on the battery dimension, leading then to a reduced battery pack (economic saving) or in offering premium machine performances to customers that can count on extended duty cycles.

Efficiency maps, for example, provide crucial visual representation of motor performance across operating conditions. These contour plots reveal:

Operating points optimization, which highlight peak efficiency regions, optimal speed-torque combinations and performance boundaries at different operating conditions.

System design benefits from these maps include energy consumption reduction strategies, a better understanding of thermal management requirements and duty cycle planning capabilities.

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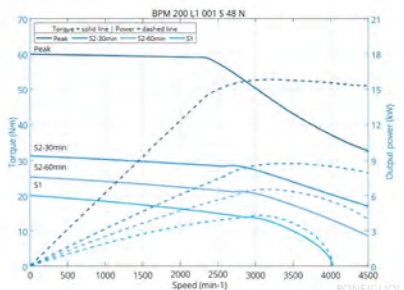
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Power and Torque Curves

Power and torque to speed curves are critical for motor selection and system integration: Characteristics include:

- Peak torque capabilities across speed ranges
 - Continuous operating limits
 - Power delivery characteristics
 - Field weakening region behavior.
- Design application benefits include:
- Enabling accurate machine performance prediction through simulation
 - Reduces development time by validating designs before physical testing
 - Facilitating optimal gearbox ratio selection
 - Preventing system mismatches in early design phases.



Power and torque curves are critical for motor selection and system integration.

Voltage Selection Strategy

The choice between low-voltage (LV) and high-voltage (HV) systems requires careful consideration of many different factors. While some of the situations and challenges are similar, they manifest in different ways.

When it comes to low-voltage systems (24 to 96 Vdc), they are traditionally preferred for lower applications because of:

- Wide availability of LV components
- Reduced safety system requirements
- Simplified maintenance procedures
- Lower system complexity.

While high-voltage systems (400 to 800 Vdc) are historically reserved for high-power applications, they're seeing broader adoption due to:

- Improved component availability
- Enhanced charging capabilities
- Higher system efficiency
- Reduced current requirements.

With modern applications, advancing technology has blurred traditional voltage selection criteria because high-voltage components are more viable for lower applications. System choice now depends on specific applications.

Customization and Integration Considerations

The integration of electric powertrains into existing equipment designs requires operators and engineers to consider several factors. With modular motor design, consider things such as customizable internal stack lengths, scalable power and torque outputs and adaptable mounting configurations. The interface also should be flexible when it comes to power connections, mechanical interfaces and system integration.

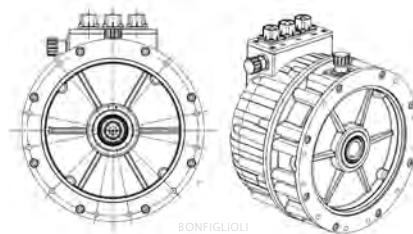
For power connections, consider configurable cable arrangements, application-specific connectors and customizable terminal layouts to find the best possible solution. For the mechanical interface, consider its compatibility with already existing components to cut costs and think about mounting options and adaptable output flanges.

System integration considerations include sensor integration points, choosing the right control system interface and cooling system connections.

The system also should be compatible, which can cause some challenges when it comes to system integration. For a hydraulic system, engineers should be aware of direct pump drive capabilities, mounting configurations and pressure system requirements.

For a drivetrain adaption, the gearbox and traction should be top of mind

as well as whether multiple shaft configurations are needed.



Integrating electric powertrains into existing equipment designs requires careful consideration of design enabling, flexibility and system compatibility.

Future Electrification Technology Developments

As electrification technology continues to evolve, we can expect advancements such as:

- Improved battery chemistries with higher energy density
- More efficient and compact power electronics
- Advanced motor designs with even higher power density
- Integrated systems that combine electronic, electric, and hydraulic technologies for optimal performance.

The electrification of construction equipment presents significant opportunities for improved efficiency and reduced environmental impact. Success requires careful consideration of motor technology selection, thermal management, system integration, and performance optimization. As these technologies advance, their adoption will increase across many applications, supporting productivity and sustainability goals. ■

Mattia Buscherini is Bonfiglioli eMobility Sales Manager, North America.

Developing Tire Technologies for **DIFFERENT INDUSTRIES**

Hrishikesh Damodar answers questions on how to develop the right tires and what companies can do to improve R&D as well as better understand how to meet customer expectations and demand.

by Hrishikesh Damodar



Off-highway tires vary depending on the application and the industry and knowing what is required to meet customer expectations is tricky. Many off-highway environments are difficult and demanding for the workers as well as the vehicles used. Whether it's a mine, a farm or a construction site, the large vehicles companies use need to be dependable and reliable and that's especially true for tires. They can't risk a breakdown or have issues.

Understanding what's needed for these different environments and staying ahead of the curve is a challenge for off-highway vehicle tire manufacturers.

Hrishikesh Damodar, lead technology and coordination for BKT Tires, discussed some of these challenges in a Q&A with *OEM Off-Highway*. He also addressed

the role alternative materials play as well improving fuel efficiency, reducing carbon footprints and improving sustainability.

QUESTION: What are the latest advancements in tire and track technologies for off-highway vehicles?

Damodar: Modern agriculture is constantly evolving and demands increasingly advanced solutions to tackle complex challenges and to ensure efficiency and productivity in the fields.

To address these needs, it is crucial to choose the right tire for the specific application. The development and implementation of very high flexion (VF) tire technology has emerged as an effective solution to meet these demands, allowing for carrying 40% more load at the same inflation pressure compared to a standard tire of the same

size or operate at 40% lower pressure while carrying the same load.

For this reason, we have invested a lot in developing new solutions that significantly improve customers' operations and satisfaction.

We also are exploring the integration of smart technologies in their products. This includes sensors embedded in tires to monitor parameters such as temperature, pressure, and tread wear, allowing for real-time data collection and improved fleet management.

QUESTION: What roles do alternative materials play in the development of off-highway tires and tracks?

Damodar: As a responsible tire manufacturer we examine the entire manufacturing process, from the acquisition of raw materials to the tangible finished goods. The BKT's

Poddar Innovation Hub in Bhuj, India, is an example that demonstrates our commitment to excellence: From the continued improvement of the tire design, to the development of specially formulated compounds aimed at optimizing performance across various terrains and operational conditions.

Through our R&D investment, we ensure the continuous introduction of innovative technologies and materials. For example, one key areas of focus have been the recycling and replacement of existing raw materials with more sustainable alternatives. Our Research & Development team is actively working on replacing petrochemical-based materials with bio-based options..

QUESTION: What are the key design differences between tires and tracks for optimal performance in various terrains?

Damodar: The main design differences between tires and tracks are related to the contact surface area, to traction

and maneuverability, speed and efficiency, durability, cost and maintenance. In detail, tires have a smaller contact patch which provides higher ground pressure but less traction on soft or loose terrain, performing better on hard and solid surfaces. While tracks have a larger contact area, thus reducing ground pressure and increasing traction on soft, uneven, or loose terrains like mud, sand or snow.

Traction also is one of the main differences, as tires are designed with tread patterns to optimize traction on various surfaces, such as asphalt, gravel, or agricultural fields; on the contrary, tracks provide superior traction on soft, slippery, and uneven terrains because they grip more effectively across a larger area. In terms of maneuverability, tires allow high-speed transports and are easier to drive, while tracks offer slower speed due to higher rolling resistance, making them more difficult to manage on hard



HRISHIKESH DAMODAR

Lead Technology and Coordination

BKT Tires

surfaces, as more effort is needed to move the vehicle.

QUESTION: What innovations are improving fuel efficiency and reducing carbon footprints in off-highway vehicles through tire and track designs?

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Damodar: There are some measures we are actively working on to improve fuel efficiency and reduce carbon emissions. These include the development and usage of eco-friendly compounds in the tire manufacturing process, specifically designed to ensure lower rolling resistance, thus affecting fuel efficiency. We are also incorporating recyclable and renewable materials to make our products more environmentally friendly, without compromising performance and durability. In fact, we are focusing on improving the lifespan of our solutions for a reduction in the frequency of replacements. Our sustainability approach extends throughout the entire supply chain, working closely with our suppliers and partners to ensure that materials and processes are responsibly.

QUESTION: How do tire and track requirements differ across industries, such as construction, agriculture, forestry and mining?

Damodar: Each sector has unique challenges that influence tire and track design, performance, and durability, all these related to the specific application needs. Construction tires need to be able to work in harsh environment carrying heavy loads, so their main features are robustness and resistance. Also, they need to provide excellent grip and stability even on unstable grounds, resulting in efficiency and security. These requirements are almost similar of those of mining tires, that need to support massive weights in harsh conditions and on uneven surfaces. Moreover, they need to withstand high temperatures due to prolonged heavy load operations. Finally, agricultural tires are engineered to minimize soil compaction and to preserve crops. Given the large distances often travelled in fields, agricultural tires ensure lower rolling resistance, improving fuel efficiency and lowering operating costs, which results in more efficiency and productivity.

QUESTION: How do extreme weather conditions, such as heat or freezing temperatures, affect tire and track performance in off-highway vehicles?

Damodar: Extreme weather conditions, such as heat and freezing temperatures, can significantly impact the performance and longevity of tires and tracks. These weather conditions affect the rubber compounds, traction, durability, and safety, which are critical for the performance. For example, at freezing or sub-zero temperatures, rubber compounds become stiffer and less flexible. This results in reduced grip, as the tire or track is less able to conform to the surface it is operating on. In extreme cold, it can also lead to poor traction, making it difficult for vehicles to operate safely and efficiently. ■

Hrshikesh (Rishi) Damodar is lead technology and co-ordination for BKT Tires.

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OTR CHANGES for Manufacturers and Suppliers

Off-the-road (OTR) tire manufacturers are facing many challenges, but also many opportunities with the rise of automation and autonomous vehicles.

by Harshawardhan Honmode

Off-the-road (OTR) tire manufacturers are facing many challenges, but also many opportunities with the rise of automation and autonomous vehicles. Harshawardhan Honmode, global head of Yokohama OTR, offers insights on some of these challenges and what lies ahead for the OTR market, particularly in the U.S., which has been growing in importance the last several years.

QUESTION: What are the current challenges faced by OTR tire manufacturers and suppliers?

Honmode: OTR tire manufacturers are facing several challenges in today's rapidly evolving market. One of the biggest challenges is the increasing cost of raw materials, such as natural rubber, steel and oil-based products, which directly affects production costs. At the same time, there is a growing demand for more durable and high-performance tires to meet the needs of industries like mining, and construction that we at Yokohama OTR caters to.

Another challenge is the growing emphasis on sustainability, both in terms of reducing the environmental impact of tire production and developing tires that are more fuel-efficient and have a longer shelf life.

Additionally, there is increasing pressure to develop solutions that incorporate advanced technology, such as tire pressure monitoring systems (TPMS) and central tire inflation systems (CTIS), which require significant investment in R&D and technology integration.

QUESTION: How are advances in automation and autonomous vehicles affecting OTR tire design?

Honmode: Advances in automation and autonomous vehicles are having a significant impact on OTR tire design. Autonomous vehicles, particularly in industries like mining and construction, require tires that can withstand the demands of continuous, high-speed operation, as well as handle heavy loads over longer periods without failure. Autonomous systems also require more precise monitoring and predictive capabilities, which is influencing tire manufacturers to incorporate sensors and smart technologies into tire designs. The push for autonomy in off-highway industries is driving OTR tire manufacturers to innovate faster, integrating smart sensors and automation into tire systems to ensure continuous performance monitoring, predictive maintenance and improved overall efficiency.



QUESTION: How do you see the role of OTR tires evolving with the rise of electric and hybrid off-highway equipment?

Honmode: With the rise of electric and hybrid off-highway equipment, OTR tires are evolving to support the increased torque and weight distribution demands of these machines. Electric vehicles (EVs) generate more torque at lower speeds, which requires tires that offer superior traction and wear resistance. Hybrid and electric machinery also often require more advanced tire designs for better heat dissipation and higher load capacities, which in turn drives innovation in tire materials and structures.

QUESTION: What are the most critical factors in designing OTR tires for mining compared to construction or agriculture?

Honmode: Each sector has unique requirements for tire design. For mining, durability and resistance to punctures, cuts, and heat are paramount due to the harsh conditions and heavy equipment involved. In construction, versatility and a balance of traction, stability,

and load-bearing capacity are critical, as these tires often need to perform on a variety of terrains. For agriculture, tires must offer excellent flotation to prevent soil compaction while providing good traction in muddy and uneven conditions.

QUESTION: What are the best practices for extending the lifespan of OTR tires and how often should they be inspected/rotated?

Honmode: To extend the lifespan of OTR tires, it is crucial to ensure proper tire maintenance, which includes regular inspections, maintaining optimal tire pressure, and ensuring correct alignment and balance. Frequent rotation is necessary to ensure even wear, especially in high-use conditions. There must be timely inspection of tires at least once a month for signs of damage such as cuts, punctures, and wear and tear. Additionally, operators should regularly check tread depth, monitor temperature fluctuations, and avoid overloading vehicles to prevent premature wear. Best practices have moved to real time and continuous monitoring of tires to optimise the tire usage.

QUESTION: How is the industry preparing for the integration of artificial intelligence and predictive analytics in OTR tire management?

Honmode: The integration of AI and predictive analytics in OTR tire management is an exciting development. The industry is focusing on using these technologies to predict tire failure before it occurs, optimizing tire performance, and improving maintenance schedules. Predictive analytics can analyze data from sensors and TPMS to identify patterns that indicate wear or potential issues, allowing operators to take preventive action and minimize downtime. AI can also help in designing tires by simulating real-world conditions and evaluating tire performance under various scenarios.

AI is also playing a key role in developing materials and compounds for the tires to improve performance.

QUESTION: What strategies can companies use to maximize ROI on their OTR tire investments?

Honmode: Maximizing ROI on OTR tire investments requires a combination of smart purchasing decisions, proactive maintenance, and data-driven tire management. Companies should invest in tires that match the specific needs of their operations, ensuring they are using the right tire for the job. Implementing tire monitoring systems and conducting regular inspections can prevent unexpected failures and extend tire life. Additionally, training operators on proper tire care, such as maintaining correct inflation and avoiding harsh driving conditions, can significantly reduce unnecessary wear. By tracking tire performance data, companies can also optimize tire usage and replace tires at the right time, maximizing their investment.

QUESTION: What safety standards and regulations govern OTR tire usage in the off-highway industry?

Honmode: OTR tires must meet a variety of safety standards and regulations, which can vary by region and application. Some of the key regulations include the International Organization for Standardization (ISO) standards, which govern tire dimensions, load ratings, and performance. Additionally, establishments like European Tire and Rim Technical Organization (ETRTO), Japan Automobile Tyre Manufacturers Association (JATMA) and The American Society for Testing and Materials (ASTM) provide guidelines for tire durability and safety, including tests for puncture resistance and heat resistance. Each country also may have specific regulations around tire marking,



HARSHAWARDHAN HONMODE
Global Head
Yokohama OTR

load limits and vehicle compatibility. Ensuring compliance with these standards helps mitigate safety risks, particularly in industries like mining and construction where tire failure can have severe consequences.

QUESTION: What advancements are expected in smart tire technology for off highway applications?

Honmode: Smart tire technology for off-highway applications is rapidly evolving. Future advancements include the integration of sensors that monitor tire pressure, temperature, tread wear and load in real time, providing operators with vital data to optimize tire performance. We also can expect further development in tire materials and structures, such as self-healing rubber or more energy-efficient compounds.

As the demand for automation increases, smart tires may also integrate with autonomous vehicles, allowing for more precise monitoring and control of tire performance in real-time. ■

Harshawardhan Honmode is global head of Yokohama OTR.

THERMAL MANAGEMENT

Advancements for Off-Highway EVs

While ICE vehicles can operate effectively across a broad temperature spectrum, EV components require more precise thermal control.

by Gina Bonini

The rise of electric vehicles (EVs) on our roads is undeniable, yet their off-highway counterparts remain a rarity. These rugged workhorses, indispensable in construction and agriculture, face unique challenges in their electrification journey. The demanding workloads, intense duty cycles, confined vehicle spaces, and harsh environments of off-highway vehicles require more than just scaled-up passenger EV technology; they demand innovative, purpose-built solutions.

At the heart of this challenge lies thermal management, a critical hurdle in EV design that becomes even more formidable for electric off-highway vehicles. Extreme temperatures can devastate EV battery efficiency, range and reliability, threatening performance and longevity. The greater carrying capacities, higher torque requirements and extended operating times of off-highway EVs necessitate cutting-edge thermal management systems for their battery packs, power electronics and operator comfort.

With heat waves intensifying nationwide, fleet operators must understand how high temperatures affect electric off-highway vehicles differently than their internal combustion engine (ICE) counterparts. Built on solid scientific and manufacturing foundations, current vehicular thermal management technology offers robust solutions for



Innovative thermal management solutions empower electric off-highway vehicles like excavators to conquer extreme heat, high vibrations and dirty work environments, ensuring optimal functionality in the most demanding settings.

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these demanding electric applications. This advanced technological foundation addresses the unique challenges of electric off-highway vehicles, enabling performance that matches or exceeds ICE vehicles across various operating conditions.

Advanced Thermal Management In The EV Era

Vehicular thermal management has advanced dramatically over the last hundred years. Today's EVs use advanced cooling systems leagues ahead of their predecessors. These systems combine smart heating and cooling circuits, temperature sensors, and complex control software to keep everything running smoothly, even in the most

challenging environments.

Managing temperature isn't just a nice-to-have

for electric off-highway vehicles — it's crucial. EVs present distinct thermal management challenges compared to traditional vehicles. While ICE vehicles can operate effectively across a broad temperature spectrum, EV components require more precise thermal control. The primary heat-generating elements in EVs — the battery pack and power electronics (traction motors, inverters and chargers) — demand careful temperature regulation. EV batteries, in particular, function optimally within a narrow range of 20 to 45°C. This specificity necessitates implementing a sophisticated battery thermal management system (BTMS), especially for EVs operating in diverse climate conditions like off-highway vehicles.

Thermal management systems in EVs serve dual critical functions. In cold environments, they efficiently raise component temperatures to optimal operating levels, ensuring prompt vehicle readiness. Conversely, these systems act as crucial heat dissipation mechanisms in high-temperature scenarios, preventing overheating and maintaining peak performance. Advanced thermal management systems are indispensable for electric off-highway vehicles, which frequently operate in demanding environments. These systems must keep all powertrain components at optimal temperatures to prevent decreased performance, shortened lifespan, or even component failure.

Smart Cooling To Beat The Heat

Battery pack temperatures can overheat in the hot summer months. High temperatures pose significant challenges for battery systems, accelerating chemical reactions, leading to higher internal resistance and reducing capacity and power output. As such, off-highway EVs like earthmovers or tractors require sophisticated thermal management systems built into their design to handle intense heat generation during demanding operations.

To preserve battery life and maintain range, off-highway EVs should feature a comprehensive thermal management system, including an active cooling circuit with a refrigerant loop that pre-conditions the battery pack prior to use. When the ambient temperature exceeds the battery pack temperature, the BTMS engages and starts the active cooling circuit to pre-condition the battery pack. This process transfers heat from the battery pack to the coolant and then to a refrigerant through a chiller. The active cooling system, which includes a compressor, draws more power but is essential for maintaining optimal temperatures in challenging conditions. These advanced systems balance power consumption, vehicle performance and component lifespan.

Power Balance: Cooling Operators Without Sacrificing Range

As temperatures soar to unprecedented levels, off-highway vehicle operators also feel the heat, but cooling down in an EV isn't as simple as in an ICE vehicle. Every degree of comfort comes at a cost to battery life, forcing operators to find the sweet spot between staying cool and retaining vehicle range. For example, air conditioning use on a 95-degree day can diminish an EV range by around 17%.

For electric off-highway vehicles, cabin preconditioning offers a smart solution to the comfort-range trade-off. Operators can start their day in comfort without draining the battery by heating or cooling the cabin while the vehicle is still plugged into a charging station. This method uses grid power instead of battery energy, preserving the vehicle's total range for operation. It's an efficient strategy that simultaneously enhances worker comfort and vehicle performance, addressing two critical needs.

Modern thermal management technologies can also be integrated into electric off-highway vehicles to enhance cabin preconditioning methods. Specifically designed for these vehicles' chassis, these high-performance systems utilize advanced electric components like ingress-protected high-voltage compressors, high-voltage coolant heaters, coolant pumps and coolant valves in concert with heat exchangers. This integration ensures optimal interior temperatures and performance in any environment, essential for off-highway vehicles operating in rugged and rough terrain.

Summer-Proofing Future Off-Highway EVs

The shift to heavy-duty EVs represents a major step in cutting carbon emissions from agriculture and construction sectors. Yet, as climate change pushes temperatures to unprecedented levels, these powerful electric machines —

ranging from wheel loaders to towering cranes — face a critical test. They must now demonstrate their ability to perform under the harsh conditions created by the very problem they're meant to address. This presents a unique opportunity for technological advancement, driving the development of modern thermal management systems and climate-adaptive designs.

In response to these challenges, the evolution of thermal management technology has made significant progress, largely mitigating concerns about EV batteries and system temperatures through substantial strides in cooling and heating solutions. Ongoing improvements in thermal management promise further reductions in costs and environmental impact, bolstering the case for off-highway vehicle electrification. As fleet operators transition to electric, they can be confident state-of-the-art thermal management systems are designed to tackle the most challenging operational conditions, including intense heat.

These cutting-edge thermal management technologies will ensure off-highway EVs remain durable, efficient and ready to perform reliably throughout all seasons and environments. ■

Gina Bonini is VP and general manager of advanced thermal systems at Modine.



MODINE MANUFACTURING COMPANY

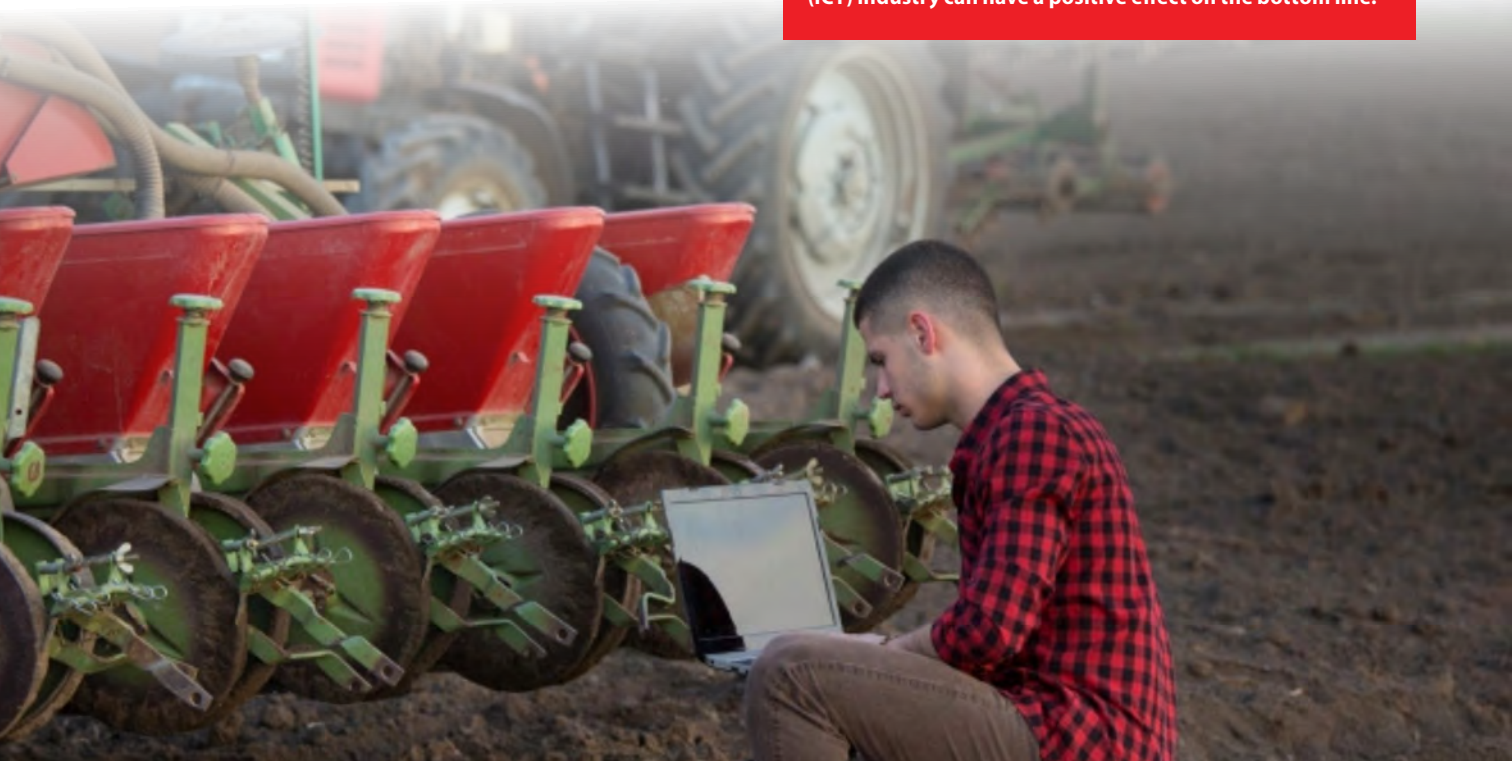
On construction sites, battery electric vehicles require a thermal management eco-system for the lithium-ion battery packs, power electronics and cabin. A thermal solution for all three ensures optimal operation and passenger comfort.

The Link Between Autonomy and Cybersecurity

The automated safety features built into today's off-road equipment are controlled by software and vulnerable to cyber attacks.

by Mark Brubaker

Autonomy in the industrial and commercial transportation (ICT) industry can have a positive effect on the bottom line.



TE CONNECTIVITY

Autonomy in the industrial and commercial transportation (ICT) industry is racing forward. After all, semi-autonomous and autonomous construction, mining and agriculture vehicles are advantageous, offering benefits in terms of safety, efficiency and sustainability, which can have a positive effect on the bottom line.

As it stands today, vehicles in the mining and construction industries are already leveraging some degree of automation to drive throughput and increase worker safety on the job.

Manually-operated and autonomous vehicles use sensor-guided systems to make tight turns in constrained spaces, turn in unison to avoid collision and avoid rolling over. Even with partial autonomy, vehicle and worker safety and productivity improve when using these systems.

From a productivity standpoint, autonomous vehicles can operate for longer periods of time and do not require rest breaks or shift changes. Routes are also able to be optimized, leading to less wear and tear on the vehicles themselves.

In terms of sustainability, the increased efficiency and fuel economy delivered from semi-autonomous vehicles also delivers value by helping to reduce fuel consumption, which can decrease costs while positively impacting the environment.

The Intersection Of Autonomy And Cybersecurity

These types of semi-autonomous/autonomous vehicles, as well as drones and other robotic machines, are transforming the off-highway sector, and we can expect to see these devices

used even more in the coming years as more realize their benefits. In fact, the global autonomous off-road equipment and machinery market is estimated to experience a compound annual growth rate (CAGR) of almost 13% between now and 2032.

While this growth is impressive, it is not without its challenges. The automated safety features built into today's off-road equipment are controlled by software. Whenever software is involved, cyber vulnerabilities become a major concern.

On a jobsite, a cyberattack could result in a takeover of equipment and a disruption of projects. What's more, construction and mining sites require real-time communication between systems, workers and vehicles. If this is compromised, safety could be jeopardized and accidents could happen. When it comes to farming, a breach could mean crops are destroyed, resulting in operations being impeded and lost revenue.

Electronification Intensifies Cybersecurity Needs

Autonomous functionality isn't the only example of the exponential increase in the reliance trucks and off-highway equipment have on software and data. Commercial equipment is now incorporating sensors that gather data from other vehicles and even the environment itself using cameras and LiDAR and connecting to cloud-based platforms to enable advanced navigation and fleet management services.

For example, on a jobsite, GPS systems with LiDAR and radar sensors integrate with telematics software to provide the real-time location of all machinery, while proximity and other sensors detect blind spots and the proximity of nearby equipment, information that can then be used to improve safety, productivity and performance.

Remote condition monitoring and diagnostics also are becoming more common in the industry with information on the vehicle's status or equipment being used to prevent

maintenance issues before they occur.

The result of all this new technology is the creation of massive amounts of data. As this data becomes more interconnected and intertwined, the more vulnerable it becomes as well. If an attacker were able to access and manipulate vehicle data, incorrect decisions could be made, operations could be impacted or injuries could occur.

For example, an operator controlling a backhoe at a construction site can avoid hitting a utility line thanks to a cloud connected device that limits how deep the equipment can dig. If a hacker were to take control of the data or manipulate it in some way, the operator might act in error, putting themselves, bystanders, their equipment and the project at risk.

Four Ways To Minimize Cyber Threats

While the threat of a cyber attack could stall work at a jobsite is real, there are ways to minimize those risks and ensure the systems are as secure as possible with these four methods:

- **Decide what data to collect and store.** Off-highway vehicles are using more and more sensors to collect data on system performance and conditions. This data is typically captured and streamed into large data lakes to enable real-time analytics. However, these cloud-based systems can have potential gaps and vulnerabilities. As a result, designers should carefully consider the data they are collecting and how long that data may be available to the end user.
- **Assess vehicle-to-everything (V2X) communications.** Heavy equipment, such as construction or mining vehicles used in tight operating environments, need V2X communications to adapt their response to changing conditions, especially when they need to coordinate movement and turns. These vehicles should have robust encryption protocols to protect all V2X traffic. However, slower-moving

equipment, such as tractors used on farms, may be able to use less robust cellular networks if they don't need to communicate with other vehicles or maneuver around them.

- **Determine what's wireless and what's not.** While using wireless sensors and antennas to capture and transmit all data is tempting, it creates greater risks. Original equipment manufacturers (OEMs) may consider saying wired for internal communications and using shielded copper cables and connectors for external communications.
- **Leverage advanced technology to improve security.** Data analytics can uncover security gaps and vulnerabilities so teams can address them before they impact vehicle operations. Data integrity solutions can validate the authenticity of data transmitted from sensors and systems. AI-based systems also can detect behavioral anomalies, such as unusual driving patterns, while adaptive security protocols can automate a corrective response such as cutting vehicle power.

Innovation And Vehicle Security Go Hand In Hand

Vehicle security and minimizing cyber threats need to be top of mind for OEMs as the commercial vehicle industry continues to add new features and functionality through electronification and autonomy.

By joining forces with component manufacturers, connectivity providers and security system vendors, OEMs can evolve security strategies, systems and processes. This is important in the off-highway sector because many companies rely on third-party vendors for autonomous technology. All in all, as the industry continues to progress forward, OEMs and end users can rest assured vehicles are secure, resilient and adaptive thanks to their collective efforts. ■

Mark Brubaker is senior manager of business development at TE Connectivity.

Powertrain Themes, Trends and Emerging Technologies

Three experts in the off-highway industry offer insights on emerging powertrain themes, trends and technologies in the off-highway industry and highlight opportunities and challenges OEMs face.

by Chris Vavra

Powertrains are comprised of components that generate and deliver power to the road surface and are critical for off-highway vehicles and technology. The mining, agriculture and construction industries often deal with challenging terrain and conditions and need the technologies to match these conditions. The future of the off-highway industry will depend a lot on powertrains and there are many challenges and opportunities ahead.

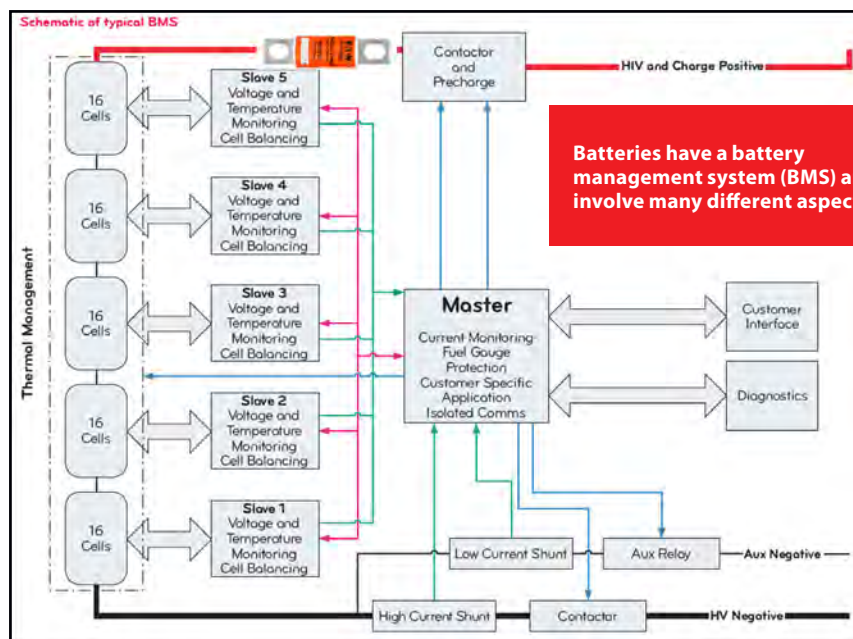
These industry experts on the off-highway industry offered their insights on powertrains in a roundtable format:

- **Dr. Mihai Dorobantu**, director of technology planning and government affairs, Eaton
- **Jamie Fox**, principal analyst, Interact Analysis
- **George Paterson**, vice president of product, Turntide Technologies.

QUESTION: What emerging technologies are shaping the future of powertrains in the off-highway industry?

Dr. Mihai Dorobantu: Emerging technologies that will shape future powertrains used for off-highway applications include ultra-low NOx diesel engines, hydrogen and other low-carbon fuels as well as hybrid solutions.

Jamie Fox: Automation (such as Monarch tractors), connectivity and a trend away from diesel are all slowly shaping the future of powertrains.



Batteries have a battery management system (BMS) and involve many different aspects.

Future generations of machines will be more connected, sharing more data, less reliant on diesel and likely self driving in at least some cases. This will either add value to the machines, enabling them to be sold at higher cost, or provide opportunities for cost savings. Efficient hydraulics also will; support the transition to electric or lead to engine downsizing.

George Paterson: Advancements in manufacturing techniques have allowed axial flux motors to become viable for more mainstream applications while battery chemistry improvements continuously provide more power and energy density for our customers.

With new battery regulations on the horizon for vehicles and equipment, designers and manufacturers of batteries have new challenges that

include fire safety and thermal propagation, recycling and battery passports.

Original equipment manufacturers (OEMs) should ensure that they are working with a partner that continuously looks ahead to meet existing and upcoming regulations. In addition, axial flux motors are becoming a requirement in high-torque, space-constrained applications, which is typical of most electric vehicle and equipment.

QUESTION: How are powertrain components evolving to meet the needs of increased automation and connectivity in off-highway vehicles?

George Paterson: In today's off-highway sector, most components are connected with whole vehicle

ROUNDTABLE EXPERTS

telematics or component technology. Batteries have a battery management system (BMS), which includes individual cell management and battery management as a whole unit. This important system:

- Ensures the battery operates and performs as designed.
- Protects cells and the battery from abuse and out-of-specification scenarios.
- Maintains the battery in a state where it can meet the requirements of the application.
- Interfaces with the host application
- Allow over the air diagnostics and updates.

In addition to batteries, there are also:

- Intercomponent communication between the battery, inverter, motor, and cooling components
- Over the air diagnostics and updates
- Sensors monitoring speed, torque, temperature, and vibration, among other parameters
- Integration of components such as motors, inverters, and gearing.

QUESTION: What role do hybrid powertrains play in the current landscape of off-highway vehicles, and how do they compare to fully electric solutions?

Dr. Mihai Dorobantu: Series hybrid powertrains, or said differently, diesel-electric powertrains, are gaining momentum. These systems use an internal combustion engine (ICE) to drive a generator, which powers an electric drivetrain without directly driving the wheels. They are suited for high-demand applications like mining trucks and wheel loaders.

Parallel hybrids, which combine ICE and electric power for specific tasks, are ideal for stop-and-go vehicles like dump trucks, where braking energy can be recovered efficiently.

Compared to fully electric solutions, hybrids are more viable for vehicles requiring high energy per trip. Battery electric vehicles (BEVs) face challenges such as heavy batteries (6 to 10 tons) costing well over \$200,000 and the lack of charging infrastructure at job sites.

Jamie Fox: Hybrids are often talked about and can offer an alternative to full electrification where the latter is too challenging or expensive. Hybrids do require the development of dual powertrain, but can ease the burden of charging infrastructure and concern of machines running out of energy. However, in practice there are currently few hybrids on the market or in development due to the complexity of the powertrain and the fact that electrification is perceived as a better long-term environmental solution, at least in compact equipment and the mining sector.

There is a good chance that hybrids will not attract government support in the future so it can make more sense to continue with diesel until a company is ready to develop a full electric solution. Hybrid approaches can also be used in the hydraulics as well as the powertrain.

George Paterson: In the off-highway sector, batteries may be needed to provide a boost to other fuel sources to get the torque and lift power required of some of the larger pieces of equipment. Hybrid systems are sometimes the only option if very long range or duty cycles are needed.



DR. MIHAI DOROBANTU

*Director of Technology Planning
and Government Affairs*

Eaton



JAMIE FOX

*Principal Analyst
Interact Analysis*



GEORGE PATERSON

*Vice President of Product
Turntide Technologies*

QUESTION: How are the challenges different for powertrains different in the construction industry vs. the mining industry vs. the agricultural industry?

Dr. Mihai Dorobantu: There are several differences among the three industries such as:

- **Construction:** Vehicles like dump trucks benefit from parallel hybrids, which recover braking energy and use electric power for fuel savings and driving implements like PTOs.
- **Mining:** Powertrains must handle massive loads uphill and absorb significant braking energy downhill, which batteries cannot store. Diesel-electric systems, similar to locomotives, are common.
- **Agriculture:** Tractors face diverse work cycles, from light- to heavy-duty tasks. Hybridization is less practical,

except for mild hybrids (48 V systems) to power implements like seeders and planters.

Jamie Fox: The challenges for some machine types are very different to those of others, even within a sector. However, there are some general themes. Construction equipment such as mini excavators are more likely be used in cities, or even indoors, which makes air and noise pollution more important. The mining sector has a stronger focus on emissions and climate change than the agricultural sector.

For mining, the size of individual projects and level of investment can be very high, so there is more ability to look at solutions that require research and development and investment. In the case of electrification for example, this might mean battery swapping and tethered vehicles may stand at least some chance, but this wouldn't be considered for tractors. Finally, the

mining industry has very high running costs and so that is more of a focus.

George Paterson: In mining, processes are often repetitive (especially for dump trucks), so electric systems with charging available as trucks are loaded and unloaded are ideal. In the agriculture sector, electric power trains can offer a compelling alternative to traditional ones, especially when total cost of ownership is considered. In construction, for small- and medium-size equipment, electric power is either the norm or becoming the norm, especially in indoor and urban areas and other locations that require quiet, zero-emission operation. For larger machines in the short-term, hybrid or highly efficient biodiesel engines will likely be dominant because of the energy density offered by the fuel.

QUESTION: Taken another way, how are the challenges similar in each industry?

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Dr. Mihai Dorobantu: All off-highway industries rely heavily on diesel engines for long periods of high power. Mining trucks climbing hills, tractors plowing fields, and cement mixers all require peak performance for extended durations. The shared challenge is achieving low emissions at high power, which differs from on-road trucks that optimize efficiency at medium loads.

Jamie Fox: Off-highway machinery in all sectors needs to be reliable, resistant to dust and dirt, able to deliver the energy needed during the day and be able to work in a variety of different types of remote locations away from existing infrastructure. Safety is always important and is important in any industry, and this will become even more of a discussion as vehicles become autonomous in the future. Customers in all three industries can be conservative at times and look for a reliable supplier/partner that has a good track record of meeting their needs and getting the job done.

George Paterson: The federal emission requirements are the same and some of the power and torque requirements are similar. For larger equipment, providing the required energy density is a challenge across most industries.

QUESTION: What do you see as a dominant theme involving powertrains in the next 3-5 years and how can companies prepare?

Dr. Mihai Dorobantu: Over the next 3 to 5 years, the focus will be on reducing NOx and CO2 emissions, driven by regulations at all levels. Electrification of accessories will also grow. Companies should adopt proven on-highway technologies where feasible while tailoring solutions for off-highway needs to maximize efficiency and compliance.

Jamie Fox: Electrification will continue to be a key theme. Suppliers of machines need to understand demand and customer's concerns now. However, biofuel, in areas such as agriculture, is also an area of interest. Biofuel machines would be more similar to conventional

diesel in familiarity and use, and not require a change in operations or supply chain. Biofuel is in theory close to carbon neutral, since although it emits CO2 in operation CO2 has also been removed from the atmosphere in the process of growing the crops.

George Paterson: The use of axial flux motors in space-constrained electric systems is a major trend moving

forward. As these motors' manufacture is scaled to be used in more than niche applications, they will become the choice for many off-highway machines. Working with a manufacturer with strategic partnerships to provide all the components required for an electric drive train will become paramount. ■



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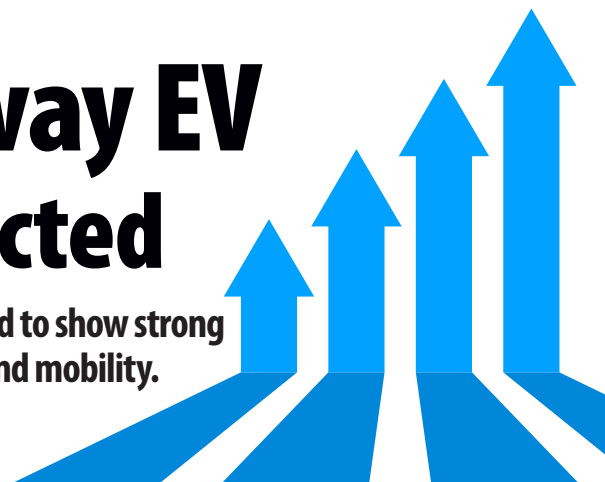


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On- and Off-Highway EV Market Growth Expected

The EV market for on- and off-highway vehicles is expected to show strong growth in many industries such as construction, mining and mobility.

by Mika Takahashi



Electrification is rapidly expanding beyond automotive, with IDTechEx predicting that by 2045, the electric vehicle (EV) market will be worth \$1 trillion. IDTechEx's report, "Electric Vehicles: Land, Sea, and Air 2025-2045", covers 11 key vehicle segments, breaking down historic and forecast growth across 148 forecast lines, including battery demand, drivetrain share, and market value. The outlook for the varying on- and off-highway vehicle industries is positive, but the degree to which varies.

Passenger cars - CAGR of 9.8%

Electric cars are the most visibly deployed EVs on the roads today. With some 16 million vehicles sold in 2024, they are already well established with a ~13% market share, although it was a year of slower-than-historic growth. The next decade of electric cars is set to be shaped by increasingly stringent regulations, particularly in Europe. By 2035, 100% of cars sold in the EU must be battery electric, although there are increasing calls from certain industrial and political circles that this goal is unrealistic. 2025 will be a key year to watch as an indicator of OEMs ability to

meet these targets. IDTechEx expects cars to remain the biggest sector in terms of value and battery demand, but its relatively established electrified share means its CAGR will be a more modest 9.8% by 2045. More than 70 million cars are expected to be sold by 2045.

Commercial vehicles - CAGR of 15.1%

Although they are deployed in smaller volumes than cars, as significant contributors to global emissions there is a strong drive to electrify commercial vehicles. IDTechEx covers 3 key commercial segments, buses, vans and trucks. These segments are collectively at an earlier stage of electrification than cars but are making significant progress.

Electric buses presented an early market in China. IDTechEx predicts that due to the saturation of China's electric bus market, global sales will not surpass their 2016 peak until 2040, with future growth fueled by replacements in China and greater adoption in Europe. Much of the European market has been underpinned by Chinese OEMs, but local supply is now starting to ramp up. Interurban and long-haul coaches are the least electrified due to technical

constraints, and this sector presents the greatest opportunity for fuel-cell electric buses (FCEBs).

Electrification of light commercial vehicle (LCV) fleets is proving to be an effective way to demonstrate green credentials to customers, however total cost of ownership (TCO) remains the biggest obstacle. IDTechEx research indicates significant vehicle depreciation is the biggest single contributor to a higher TCO. However, battery electric vans are already sufficient to cover the daily mileage of most requirements.

Long-haul trucking is one of the most challenging on-road sectors to electrify due to the high daily mileage and lack of charging infrastructure. Despite these barriers, IDTechEx predicts more than 1.7 million electric (fuel cell and battery) vehicles will be sold, driven by a mix of regional policy, TCO considerations, and increasing model availability from major OEMs.

Micro-mobility - CAGR of 4.6%

Two-wheeler, three-wheeler, microcar, and electric scooter sales collectively amounted to over 25 million units in 2024. This makes micro-mobility the largest vehicle sector in terms of unit sales, but with a much smaller battery demand and vehicle value than other sectors.

Electric micro-mobility is already well established, particularly in China, India, and Southeast Asia. The popularity of the segment can be attributed to low price, ease of use, and small form factor which is ideal for dense urban

"The construction and mining sectors are relatively unelectrified, but smaller machines — such as mini excavators and other light vehicles — are relatively easy to electrify."



🔑 **Electric Vehicles: Land, Sea, and Air 2025-2045 covers eleven key vehicle segments.**

centers. With such strong sales already, growth potential is more modest when compared to other sectors.

Construction and mining - CAGR of 24.4%

These off-road sectors have highly varied workloads, power requirements, and operational conditions. With a relatively lax regulatory push to electrify, it is TCO that will be the primary driver to shift operators away from traditional diesel machines. The construction and mining sectors are relatively unelectrified, but smaller machines — such as mini excavators and other light vehicles — are relatively easy to electrify. Much larger vehicles like mining haul trucks are expected to require batteries on the order of MWh in scale. Despite this, the enormous TCO savings are expected to drive growth in these sectors, but minimizing downtime due to charging remains a key concern.

Electric and hybrid marine - CAGR of 16.4%

Today, electric & hybrid propulsion systems in marine have mostly emerged in recreational boating, ferries, and short-sea or inland vessels, where they have enjoyed steady uptake due to small vessel sizes or well-defined operational profiles that allow for opportunity charging. In larger deep-sea

vessels, uptake is less rapid but gaining momentum as unprecedented global emissions regulations from the IMO and EU, which initially targeted NOx, SOx & PM, are now focussing on carbon & GHG emissions. IDTechEx expects this to lead to significant growth in the battery demand for marine vessels, although a slightly more modest CAGR represents a more gradual electrification compared with other sectors.

Electric trains - CAGR of 11.4%

Although most electrification of train networks comes from overhead catenary electrification, in some instances this is not possible or economically viable. In such circumstances, battery or fuel cell electric trains are being deployed to replace diesel multiple units, shunters, and locomotives. IDTechEx expects substantial growth in this sector, with multiple unit sales driving growth initially before locomotives and shunters are deployed at scale.

Electric aircraft - CAGR of 45.6%

Conventional take-off and landing aircraft are some of the most technically challenging vehicles to electrify. Enormous energy requirements and strict limits on vehicle weight and safety make some routes unviable for electrification. Nevertheless, smaller high-traffic routes and general aviation

(GA) are good candidates for battery electrification, and the incredibly low penetration as of 2024 gives a very strong growth outlook until 2045.

eVTOL - CAGR of 35.1%

Electric vertical take-off and landing (eVTOL) is an emerging branch of urban mobility that is in the early stages of development. Most deployments as of 2024 were pilot and small-scale demonstrator projects, but IDTechEx expects cargo applications and air-taxi will begin to see more substantial adoption in the early 2030s, as regulatory and technical hurdles are overcome.

The EV market is expected to grow in the coming years with different industries growing at different rates. The on- and off-highway industries will play a key role in their growth, as well, with technology advances as well as bringing them more into the mainstream. Downtime, availability and affordability remain key concerns, but those also will be addressed as OEMs continue bringing them into their operations as they take advantage of their benefits. ■

Mika Takahashi is a technology analyst at IDTechEx.



2D Machine Control Solution Provides Precision Excavation

Unicontrol's 2D machine control solution, Unicontrol2D is tailored specifically for small to medium-sized construction companies and featuring its premium hardware. It is designed to make precision excavation easy to use as well as providing a future-proof first step on the journey to 3D machine control. 2D machine control is the ideal choice for companies facing tight budget constraints or those without a continuous project pipeline. Users can start reaping the benefits immediately as it can be easily retrofitted to existing equipment, removing all barriers to adoption. The 2D machine control technology can help companies achieve their goals to address higher costs with more precise work that minimizes rework and prevents over-digging.



G3500K Series Gas Generator Series

The G3520K HR (High Response) from Caterpillar is rated at 2.5 MW of continuous power and is available in 50 or 60 Hz packages. It starts quicker, accepts higher loads and ramps up to 100% load capacity faster than previous models. The G3520K HR can start, take on full load, and sync to the grid in 4.5 minutes. This enables customers to get to full power more quickly and reduces the risk of unexpected downtime and creating immediate capacity when requested by the utility. The series comes with available asset monitoring capabilities that provide insights to customers by offering predictive analytics to identify and prevent failures, ultimately avoiding the costly implications of downtime. Customers also can realize more economic benefits by leveraging the Cat Active Management Platform (Cat AMP), Caterpillar's Distributed Energy Resource Management System (DERMS) offering.



Hydraulic Cylinders For Construction Machinery Applications

Liebherr's next-generation hydraulic cylinders are designed to meet the growing demand for sustainable, smart, high-performance machinery. They deliver peak efficiency, while reducing environmental impact and offer a forward-thinking solution for industries that strive to meet performance and sustainability goals. They are built to last, proving an exceptional reparability and ensuring a continuous supply of spare parts. They also integrate sensors that can monitor a hydraulic cylinder's performance in real time. The technology helps detect wear early, to prevent failures, to optimize repair schedules and minimize unplanned downtime. This not only increases machine safety, but it also extends the component life. By using carbon fiber reinforced plastic (CFRP), the company has reduced the weight of its hydraulic cylinders, enhancing machine performance and reducing CO₂ emissions. This enables longer booms, more agile movement and improved energy efficiency.



Airless Tire For Skid Steers and Loaders

Galileo Wheel's SkidCup is an airless tire for skid steers and loaders. Unlike conventional products that force operators to choose between solid tires' durability or pneumatic tires' shock absorption, SkidCup's air cavity design maintains full operational capabilities without inflation. The technology eliminates puncture-related downtime while demonstrating superior impact absorption and traction compared both to solid and pneumatic tires, with reduced shock and vibration transmission to machinery components and operators. This eliminates the traditional trade-off between puncture resistance and equipment preservation. At the core is their CupWheel technology, which features a proprietary sidewall concave design. This creates a non-pressurized air cavity that delivers superior shock absorption and traction without vulnerability to punctures.



Engine Overhaul Kit Improves Equipment Life Cycles, Sustainability

Perkins has introduced four overhaul kits for six-cylinder Perkins 2000 Series engines that provide budget-friendly alternatives to replace and restore engines to like-new performance. The overhaul kits include the genuine Perkins parts needed for technicians to perform progressively complex levels of service, based on running time and condition. The Copper, Bronze, Silver and Platinum overhaul kits provide the factory fit and performance of genuine Perkins parts, by simplifying ordering with a single part number. They also come with a 12-month Perkins warranty and support sustainability initiatives by decreasing the flow of waste to landfills. The overhaul kits are suitable for 13-, 15- and 18-L 2000 Series engines offering power output ranging from 358 to 470 kW. The 2000 Series engines are used in applications such as generator sets, hydraulic excavators and large industrial pumps and compressors.



TRAVELING BELT LOADER EVOLUTION

Traveling belt loaders were designed to solve the problem and weaknesses elevating graders had in loading bank material.

by Thomas Berry, Archivist, Historical Construction Equipment Association

In their heyday, elevating graders were quite an efficient way of loading bank material into wagons. However, as hauler size began to increase significantly with Euclid's development of modern bottom dump trucks in the mid 1930s, these machines proved to be the weak link in their use.

To solve the problem, Euclid began developing the first traveling belt loader in the late 1930s. Introduced in 1944 and dubbed the BV, or BladeVeyor, which was a much larger, more powerful and more robust machine than what it replaced. The flow of material was more efficient; rather than forcing material to move at a right angle, the conveyor elevated it from the cutting blade at one corner to the discharge at the opposite corner, resulting in a narrower workpath than an elevating grader.

Like the elevating grader, it was drawn by a tractor, but it required more power; two tractors were sometime used, fore and aft, for added propulsion. It also carried its own diesel engine to power the conveyor. Where elevating graders rode on steel wheels, it traveled on a heavy crawler assembly.

For its considerable power and productivity, the BV had drawbacks. Like an elevating grader, the conveyor belt was prone to damage, especially from excessive slippage and trapped rocks, and cost \$3,000 to replace. Even with the open versus right angle of the conveyor, clogs still occurred, and the low angle of the belt did not eliminate material slipping and rolling back.

The crawlers were a maintenance expense, and required it to be moved by lowboy or dolly accessory. It was impractical for smaller cuts, the design interfered with maintaining grade, and the fixed cutting edge could not be adjusted for contour work.

The BV's only real competition was the EI-Loader. Developed by C&D Manufacturing Company of the Sacramento suburb of Perkins, Calif.,



The closest competitor to a BV was the Sierra Loader, developed by C&D Manufacturing and acquired by P&H. Note the extra-wide gauge rear axle and the much wider working width compared to a BV. This one is loading what appears to be a Heil or early International Harvester motor scraper; ironically, advances in scraper design and size were the driving force in the obsolescence of BVs and Sierra Loaders.

it was a glorified elevating grader. It followed many of the same design principles, but on a much larger scale, requiring two Cat D8s or one D9 (or equivalent) for propulsion. Its advantages were it broke down compactly for transport on a 35-ft flatbed, and was more mobile on the jobsite because of its rubber tires. Sales were limited, and the line was acquired by crane and stabilizer manufacturer P&H.

BVs and EI-Loaders were used mainly to load bottom dump haulers, but scrapers could be loaded as well, albeit with a bit more care due to the shorter target area of the bowl compared to an elongated bottom dump wagon. Further development of larger and more powerful motor scrapers rendered these machines obsolete in the 1960s.

Euclid had one more go at the BV design, the BV-II or Super BV, in the late 1960s for larger bottom dumps, but it was unsuccessful. ■

Thomas Berry is an archivist and editor with the Historical Construction Equipment Association (HCEA). The Historical Construction Equipment Association (HCEA) is a 501(c)(3) nonprofit organization dedicated to preserving the history of the construction, dredging and surface mining equipment industries. With over 3,500 members in a dozen countries, its activities include operation of National Construction Equipment Museum and archives in Bowling Green, Ohio; publication of a quarterly magazine, *Equipment Echoes*, from which this text is adapted, and hosting an annual working exhibition of restored construction equipment. Individual annual memberships are \$45 within the U.S. and Canada, and \$65 elsewhere. HCEA's next International Convention and Old Equipment Exposition will be Sept. 18-20, 2025, at the National Construction Equipment Museum in Bowling Green, Ohio. HCEA seeks to develop relationships in the equipment manufacturing industry, and offers a college scholarship for engineering students. Information is available at hcea.net or by calling 419-352-5616 or emailing info@hcea.net.





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