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Technology Improvements Through EVOLUTION, REVOLUTION

CHRIS VAVRA
cvavra@iron.markets

The Perkins press conference at The Design Studio in London was an interesting choice for a setting. Highlighting engine technology developments, public-private partnerships for hybrid engines and alternative fuels and a preview for bauma 2025 in Munich might seem strange. Then again, there were displays throughout the museum that highlighted the evolution of technology and how far we've come. So... maybe not so much.

"The future is changing and there's no one right solution," said Vicki Reeves, global marketing and channel development director at Perkins, during the opening presentation.

Perkins's emphasis on partnering with other companies and universities is one way in which they're trying to build on the future. Project Coeus, which is focused on delivering a power solution with alternative fuels.

Indulging my James Bond fandom during my trip to London for the Perkins press conference with a picture of MI-6, the Secret Intelligence Service, at Vauxhall Cross.

Results will be on display at bauma in Munich in April and it'll be interesting to see what progress has been made and what the end result will be in two years when the project officially winds up..

As it is with all manufacturing, there is an evolution and revolution stage. The revolution leads to evolution and back around it goes.

There was plenty of that during the Perkins press conference in London and there will be even more in bauma.

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Perkins Conference Highlights Engine, Digital Developments

Perkins' press conference event in London previewed their plans for bauma 2025 in Munich, which focused on the evolution and revolution of engines.

A consistent theme during the Perkins press conference at The Design Studio in London was the need to adapt to a constantly changing future. Perkins, a subsidiary of Caterpillar, emphasized the need to work with OEMs and developing solutions on the mass market..

The press conference highlighted finding the right balance by straddling the line between diesel engines and future engines, which will be powered by multiple sources.

They highlighted two engine models, the 900 and 2600 series, which are part of the revolution because they will be taking the next step forward for customers in off-highway and other industries. Developing these engines takes many years, and goes through many steps.

Another key topic was condition monitoring. They described an end-to-end solution that helps find the fault on the engine and get it to the OEM and get it up and running. The result is it saves OEM dealers and helps them avoid major breakdowns and faster resolutions.

They also discussed alternate fuels and emphasizing sustainability. They are embarking on collaborations with other companies and universities to find new methods with hybrid engine solutions that utilize alternate fuels. Project Coeus is a collaboration designed to address these challenges for the off-highway industries as well as others.

Click on the links below for more information about Project Coeus and other developments Perkins highlighted during their press conference. ■

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Off-Highway Industry GROWTH REMAINS TENUOUS

While there are some positive signs to start 2025, the picture remains unclear for the construction and agriculture industries as they face inventory headwinds and tariff worries.

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.

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Manufacturing showing growth rates in early 2025

There has been a great deal of activity from a political standpoint in 2025 and these actions, particularly the looming tariffs, could cause seismic changes short- and long-term. Going into 2025, the U.S. economy had slowed down a bit with 2.3% growth in the fourth quarter (compared to 3.1% in the quarter prior). Concerns about the industrial markets, particularly with sticky inflation, elevated interest rates and excess inventories especially in construction and agriculture have raised concerns about gross domestic product (GDP).

That said, there are some early positive signs in 2025. U.S. manufacturing showed expansion for the first time since 2022 according to the Institute for Supply Management (ISM), which monitors the industry's strength with their Purchasing Manufacturers' Index (PMI). It registered 50.9 in January, the first expansion in 26 months, and a welcome sign for an industry that has been trying to find its footing through a turbulent first half of this decade.

The global manufacturing economy also showed some modest expansion in early 2025. though China and Latin America remain flat while Europe continues to struggle.

The next six months in the U.S. will likely depend on the policies emanating from the new Trump administration. This will reflect their actions toward governments spending and Tariffs. New spending priorities will determine the spending levels of the three key industrial programs: The Inflation Reduction Act, the CHIPS act and the Infrastructure Investment and Jobs Act.

> **"Construction sectors likely to benefit from the changes in economic policies include data centers, energy projects for artificial intelligence (AI), manufacturing projects for onshoring, and infrastructure such as roads and bridges."**

Tariffs remain the big elephant in the room, however. As of this writing, the situation with tariffs on countries and commodities (such as steel) remain in flux as everyone waits for the definitions of reciprocal tariffs. Whatever happens with the tariffs the U.S. imposes will, in turn, create a response in kind. In the short-term, this means prices will go up.

The impact this has on inflation, which has cooled globally, could

> **“Costs on imports and exports will change the game and those in the off-highway industry, regardless of region, will feel it.”**

create a chain reaction. No one will be unaffected, of course, and regions such as Europe, which have been in a recession due to the pandemic and geo-political factors, could suffer. So, in turn, could the U.S., which will need policy actions particularly on regulation and taxes to help offset possible inflation, supply chain challenges and secondary affects.

Costs on imports and exports will change the game and those in the off-highway industry, regardless of region, will feel it. Agriculture, exports in particular, could take a nasty hit if tariffs affect what they send. This will affect commodity prices and how original equipment manufacturers (OEMs) approach what they produce for the industry. The same is true for mining and construction.

State of the key off-highway industries

A closer look at the three key off-highway industries: Agriculture, construction and mining. This will provide a closer look at what's happening in these industries as well as the contributions the major off-highway players are providing.

State of the agricultural industry

Farm equipment sales declined sharply through the second half of 2024 in the North America. Equipment manufacturers sharply lowered production to reduce inventory, which still were at elevated levels entering 2025. First half 2025 production will be down sharply to reduce new and used inventories suggesting very weak results in the first half of the year. Equipment sales are likely to be 80 to 85% of mid-cycle level, setting the stage for a recovery when fundamentals improve.

That may be not that far away. Despite the troubled outlook, farmer sentiment continues to improve as the industry believes the current administration will bring more favorable conditions for them. Further, the recent improvements in the crop outlook reflecting downward revision in crop production and a dramatic increase in government payments (from $9.6 billion in 2024 to $42.4 billion in 2025) suggests that the first half of 2025 could quite possibly be the bottom for the farm equipment industry.

Globally, huge crops are projected in South America for soybeans and corn. Even with the recent weather fears, this could lead to major increases in supply to meet demand without having to necessarily depend on the U.S. The effect this will have on prices remains to be seen because of tariffs, but it could give South American OEMs a chance to flex their muscles a bit.

State of the construction industry

Construction spending slowed through the second half of 2024 and equipment sales had a steep drop in the fourth quarter due to weak sales and wide-spread inventory liquidation spurred by merchandizing programs and targeted discounting. Entering 2025, there is still a glut of inventory for manufacturers. There is some general optimism for 2025, but it's more toward the second half of the year as OEMs work through the inventory issue they are currently going through. OEMs also project construction activity to be relatively flat globally in 2025 with North America likely in decline. This suggests the first half of 2025 will see lower sales to end users and significant inventory liquidation. Construction equipment forecasts focus on a 5 to 10% decline in NA and flat +/- 5% worldwide.

State of the mining industry

Major mining companies are dedicated to improving their bottom line, saving energy, and lowering costs with a focus on supporting domestic supply chains, resource security for critical materials, and optimizing to improve efficiency, emphasize cost savings and investing in automation. With mining markets expected to soften through 2024 into 2025, it was not surprising the sector reported declining sales to end 2024, reflecting lower sales to end users and inventory liquidation. With inventory levels still elevated, the weakness will continue through the first half of 2025.

Global projects appear to be peaking and slowing a bit. Industry forecasts suggest mining projects and spending in 2025 are moving sideways but at a relatively high level.

A closer look at the construction industry

There is likely to be a change in the mix of construction spending as the Trump Administration unfolds its economic objectives. This will have immediate effects, though some won't be felt until further down the road.

Construction sectors likely to benefit from the changes in economic policies include data centers, energy projects for artificial intelligence (AI), manufacturing projects for onshoring, and infrastructure such as roads and bridges. Much of this was already in place due to the policies enacted by the Biden Administration, but there could be a more renewed focus, particularly on infrastructure, which is always a popular focus regardless of who is in charge.

Given the state of bridges, railways and the like, it should be.

The construction sectors with a more difficult outlook could include alternative energy such as wind and solar, high-speed rail, electric vehicle (EV) and battery facilities; water projects will likely favor a roll back of regulations and more control given to states. Even so, alternative energy and hybrid projects will remain a priority for OEMs looking at the long game.

At the Perkins press conference in London, there was a strong emphasis on hybridization and working with alternate fuels. While internal combustion engines (ICE) and diesel will remain the standard, Perkins is emphasizing a hybrid approach where different fuels can be used in tandem with diesel to reduce overall costs. Project Coeus is an example of working with other companies and universities to find a better solution and they will be displaying their findings at Bauma 2025 in Munich.

The mood and feeling of the construction equipment manufacturers right now is cautious because of excess inventory and a general wait-and-see approach. That said, the construction industry has shown its resilience, and most trade associations are more optimistic believing the second half of 2025 and 2026 will be good for the industry overall.

For example, Dodge Construction Network and Construction Connect both forecast increased construction starts up to 9% in 2025.

During an Association of Equipment Manufacturers (AEM) webinar, Tom Hopgood, an economist for GlobalData, said the world construction market is characterized by an overall lack of demand. Everyone, Hopgood said, is feeling the effects of the previous inflationary period. He did say the world construction industry should reach growth rates of 4% by 2028, with a lot of the activity and growth coming from Asia— particularly China and India. The U.S. won't be a slouch, either, he said.

The key issues to watch for the construction industry are interest rates, a potential shift in priorities by the Trump Administration and labor availability. Hopgood said the deportations on undocumented workers could cause problems because the construction and agriculture industries, in particular, depend on them. He warned this could create a real drag on the industries, which are trying to find their footing. The other unknown is the impact of tariffs, particularly on construction costs. If there are tariffs on steel and other building products and commodities, this could create quite a major impact. Recent talks of reciprocal tariffs could, again, create a chain reaction that cause higher costs. This, coupled with fewer available workers, could send the construction industry into a tailspin.

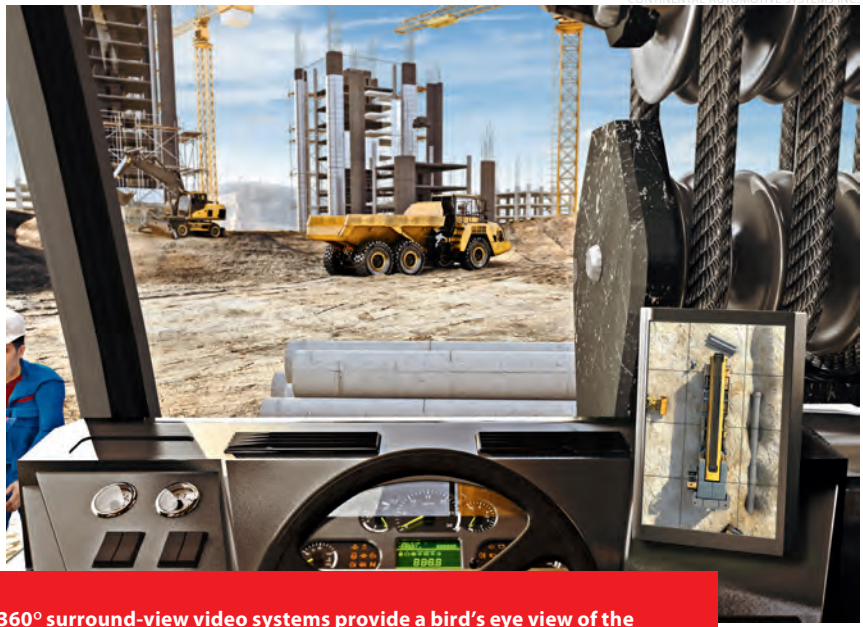
OEMs are resilient and they will continue to endure, but they will have to adjust and be flexible. The industry can change overnight as this decade has proven. Companies working for the long-term as well as the present are the ones that will not only endure, but thrive despite everything happening around them.

Multi-Camera Monitoring Systems IMPROVE OPERATOR SAFETY

Current monitoring systems provide operators with a 360¬∫ view and offer a complete view of their surroundings.

by Jared Hall

CONTINENTAL AUTOMOTIVE SYSTEMS INC.



360° surround-view video systems provide a bird's eye view of the entire vehicle and its surroundings to make operations easier and safer.

Rear-view cameras have been a feature of modern equipment for over a decade, and their benefits are obvious behind the wheel because they provide the operator a full view of what's behind them. The latest generation of 360º surround-view, multi-camera monitoring systems take the principle of rear-view cameras to the next level.

There have been TV commercials for multi-camera monitoring systems that are offered as upgrades on some higher-end pickup trucks. On a screen in the cabin, the driver sees a view around the vehicle that seems as if it were taken from a video camera mounted several feet directly above the vehicle. The driver sees a view around the vehicle that shows obstacles, people and other vehicles without any interference from pillars or passengers' heads.

The same type of systems are now available for commercial equipment as OE systems and as retrofits for existing equipment. These surround-view monitoring systems combine the inputs of multiple wide-angle cameras into a single image that appears to have been shot with a conventional lens placed above the equipment.

The system's software "stitches" the video feeds from as many as six cameras into a single video image with no distortion or blind spots. These surround-view systems are ideal for commercial vehicles and heavy-duty trucks as well as agricultural and construction equipment.

Nate Stehman from Continental Automotive Systems said, "The 'birds-eye' view provides benefits for the operator and everyone working on the job site. In addition to creating a safer working environment, being able to see 360º around the equipment reduces driver stress and increases operational efficiency."

These video systems eliminate blind spots to make drivers fully aware of everything that's happening around the vehicle during any work activity. The view from above the equipment eliminates the guesswork of determining where obstacles, other vehicles, and personnel are so the vehicle or equipment can be operated in a much safer manner.

The most advanced 360º surround-view systems are compatible with CANbus and other general-purpose input/output (GPIOs) and feature software tools for easy customization to meet specific vehicle or worksite requirements.

Some systems feature touchscreen monitors and the ability to switch from the bird's-eye view to individual views from each camera. System software converts the wide-angle video feed into a conventional view for better clarity for the operator. The software also allows

individual camera views that can be viewed in single, split-screen or quad-camera views. This gives the operator greater freedom and peace of mind, which can be helpful in situations where there's a lot of activity in the immediate vicinity.

Four things to consider when choosing a surround-view system

When selecting a surround-view system for off-highway equipment there are several features and specs to consider:

- **System software:** Does the system's programming tool offer the configuration capabilities needed to optimize the system for the application? Is the setup and calibration simple enough for customizing the system as needed? Is the system itself compatible with the vehicle network?
- **Physical characteristics:** Will the cameras and the system electronics be able to stand up to the conditions the equipment will face? What are the IP ratings for the camera and the electronic case(s)? What is the approved operating temperature range?
- **Video performance:** Users should ask questions such as: What is the sensor size of the camera? What is the dynamic range? What is the display resolution? Frames Per Second (fps)? What is the image latency? How well is the system protected against frozen frames?
- **Electrical characteristics:** Is this system voltage compatible with the application? What are the cable and connector options? Does the system provide transient, overvoltage, and reverse polarity protection? What is the maximum allowable cable run?

An all-around smart choice for enhancing safety and reducing accidents

Safety on the worksite is essential to successful and profitable operations. Companies spend significant sums of money and manhours establishing safety procedures, conducting safety training, and tracking compliance with safety procedures.

However, in some cases, technology can add a dramatic and immediate boost to safe operations. Adding a surround-view, multi-camera monitoring system is one of the best ways to help ensure the equipment is operated safely.

Jared Hall *is product manager commercial and special vehicles, Continental Automotive Systems Inc.*

How AI and ADAS Help Operators

It's important to understand the difference between AI and ADAS and how they're helping off-highway vehicle operators be safer.

by Corey Heniser, Henry Morgan

BRIGADE ELECTRONICS

Person is outlined and there is also a red detection grid to add to the visual image of the person, showing where they are around the vehicle.

There's been a lot of interest and confusion between artificial intelligence (AI) and advanced driver assistance systems (ADAS) within the off-highway industry, and how they have evolved and work together.

To start with, it's important to understand the differences between ADAS and AI.

At the most basic level, ADAS is offered for various purposes from creating a warning system to taking control of the vehicle. For example, a collision warning system that alerts the driver, but does not take control of the vehicle would be consider L0 ADAS, while a forward collision warning that applies the brakes when an object is detected could be L2 to L4 ADAS, depending on the integration. In contrast, AI utilizes machine learning or programming to receive more information about the surroundings or situation prior to providing alerts or haptic responses in the vehicle.

"ADAS has been around for a long time," said Corey Heniser, CEO of Brigade Electronics. "It's a practical technology because it's very specific about what it's looking for and it's continually developing. AI cameras have been a subset of ADAS, but now we're seeing their potential and they are becoming a whole new field of their own. Until very recently, the reliability of detection on AI cameras has not been as good as we would like it to be. There were too many false positives as well as false negatives, but we're now getting to the stage

where AI can make a huge difference to vehicle safety."

Henry Morgan, sales development manager for Brigade, acknowledged there are still issues to be addressed. For example, standard AI cameras need lights to function. In off-road and outdoor settings this can be problematic due to poor visibility, mud or clouds of dust. Very bright or low-light conditions and bad weather such as fog, snow or heavy rain also can obstruct camera views, particularly with standard cameras.

However, reduced latency and better pricing are helping to increase the number of AI applications. Morgan recognized that research and development is now based on the premise that if there's a risk, how can AI be used to reduce it? New applications are being worked on all the time.

AI, ADAS technology are improving

AI cameras are becoming much better, faster, sharper by using algorithms to work out what they do with the information they receive to deliver a safe and beneficial outcome and learning from each experience.

"I always get concerned when people focus directly on the technology rather than looking initially at the problem they are trying to solve," Morgan said. "This often means that they have a preconceived idea about what the technology can and can't do. Whereas the only real way to use technology to address problems is to work out a very carefully defined risk storyboard. Here's the risk. Here's a situation where it happens. Here's what's needed to remove the risk and defuse the situation. Let's make it."

Heniser provided an example of a maintenance engineer working at a quarry who wants to speak to the driver of a large excavator. They attract the driver's attention and get out of their own vehicle. At this point they may be temporarily out of the driver's sight and the driver isn't sure if they're heading to the front or to the access ladder to get on board. An ADAS camera will spot the engineer and alert the driver, but one embedded with AI will learn an approaching person is likely to be heading for the access ladder, and if the access ladder is lowered, the excavator will be immobilized.

BRIGADE ELECTRONICS

A basic ADAS camera will alert the driver to an obstacle, but this could be scaffolding or a pallet of bricks. Add AI into the mix and the driver can differentiate between a vulnerable site worker and a pile of concrete blocks and act accordingly — the concrete blocks will stay where they are, the human could veer off to the left or right.

Each risk must be examined to see what the technology can do to alleviate it. Each vehicle, industry and work site can have different risks. If there is a specific problem to be addressed, such as a dump truck driver on uneven terrain or a sharp gradient which might obscure an approaching worker, a particular workaround can be built into an AI solution.

"When it comes down to it, though," Heniser said, "it's still the driver who must react when alerted. You still need training, the driver knowing they are still in charge, backed up by the right systems."

CAN-based radar as an alert system to detect moving objects and automatic braking if connected are examples where ADAS has traditionally worked well. For dashcams, however, AI cameras are fast becoming an essential component.

As a comparison, Brigade's Backsense Radar Obstacle Detection, which is an ADAS product, detects people and objects in blind spots, which can be particularly large on off-road construction vehicles, and provides the driver with in-cab visual and audible warnings.

On the other hand, Radar Predict uses AI technology to analyze data such as the speed and direction of a person, and its self-learning mode detects, for example, whether a digger is fitted with a trailer and, if so, prevents time-wasting false alerts.

Improving off-road vehicle safety

There are many benefits safety enhancements can bring to off-road vehicles. This includes the increasing sophistication of vehicle telematics, a combination of GPS systems, onboard diagnostics and wireless devices which transmit data and information contributing to the safety of the vehicle and driver.

From spotting obstacles to controlling speed going downhill to preventing vehicles from tipping over on rough ground, the driver is provided with information to decide while reducing potential false alarms.

There are more than 1,000 fatal occupational injuries in the US construction industry alone every year, and construction deaths account for 19% of deaths in the US workforce per year. In addition, in 2022 there were 169,600 non-fatal construction injuries and illnesses. 24.2 million working hours were lost as a result.

Working off road is still one of the most dangerous occupations. All site vehicles should be equipped with the most up-to-date safety solutions, whether they are ADAS or AI or, as is becoming more likely, a combination of the two.

Corey Heniser *is CEO of Brigade Electronics Inc.;* ***Henry Morgan*** *is sales development manager for Brigade Electronics Inc.*

Leveraging TELEMATICS in Heavy Machinery

Significant advances in artificial intelligence (AI) and 5G connectivity are making telematics an attractive option for OEMs in the off-highway industry.

by Rafael Cardoso

In today's evolving market, original equipment manufacturers (OEMs) are grappling with a range of complex challenges. A growing scarcity of skilled operators, the rising demand for personalized machine performance, and mounting pressure to maintain cost-effectiveness are a few challenges OEMs face. Balancing intuitive machine design with an advanced control system that adapts to diverse operator profiles and usage scenarios is no small feat. Amid these challenges, telemetry systems are emerging as a promising solution is emerging.

Telematics' role in optimizing machinery operations

Telematics, while not a new concept, is experiencing significant advancements that are opening fresh opportunities for OEMs. With more machines incorporating electro-hydraulic (EH) actuation and control systems powered by software, the synergy between data collection and software-driven systems offers substantial potential to tackle operational challenges head-on. At its core, a telematics system connects a mobile machine with its operator, enabling real-time information exchange. This information can be leveraged to predict maintenance needs, optimize machine performance and tailor operational patterns to specific user requirements.

In recent years, telematics has become even more impactful thanks to advancements in 5G connectivity, particularly in remote areas. Recent breakthroughs in artificial intelligence (AI) also are playing a critical role in enhancing telematics systems, enabling smarter data analysis and more accurate predictive capabilities. Industries such as construction, forestry, transportation and logistics are increasingly relying on telematics to monitor machine functionality, predict potential failures and optimize performance.

AI-powered analytics can process vast amounts of real-time data, uncovering patterns and providing actionable insights that were once difficult to identify. Understanding the operational profile of a machine — shaped by its duty cycle and the individual operator — can become a key differentiator for OEMs aiming to meet the growing demand for personalized machine performance. The combination of 5G connectivity and AI-driven data analysis presents a great opportunity for OEMs to provide a level of operational customization that drives efficiency and productivity.

5G connectivity paired with AI-driven data analysis can provide customizable operations to drive efficiency and productivity — even in remote areas.

BOSCH REXROTH

Data-driven and software-centric adaptability

One exciting development is the ability to optimize machine performance remotely. By connecting the machine, operator and operation via telematics, OEMs can trigger over-the-air (OTA) configuration updates when specific usage patterns are detected. These updates can adjust parameters like implement response, engine behavior or drive profiles to better suit particular conditions or user preferences. This dynamic adaptability — made possible by software-centric control systems — means the same hardware can be fine-tuned to perform differently depending on the operational context, enabling OEMs to serve multiple market segments with a single, versatile system.

This level of flexibility not only boosts performance but also drives cost-effectiveness by reducing the need for multiple hardware variants. By transferring functions from mechanical or hydraulic systems to software, OEMs can simplify hardware complexity while enhancing functionality. The result is a more cost-effective and adaptable system that can be modified to suit different operational needs without requiring significant hardware changes.

Telematics systems provide valuable insights into machine behavior and operator performance, offering an excellent starting point for addressing the OEM challenge of creating intuitive, easy-to-use interfaces. Simple metrics like vehicle speed, idle time, fuel consumption and engine load during specific tasks can provide actionable insights. Fleet managers can use this data to deploy features such as speed alerts, path optimization and tailored assistance functions based on location and task.

Enhancing after-sales services and security

The potential applications of telematics extend well beyond machine operation to after-sales services. Remote troubleshooting, real-time service scheduling, inventory management for spare parts, and data-driven maintenance packages are all services OEMs can offer to improve customer satisfaction and streamline operations. Recent AI advances are further enhancing predictive maintenance capabilities, helping enable even more precise and timely interventions.

By monitoring key data points, OEMs can identify potential issues before they cause significant damage, minimizing expensive repairs and improving overall fleet management efficiency. Telematics systems also offer significant security benefits.

Features like geo-fencing can alert operators if a machine moves outside its designated area and real-time location tracking can prevent theft and unauthorized use. These capabilities not only safeguard valuable assets but also enhance operational transparency, providing fleet managers with a comprehensive view of machine location and status.

Ensuring data security and maximizing value

Data security is a critical concern for many OEMs and their customers. Fortunately, telematics systems are equipped with robust security measures, including encryption and multi-factor authentication, to protect sensitive data. As telematics systems operate primarily through the cloud, OEMs can implement strong security protocols, reducing the risk of breaches and ensuring that data remains secure.

Telematics providers also can serve as valuable partners in managing data and offer insights that help OEMs optimize operations and improve serviceability. By giving fleet managers and end-users the tools to manage their own data, OEMs can provide maximum flexibility and autonomy, empowering customers to fine-tune operations and gain actionable insights from their machines.

Incremental implementation for long-term success

For OEMs looking to integrate telematics into their operations, starting small and taking incremental steps is key. Rather than diving into a comprehensive rollout, it is beneficial to begin with pilot programs or specific use cases to understand the system's impact and effectiveness. By demonstrating the value of telematics in smaller-scale operations, OEMs can build trust and encourage broader adoption across their customer base.

As telematics technology continues to mature, it will play a pivotal role in transforming the heavy machinery sector. The combination of real-time operational insights, predictive maintenance, and remote optimization capabilities represents a significant opportunity for OEMs to enhance productivity, reduce costs and improve customer satisfaction.

Telematics providers can serve as valuable consultants and/or partners in managing the data that's coming in and offer objective insights that can further benefit operations and serviceability.

Making telemetry systems a strategic advantage for OEMs

Telematics provides a strategic advantage for OEMs looking to remain competitive in an increasingly complex market. By leveraging the power of data and software-driven control systems, OEMs can meet the demands for operational flexibility, improve maintenance efficiency, and offer enhanced security. As technology continues to evolve, OEMs who embrace telematics will position themselves as leaders in an industry that is increasingly reliant on data-driven decision making. With the right systems in place, telematics has the potential to revolutionize how machines operate by helping OEMs drive innovation, reduce costs, and achieve long-term success.

Rafael Cardoso *is an engineering manager, mobile systems and software, for Bosch Rexroth.*

Advances in COMMERCIAL VEHICLE COMPRESSED AIR SYSTEMS

Electronic air control (EAC) addresses commercial vehicles challenges while providing manufacturers with greater flexibility during installation.

by Tony Fischbach

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Today's commercial vehicles tackle an incredible range of jobs across a growing number of applications and in varying environments. One common requirement among them is a reliable supply of clean, dry compressed air for the operation of brakes, lift axles, emissions controls, automated transmissions and leading-edge safety technologies like collision mitigation.

This means modern full-function air dryer technology demands three things: More dry air for the systems today's trucks depend on, improved energy efficiency and and air system diagnostics. The emerging technology of electronic air control (EAC) addresses these evolving needs, as well as environmental regulations, while providing manufacturers with a high level of flexibility during installation.

Advancing air dryer technology

It's essential to keep moisture, oil aerosols, and other contaminants out of a vehicle's air system to the greatest degree possible, since they present a corrosion hazard to some of the crucial components within. Oil, in particular,

can deteriorate seals, cause leaks, and damage valves and brake chamber diaphragms – so there's a lot at stake.

Air dryers equipped with electronic pressure control incorporate a solenoid-operated valve that replaces the traditional mechanical governor. This electronically controlled governor enables precise regulation of the dryer's charge and regeneration cycles using electronic air control software. Now the dryer can operate under different parameters in different conditions — increasing its dry air processing capability and saving energy.

A commercial vehicle air dryer with a traditional mechanical governor is engineered with two fixed setpoints that determine when the compressor charges and unloads. When the system reaches its full charge — usually 130 psi — the governor signals the compressor to unload.

However, when an air-drive system taps into the air supply — during a brake application, for instance — the pressure decreases, and when it reaches about 100 psi, the governor again signals the compressor to recharge and build pressure anew. It's an automatic cycle based on the pressure in the tanks.

Electronic air control makes the process smarter.

Better connectivity, information and efficiency

An electronically controlled governor is operated by software that monitors information broadcast across a truck's J1939 network — data including speed, engine torque and RPM. Using those variables, the governor can modify its charge cycle based on air system and engine demands.

For example, when a compressor is building pressure, it pulls approximately 8 to 10 HP from the engine. EAC software uses the vehicle's operating information to adjust the compressor runtimes. Say you're going downhill or idling: The engine is using fewer horsepower, so it's got some energy to spare. The EAC will temporarily increase the cut-in and cut-out pressures because the compressor can charge above the standard programmed pressure without the driver losing any engine power. On the other hand, if a driver is passing another vehicle or climbing a hill, they'll want to maximize horsepower without the compressor charging. In this case, the EAC will lower the cut-in and cut-out thresholds to prevent charging. (It's important to note the EAC software is programmed not to reduce the cut-in pressure below a safe setting, per FMVSS-121 regulation.)

> **"Electric-powered air compressors are also seeing adoption in various applications, providing an ideal match for alternative-drive vehicles."**

While those are the generalities of EAC, the technology also delivers customizability. If the software determines an air system requires extra drying capacity — on a truck hauling multiple trailers or equipped with extra axles, for example — then it can command additional short purge cycles, providing more dry air for vehicles that need it.

Because an electronically controlled air dryer is connected to the J1939 network, it also offers maintenance benefits. Monitoring for excessive air demand can indicate system leaks or other issues, and information on regeneration cycles and the amount of air processed can help signal when it's time for a new dryer cartridge.

New frontiers for air compressors

In an evolving propulsion landscape with an increasing focus on more environmentally friendly heavy-duty vehicles, it's become important to develop flexible air treatment and control systems that can be integrated into both traditional internal combustion engines and new zero-emission drivetrains. This has led to the development of modular control systems as well as electric air compressors.

These modular systems can control both traditional air compressors as well as those operated by electric motors and integrate features of other electronically controlled connected systems like electronic parking brakes. Incorporating the parking brake also reduces the total weight of the air treatment system. Some current brake system features like anti-compounding and spring brake inversion can also be electronically controlled. Where original equipment manufacturers (OEMs) are concerned, these modular technologies offer scalability in the form of options for single or multiple circuit systems.

Electric-powered air compressors are also seeing adoption in various applications, providing an ideal match for alternative-drive vehicles since they run quieter than comparable piston compressors. As with EAC dryer technology, they connect to a vehicle's controller area network and respond based on changing air demand requirements. Users will find electronic compressors equipped on both hybrid and fully electric vehicles, with various types suitable for high- or low-demand applications.

By building on the proven legacy of commercial vehicle air systems, steps are being taken toward safer, more efficient and sustainable vehicles in the future.

Tony Fischbach *is director, product group air treatment at Bendix Commercial Vehicle Systems LLC.*

Mastering POWER DISTRIBUTION in Electrified Machines

A PDU is critical for an off-highway vehicle's safety architecture and they present additional challenges for users and integrators.

by Oliver Lythgoe

Figure 1: A sewer cleaning machine, on a MAN Truck Chassis electrified by DINTEC Solutions.

FAVATIS GROUP

As the off-highway industry considers the electrification of larger and more demanding machines, on-vehicle power distribution becomes a critical consideration. Larger machines require more power, which translates to higher voltages and currents. For instance, a machine requiring 350 kW, would demand up to 438 A from an 800 V system. These current and voltage levels necessitate heavy-gauge cables, robust connectors and a rigorous approach to safety.

Four challenges for PDUs in off-highway vehicles

Every electrical machine requires at least one power distribution unit (PDU), which serves as the central hub connecting the machine's electrical system. At higher powers, every cable is point-to-point and must be properly terminated. Splices are not an option.

The PDU's importance is more than connectivity: It is integral to the vehicle's safety architecture. While power distribution is already a common feature in buildings, off-highway mobile machine requirements are more challenging. There are several reasons for this:

- **Space constraint.** On-vehicle space is significantly more limited than in buildings, and shrinking the dimensions of power distribution equipment introduces both risk and cost. High-voltage components must be safely isolated. High voltages can "jump" or arc if components are too close together. As the available space shrinks, achieving safe isolation becomes more complex.
- **Harsh operating conditions.** Off-highway machines operate in challenging environments, requiring PDUs to be protected from water ingress, and to withstand impact, accelerations and vibration. Even changes in operating altitude are pertinent, as arcs form more easily at higher altitudes vs sea level due to thinner air, necessitating additional design considerations.
- **Choosing between alternating or direct current (AC/DC).** Unlike buildings, where ac systems are the norm, machines normally use dc power. DC is more challenging to manage. It is harder to switch, potentially more dangerous for humans, and if arcs form they are difficult to extinguish. By its nature, alternating current changes direction so every 100 to 120 times per second the current will pass through zero, which facilitates switching.
- **Thermal management.** Thermal challenges are familiar to all designers of off-highway machines for most components and the PDU is no exception. For example, fuses capable of protecting a 500-A circuit

generate considerable heat, and in a closed metal enclosure, good thermal management is required if temperature-related failures are to be avoided.

These factors make the power distribution solutions for mobile machines very different from those of established fixed installations. As a result, this is driving the development of a specialized engineering discipline and a range of dedicated technologies, products and solutions.

Why electrical integration is an underrated challenge

Few OEMs today have teams with deep expertise in high-voltage design. This skill set is relatively new, and skilled designers remain scarce in the industry. Even if an OEM could justify hiring a full-time high-voltage specialist, recruiting such talent is challenging.

The lack of in-house expertise often leads OEMs to underestimate the complexity of high-voltage system design. As a result, the PDU can become a critical path item on the project timeline, jeopardizing overall machine development schedules.

For smaller, low-power machines with simple operational requirements, off-the-shelf PDUs can be feasible. Lower currents and voltages mean less expensive components and make standard solutions easier and more cost-effective to implement.

However, as power requirements and operational complexity increase, a standardized approach becomes impractical. A universal PDU capable of meeting all customer requirements would likely be oversized and prohibitively expensive. The costs of components such as connectors, busbars, and contacts rise exponentially with power, making it uneconomical to incorporate components that are not strictly required.

Large cables carrying hundreds of amps further complicate matters, as they often have minimum bend radii exceeding 1 foot. The direction of cable entry into a PDU can dictate connector placement, which impacts the unit's internal layout.

Prototyping PDUs with short lead times

The PDU design cannot be finalized until late in the machine development process, yet it is one of the first components to be installed. This makes lead time a critical factor for project success.

When it comes to high-voltage system integration, short lead times are a fundamental part of every project, particularly the prototype phase. The materials and design choices are optimized for rapid delivery without compromising safety or quality.

As OEMs move beyond the prototype stage to pre-series and volume series production, the priority requirements for PDUs rapidly evolve. The focus shifts from lead time to cost optimization. This can be achieved through lower-cost components with longer lead times, such as alternative enclosure materials, or designs that reduce assembly time.

For example, prototypes and initial production would often use a busbar design. Busbars are thick bars of copper with a rectangular cross section, bent to the required form. This is proven technology but it demands a time-consuming assembly of the PDU.

When moving to production volumes, it often makes sense to move to power PCB technology, which allows for assembly time to be reduced by as much as 90%. The higher tooling cost does mean this is only viable when the machine design is frozen, ready for series production.

Four advanced PDU capabilities

At first glance, a PDU may appear to be little more than copper, connectors and fuses. In reality, PDUs often incorporate advanced functionality, including:

- **Circuit switching:** This is to determine which parts of the machine circuit are live at different points in the machine operating cycle. The power to the wheels or an implement, should, for example, be cut when the machine is charging.
- **Safety interlock systems:** This ensures the machine only operates when all connectors are plugged in.
- **Pre-charge circuits:** This reduces the voltage differential when closing a contactor, minimizing the risk of arcing.
- **Discharge circuits:** To safely discharge residual voltages.

These features make the PDU central not only to power distribution, but also to the machine's overall safety and operational reliability.

Lowering system costs with a PDU

Although the PDU is one of the last components to be fully specified, it's good to engage a high-voltage system integrator very early in the machine design process. Early involvement enables proper sizing of components which is key to cost management. The right expertise at the early stages reduces the number of design interactions and shortens the whole project cycle. ■

Oliver Lythgoe *is chief marketing officer at FÉTIS Group.*

Figure 2: Example of a power distribution unit (PDU).

Unlocking Versatility: THE POWER OF PTO

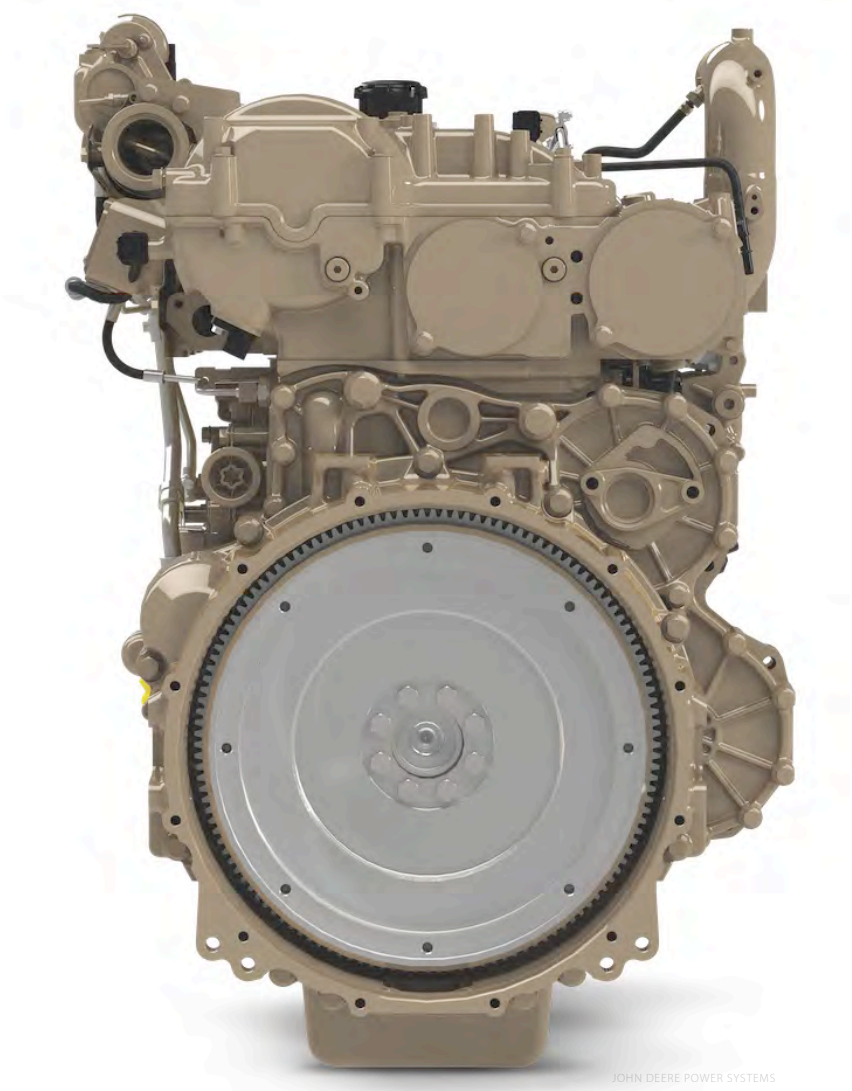
Learn how power take-off (PTO) systems are maximizing the potential of diesel engines across diverse industries, driving efficiency and versatility.

by Chris Jensenius

While horsepower and torque often dominate discussions about off-highway engines, there is another often-overlooked feature of modern diesel engines that is playing a vital role in heavy-duty industries: Power take-off (PTO). This versatile mechanism is a driving force behind countless applications, making diesel engines more flexible, more customizable, and better optimized for today's power needs.

What does PTO do for diesel engines?

A diesel engine is the powerhouse of a machine, generating energy to drive its primary function, like moving a piece of equipment forward. PTO enables a secondary outlet for that energy — a way to tap into the engine's power and direct it toward other tasks. It's a mechanical device that transfers the power generated by the engine to auxiliary attachments and components, such as hydraulic pumps or air compressors. By providing a means to power external components, PTO helps original equipment manufacturers (OEMs) reduce engine package size while expanding functionality.



JOHN DEERE POWER SYSTEMS

The John Deere JD4 industrial engine has a two forward-facing auxiliary drives and one rear-facing auxiliary drive, allowing for greater user versatility.

How a PTO system works

Although PTO systems may differ in their design and application, the fundamental principle of power transfer remains the same. A PTO is often connected to the engine's crankshaft, gearbox or auxiliary drive. As the engine runs, the PTO shaft rotates and translates power to off-boarded components. This can be engaged or disengaged, allowing controlled transfer between primary power and component power needs.

PTO systems come in various configurations to meet diverse application needs. The John Deere JD4 industrial engine, for example, features two forward-facing auxiliary drives and one rear-facing auxiliary drive. This configuration offers flexibility for original equipment manufacturers (OEMs) because components can be strategically positioned based on their size and application requirements. Taller auxiliaries such as air compressors, for instance, can be packaged using the lower forward-facing PTO drives, tucking in close to the engine block under other components.

On the other hand, hydraulic pumps low and tight to the block are difficult to plumb hoses and lines to, so these are optimally positioned in a mid-position forward or rearward. This adaptability empowers OEMs to tailor the engine package to their specific needs, optimizing space utilization and component integration.

Four PTO system benefits

PTO systems offer numerous advantages that contribute to their widespread use across diverse industries. This versatility is valuable in sectors like agriculture, construction and forestry, where PTOs drive essential equipment. This adaptability translates to several key benefits:

- **Increased efficiency:** By using a single engine to power multiple functions, PTOs eliminate the need for separate power sources for each piece of equipment, streamlining operations and reducing complexity.
- **Cost-effectiveness:** PTOs harness the engine's existing power, eliminating the need for separate engines or motors to drive accessories. This can reduce equipment costs by powering accessories directly through an efficient gear interface while avoiding the complexity and expense of installing and connecting extra engines in the vehicle.
- **Enhanced versatility:** The flexibility of PTOs makes diesel engines adaptable for a wide range of tasks, increasing their overall versatility and value.
- **Robust reliability:** PTO systems are designed for durability and consistent performance to ensure reliable operation even in demanding applications.

Beyond these benefits, PTOs play a crucial role in enabling compact engine designs. As manufacturers focus on creating more efficient engines with optimized footprints, PTO systems are becoming even more important for maintaining functionality without sacrificing performance. By integrating PTOs directly into the engine block, manufacturers can provide efficient power transfer for auxiliary components in a compact and streamlined package. This integration helps optimize space utilization and component placement, overcoming the challenges of limited space in modern engine compartments.

> **"Power take-off (PTO) is a driving force behind countless applications, making diesel engines more flexible, more customizable, and better optimized for today's power needs."**

Looking ahead for PTO systems

As technology advances, PTO systems are becoming even more sophisticated. We're seeing the emergence of features like electronic control, which allows more precise and automated operation of auxiliary equipment. Variable speed operation is another promising technology, offering greater control over the power delivered to the PTO. These advancements will enhance efficiency, underscoring the vital role PTOs will play in the future of diesel engine applications.

As the power landscape continues to evolve with the integration of new technologies like electrification and hybridization, a well-rounded power portfolio becomes more critical. Off-highway applications are adopting diverse powertrain solutions with the flexibility to adapt to both traditional internal combustion engines (ICE) and newer electric and hybrid systems.

In this dynamic environment, the PTO will serve as a vital bridge between these technologies. Its ability to transfer and distribute power makes it an essential component in the transition toward a more sustainable and efficient future. By enabling seamless integration of ICE technology with electric drives and hybrid configurations, PTO systems will contribute to optimized performance and increased efficiency. ■

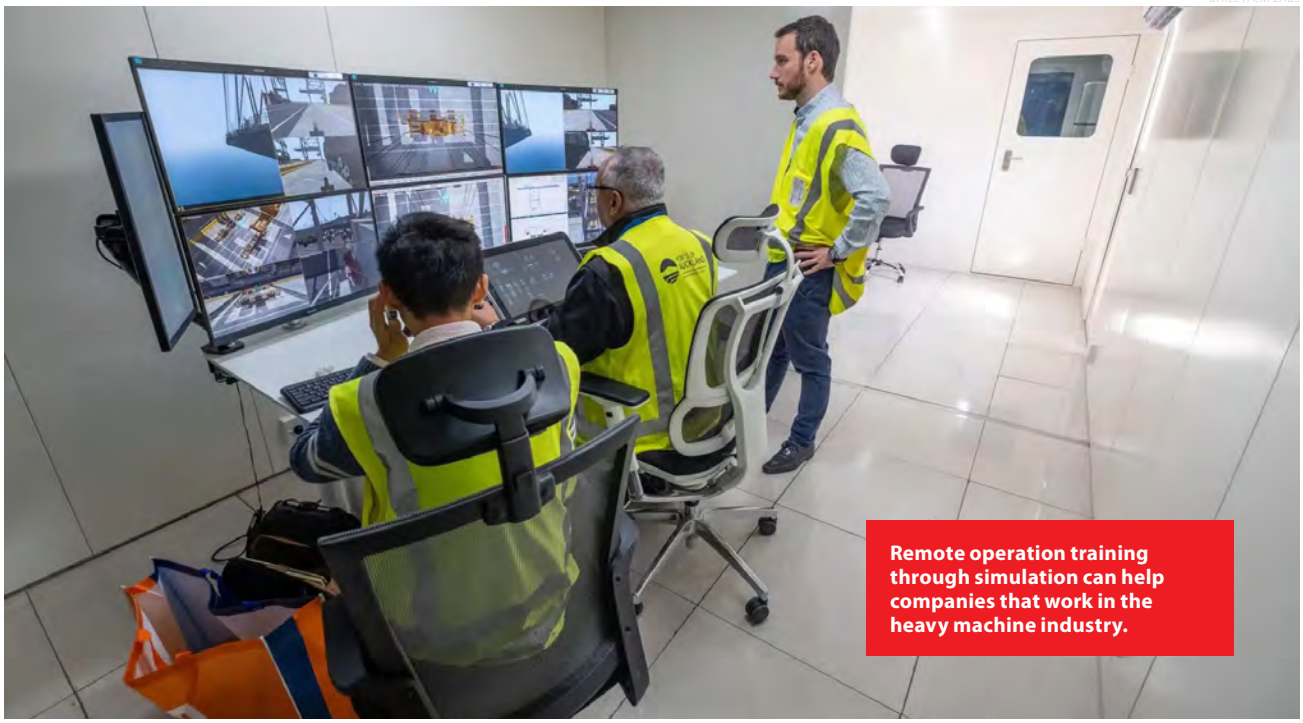
Chris Jensenius *is staff engineer, electrics and auxiliaries at John Deere Power Systems.*

Partnership Benefits for Testing, Simulation Technologies

Developing simulators capable of precision and accuracy for heavy vehicle industries is critical; developing the right partnership can help achieve greater results.

by Brianna Henderson, Mary Lee Shalvoy

BAILEY/CM LABS



Remote operation training through simulation can help companies that work in the heavy machine industry.

Simulation technology has become an indispensable tool for training operators safely and efficiently. At the heart of these cutting-edge simulation training systems lies a blend of powerful software and high-performing hardware, designed to replicate real-world scenarios. For companies in this sector, solving highly specific technical hurdles often requires cross-company collaboration — a testament to the importance of industry partnerships.

CM Labs Simulations and Bailey's partnership is an example of how these companies overcame technical challenges to find a solution that has improved simulator performance and reliability.

The need for precision in simulations

CM Labs specializes in heavy equipment simulation technology, helping businesses worldwide safely and quickly train operators. Customers use the simulation training to help operators develop muscle memory and critical skills that translate directly to real-world operations. However, creating powerful simulation systems requires components that meet uncompromising standards for performance and durability.

A key hardware need was an electronic throttle capable of precise control under extended use that could integrate into their line of simulators.

"Our customers use their simulators for years to train operators during downtime or as a regular part of their training program," said Alan Limoges, manager of product growth and partnerships. "We didn't want simulator components to become worn and break after prolonged use. We needed something that was able to withstand years of 24/7 operation while still maintaining a high degree of precision."

Standard, off-the-shelf electronic throttles fell short of their requirements. What the company needed was a solution that combined fine-tuned customization, reliability under heavy use, and smooth integration into its proprietary simulators. That's where its partnership with Bailey came into play.

Bailey, known for its expertise in developing advanced control systems, was an ideal partner.

"From the very beginning, Bailey was a pleasure to work with," said Lisa Barbieri, VP of marketing and strategic partnerships at CM Labs. "The team at Bailey was very receptive to our feedback, working closely with us to develop a solution that fully met our needs."

Jan Kershaw, Bailey's account manager for CM Labs Simulations, said of the challenge, "From the start, we understood that a one-size-fits-all solution wouldn't work for CM Labs. This project required a deep understanding of their specific simulator applications."

The collaboration centered on Bailey's Floor Electronic Throttle as a good starting point for CM Labs' needs, but one that required targeted modifications.

Bailey worked with CM Labs to tailor the throttle so it advanced performance while ensuring it met every project specification they required.

Barbieri said of the collaboration with Bailey: "They listen to us. They have a team of engineers who work alongside us to achieve our objectives."

Marc-Olivier Bouchard, CM Labs' production manager, echoed Barbieri's points, praising the collaboration process.

"What impressed us most about Bailey was its willingness to adapt. We were also impressed by the team's technical depth. They didn't deliver a product — they delivered a solution."

The enhancements made to the throttle included specialized adjustments to the internal mechanics, ensuring smoother operation under intense use. These modifications resulted in benefits including:

- **Enhanced control**: Operators using the custom throttle experienced smoother, more precise responses, replicating the behavior of real-world heavy equipment.
- **Greater durability**: The modifications ensured the throttle could handle extensive use cycles without compromising performance.
- **Improved user experience**: Smooth integration with CM Labs' simulator interfaces made for a more intuitive and realistic training environment.

Heavy equipment simulation technology needs precision to be successful.

BAILEY/CM LAB

Both companies addressed challenges collaboratively, ensuring mutual understanding and alignment at every step.

"This wasn't just about meeting specs; it was about pushing the envelope," Kershaw said. "Collaborating closely with CM Labs allowed us to create something that genuinely moved their simulators forward."

Implications for the heavy equipment industry

The results of this partnership extend beyond the two companies involved. For the heavy equipment simulation industry — and testing and simulation technologies as a whole — this collaboration sets a clear example of how tailored, industry-specific partnerships can catalyze new ideas.

CM Labs and Bailey achieved results neither could have achieved alone through their collaboration. They improved the simulation training field while reinforcing the importance of reliable, high-performing hardware in critical training scenarios. The collaboration here highlights a broader truth for enterprises in complementary industries: combining expertise, instead of working in silos, can yield greater outcomes.

The success of this collaboration carries important lessons for all organizations working at the intersection of technology and industry. Regardless of it's an original equipment manufacturer (OEM) innovating in a particular niche or a supplier looking to strengthen client relationships, partnerships built on trust, clarity and technical expertise can deliver a competitive advantage that pays dividends in the long term. By pooling resources and expertise, firms can break new ground and deliver solutions with far-reaching impacts on technological growth.

This truth signals a future of possibilities for those willing to participate. Innovation happens when technology meets teamwork. For the heavy equipment industry — and beyond — it's partnerships like these that help ensure progress.

Brianna Henderson *is marketing manager for Bailey;* ***Mary Lee Shalvoy*** *is director of communications and content for CM Labs Simulations.*

The Evolution of EXCAVATOR CAB DESIGN

Excavator cab design has evolved to enhance the operator experience, improve safety and streamline efficiency.

by Sejong Ko

In today's heavy equipment industry, the design of excavator cabs and the technology inside them are just as important as the power and efficiency of the overall machine. For operators who spend long hours each day on the job, cab comfort and functionality are critical to maintaining their productivity while reducing fatigue. Owners and fleet managers also understand the value of well-designed cabs and advanced technology because they help minimize costs like unnecessary rework, maintenance and downtime.

As the heavy equipment industry evolves, cab design has moved far beyond basic functionality to incorporate advanced features that enhance the operator experience, improve safety and streamline overall efficiency. These innovations reflect a growing recognition that operator well-being influences jobsite productivity and profitability.

VOLVO CONSTRUCTION EQUIPMENT

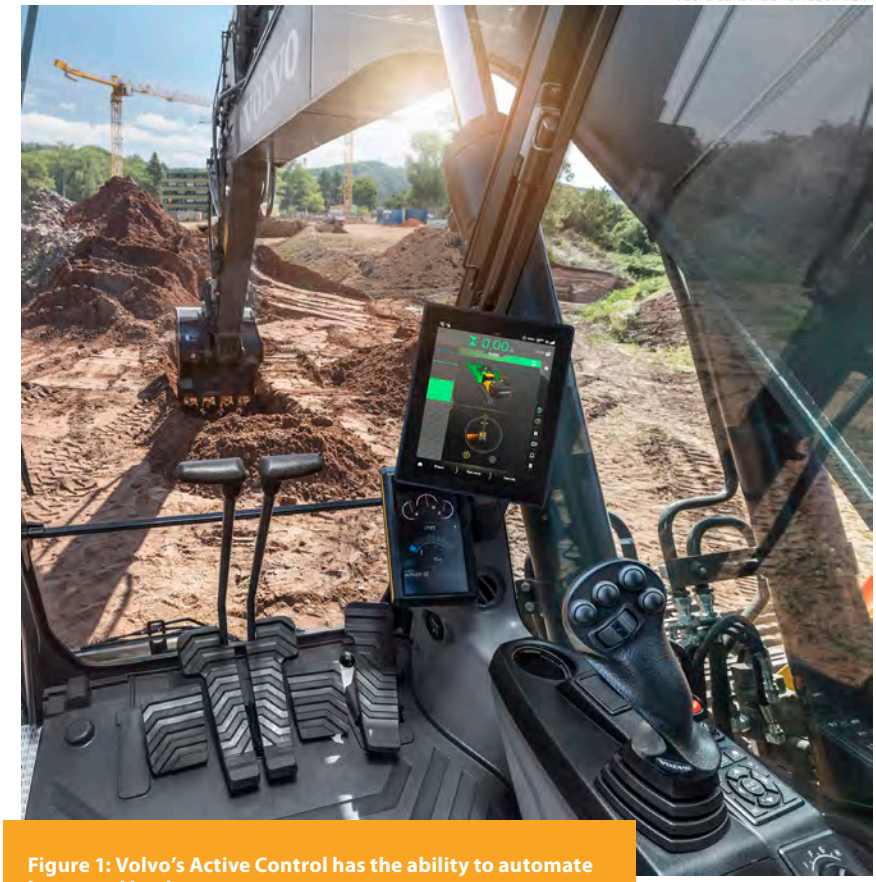


Figure 1: Volvo's Active Control has the ability to automate boom and bucket movements.

Why cab design matters

Excavator operators often face long, physically demanding workdays — their cab serves as their "office" for hours on end. A poorly-designed cab can lead to discomfort and fatigue, negatively impacting productivity and increasing the likelihood of mistakes. Ergonomic designs, improved visibility and intuitive controls help keep them focused while reducing physical strain, making these features crucial considerations when selecting a machine.

For example, multiple forms of climate control, adjustable seating and logically placed controls are seen as vital to the operator's ability to work efficiently for extended periods of time.

As cabs become more tech-enabled, machine control systems with real-time data displays contribute to a higher degree of accuracy and a reduction in expensive rework.

With the ongoing skilled labor shortage, managers are looking for ways to keep their current employees happy and returning to work each day. A machine that doesn't make them feel beat up at the end of the day is a great place to start.

Tackling challenges with smart cab design

To be their most productive, an operator should be comfortable and not feel physical strain caused by the layout of

the controls and dashboard.

However, modern cabs are expected to do more than provide comfort. Another common challenge is poor visibility, which is a safety hazard. Equipment manufacturers are addressing this concern by integrating camera systems that provide a broader view of the jobsite, allowing operators to better monitor their surroundings to avoid blind spots and reduce accidents.

While staying connected on the job is another necessity, that connectivity should be convenient and distraction-free. For example, some cabs now offer wireless phone charging and Bluetooth capability for hands-free communication. They also integrate additional comforts like built-in hot/cold storage and more compartments for personal items, so operators can access their essentials without unnecessary clutter or distractions.

Temperature control also plays a vital role in keeping operators productive, especially during extreme weather conditions. Cabs should be equipped with features like front and side window shades to help regulate cabin temperature during the hotter summers. Seats also can feature heating and cooling elements — because a long day only feels longer when the temps are tough to handle.

The role of technology in efficiency and cost management

With comfort and safety addressed, owners and fleet managers may wonder how the newest cab technology can contribute to more efficient operations. The top original equipment manufacturers (OEMs) tend to have assistive software on touchscreen tablets for things like on-board weighing and in-field design. Current models also improve user experience with larger, hi-res screens, as well.

Another feature that is becoming more common on in-cab devices is the ability to automate boom and bucket movements. Combined with real-time data and diagnostics from the cab's control systems can reduce rework costs and avoid downtime.

A smart hydraulic system that automatically adjusts power based on the task at hand will also go a long way in optimizing fuel efficiency and extending the life of the machine while reducing operating costs.

Another technological perk found in more and more cabs is a selection of work modes. These are predetermined settings that operators can choose based on the task and material at hand. OEMs also are expanding upon these modes in their new excavators. Not only does this help operators find the right power for the job and dig in, but it helps save on fuel and emissions, too.

Another addition for excavators is an auto power boost, which automatically provides more power for additional digging force and lifting capacity. In addition to the ability to adjust this manually, predefined conditions can be set up to allow this function to kick in automatically and turn off after several seconds.

VOLVO CONSTRUCTION EQUIPMENT

Figure 2: Volvo's Dig Assist, for example, provides an improved user experience in the newest models thanks to a larger, higher-resolution screen.

Exceptional performance in the right cab

The modern excavator cab has come a long way from being a simple operator station. Today, it serves as a critical component to improve productivity, enhance safety and reduce operating costs. As equipment manufacturers continue innovating, it's clear a well-designed cab can make all the difference in the operator's day — and a good day for your operators can mean a great day for your bottom line.

> **"As cabs become more tech-enabled, machine control systems with real-time data displays contribute to a higher degree of accuracy and a reduction in expensive rework."**

Sejong Ko *is product manager of large excavators for Volvo Construction Equipment.*

Electrification Challenges, TRENDS FOR OEMS

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

by Chris Vavra

Flexible design was prioritized in the development of Fundex Equipment's electric foundation rig. Its F4800E machine has the ability to switch between energy sources, ensuring it can operate on a variety of construction sites.

DANFOSS

Electrification has always been a major aspect of off-highway vehicles and technology and recent trends have made it even moreso. The mining, agriculture and construction industries are grappling with changes and challenges to the power grid and how their vehicles are powered. This is even more acute with the tide shifting towards alternative energy and fuels as a viable source in certain applications.

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

- **Dr. Wilfried Aulbur,** senior partner, Roland Berger
- **Eric Azeroual,** vice president, sales development and portfolio, Danfoss
- **Lloyd Gomm,** global director marketing, ZAPI GROUP
- **Brady Lewis, P.E.**, manager, emerging products & technology, CASE Construction Equipment
- **Athan Tsokolas,** product manager - commercial Lithium-ion batteries, Vanguard
- **Chris Wadsworth,** VP and GM, global OEM, Wesco.

QUESTION: What is driving the adoption of electrification in the off-highway industry, and how do you see this evolving over the next decade?

Dr. Wilfried Aulbur: The off-highway industry is pushing towards decarbonization to mitigate the negative impacts of climate change. The complexity of the industry regarding products and applications is a key reason why it is unlikely that we will find a one-size-fits-all solution for decarbonization of the industry. As a consequence, it is imperative to have an application-focused, technology agnostic approach to de-carbonization. Electrification will play a role, either via battery electric vehicles or hybrids, in specific applications. Key drivers here are a combination of three factors: The availability of the right product, adequate infrastructure and an overall total cost of ownership (TCO) that is competitive vs. alternative options. As battery technology continues to evolve and as battery costs

are declining, we do expect more penetration in the off-highway space in the years to come.

Eric Azeroual: Emissions regulations were the catalyst for the development of electric off-highway machinery. Legislation continues to play a role today, but the drivers have started to change. Buyers are interested in performance improvements electric vehicles can provide — instant torque is one example — and TCO calculations are starting to favor EVs. I see this leading to acceleration of electrification in the off-highway industry. We don't need to convince customers to use EVs; we need to solve the battery/charging problem.

Lloyd Gomm: There are four aspects to consider:

- **Sustainability –** Regulatory pressures pushing zero-emission compliance continue to be a factor, but the long-term operational benefits of electrification are becoming stronger motivation for OEMs to make the transition
- **Technology –** Advances in battery chemistry and charging technology are improving the performance and resilience of electric drivetrains, bringing them en par with traditional combustion engine systems
- **Practicality –** Besides significant cost-savings over time due to less maintenance and fossil fuel costs, electric systems offer efficiency, reduced noise and ease of use for operators.
- **Economics –** The cost of batteries, the most expensive component in EVs, is decreasing, and the awareness of the lower TCO that comes with electrification is increasing.

Over the next decade, sustainability and technology will primarily drive adoption.

Organizations such as the IEA and the UN's Sustainable Development Goals (SDGs) highlight the gap between goals and reality, indicating that regulatory pressure has yet to peak. As for the technology bottleneck, emerging innovations such as AI are set to overcome it, paving the way for both practical benefits and economic viability.

Brady Lewis: More and more, we're seeing projects with unique jobsite requirements. Whether it's urban centers with rules for noise or emissions, confined or congested jobsites, nighttime projects or work that requires indoor operation — EVs provide a clear advantage for these kinds of jobs because they produce zero emissions, minimal noise and require no diesel

fuel. EVs also open doors to winning contracts on projects that prioritize green credentials, which are becoming increasingly common.

These trends will only continue. Increasing urbanization will result in more confined and congested jobsites. Cities and states are introducing more rules and incentives to encourage construction crews to minimize disruptions and environmental impact. Some states like California are even offering heavy-duty voucher funds to incentivize the purchase of clean off-road equipment.

Electrification in the construction industry is still in its infancy, and the technology will rapidly evolve over the next 10 years to drive greater adoption. Consider how far EVs in the automotive industry have come in the past decade, as the median driving range has more than doubled in just 10 years. EV construction equipment could see a similar pace of change, which is why CASE continues to invest in electrification R&D.

Athan Tsokolas: Several factors are driving the adoption of electrification in the off-highway industry. Currently, emission restrictions and noise regulations are pushing the shift toward electric solutions, particularly in regions with strict environmental standards. Electric equipment's ability to operate indoors and in enclosed spaces, where combustion engines can't, is a major advantage.

Looking ahead, key drivers will be decreasing costs and TCO. As technology advances, batteries and electric powertrains are becoming more affordable, making them accessible to a wider range of users. Additionally, enhanced features like autonomous operation and efficiency strengthen the business case for electrification.

Chris Wadsworth: Clean-energy initiatives and zero-emissions goals are driving the increased interest in electrification of off-highway vehicles. Across the globe, companies are working to comply with government regulations and achieve their own sustainability objectives which, in industrial industries like construction, agriculture and mining, require a massive shift away from gas and diesel power. However, the cost to electrify a fleet of off-highway machines requires a significant investment in R&D and willingness to reinvest profits back into the business. So, while companies are eager to invest in electric vehicles (EVs), as it stands today, it's difficult to do at scale in a cost-effective manner. Plus, there are still lingering questions

about how EVs will hold up over time and what type of return on investment they'll be able to provide.

QUESTION: Which off-highway segments are leading in electrification, and why?

Dr. Wilfried Aulbur: Electrification in the construction, agriculture and mining industries is a question of application and sub-segments. For example, in construction it is comparatively easier to electrify smaller products such as skid steers. However, these products consume less energy and their overall hours of operation are comparatively low which means that their overall impact on emission reduction is limited. Large equipment is more difficult to electrify given the power and infrastructure needs. This equipment is used more extensively, has higher horsepower engines and as a consequence drives a significant amount of emissions.

Eric Azeroual: Mining, material handling and lawn and turf are generally well electrified today. Mines are closed sites where installation of fast chargers makes sense. For underground mines, ventilation can be 30 to 35% of operating costs. If we reduce or eliminate that cost through emissions-free machinery. Material handling and lawn and turf are heavily electrified, due to lower power requirements and shorter duty cycles.

Construction and agriculture aren't as advanced, and that's primarily due to charging infrastructure, power needs, and machine duty cycles. This is rapidly changing, however. Almost every construction OEM now has a lineup of battery-powered equipment, and we're starting to see production in significant volumes, especially in mini excavators.

Lloyd Gomm: Electrification has become dominant in material handling, though not always considered an off-highway segment. Forklifts, in particular, see more than 66% electrification adoption. It is also highly prevalent in aerial work platforms, which can be considered as part of the non-road mobile machinery segment.

The success of electrification in these major industrial applications sets the stage for the transition of others, such as construction. Construction is positioning for significant electrification in the coming years to meet the needs of ever-increasing urban, rural development, and compliance with stricter zero-emission regulations. The expanding charging infrastructure, led by the build-out of commerical passenger vehicle charging networks, is helping construction overcome one major limitation — availability of utility power for recharging equipment.

Brady Lewis: As emissions and noise become an increasing concern for urban construction contractors, utilities teams, municipal governments and even landscapers, the construction equipment industry has seen significant advancements toward electrification. With machines that produce zero emissions and minimal noise, it changes the game for where, when and how these crews get work done. Whether it's urban centers with strict

noise or emissions mandates, confined or congested jobsites, nighttime projects, landscaping in quiet residential areas or indoor work for building construction or utilities, electrified machines are providing a clear advantage for these kinds of jobs.

Athan Tsokolas: Construction and mining are leading the electrification of off-highway segments. Construction — particularly indoor applications — benefits from reduced emissions and noise. Mining adoption is driven by safety improvements and automation possibilities that electric vehicles offer. Compact equipment is also embracing battery power because smaller machines can utilize smaller, lower voltage battery packs, which helps reduce costs. Compact equipment is frequently used in enclosed spaces for applications like construction finishing, which benefits from zero-emissions (at the point of use) power.

Chris Wadsworth: It's hard to find a segment of the off-highway industry that is not interested in electrification. However, given the level of investment required, just how willingly businesses are to fully shift to EVs is another matter entirely. Instead, there has emerged a company profile that is most likely to take the leap into electrification. These often are global organizations who must navigate varying carbon emission requirements and ISO certifications across multiple different countries. Instead of customizing each fleet per region, they are seeking out ways to streamline and design EVs that can be used in any area in which they operate. These entities place a high value on partnerships that can help them through every phase of electrification — from design to operation — and avoid one-off investments wherever possible.

QUESTION: How can OEMs and suppliers address concerns around TCO for electric off-highway vehicles?

Dr. Wilfried Aulbur: Addressing cost in electrified off-highway vehicles takes a broader look at the ecosystem and requires collaboration from OEMs, suppliers, fleets, charging infrastructure providers, utilities, etc. In principle, we are dealing with a chicken and egg problem. Without competitive vehicles and adequate infrastructure, fleets find deployment of relevant volumes of electric off-highway vehicles unattractive. Without volumes, OEMs and suppliers are hard pressed to reduce cost and charging providers have no business case for their infrastructure investments.

Eric Azeroual: TCO can favor electric machines. Operating costs tend to be lower because electricity prices are more stable and generally less than fuel prices. Maintenance costs are also lower because there are fewer moving parts and service items in an electric vehicle. For assurance that an electric vehicle will provide TCO benefits, buyers should perform a detailed life-cycle cost analysis that accounts for upfront cost of the machine and charging infrastructure, including subsidies, as well as long-term costs including energy, maintenance, productivity/downtime, battery replacement and, eventually, estimated resale value.

Lloyd Gomm: Awareness is essential. A significant discrepancy exists between perceived and actual total cost of ownership (TCO) in electrified machinery. The challenge lies in effectively communicating these long-term savings to drive adoption.

Brady Lewis: The total cost of ownership for an EV can include both the upfront purchase price and the ongoing costs of operating the equipment. Many customers are saving on the ongoing operating costs, primarily driven by maintenance savings and the relative cost of electricity vs. diesel fuel. The upfront purchase price is the most significant item for someone trying to "run the numbers." In that regard, off-highway OEMs making EVs can see the progress made in the automotive industry. As with any new technology, the early product generations are more expensive. As technology matures and increasing volumes improve economies of scale, the cost typically decreases.

Chris Wadsworth: At this point in time, EVs are a significant investment

for any organization deploying or selling off-highway vehicles. Streamlining development and working with experienced partners that can help navigate the design process, provide clarity on the right technical innovation, and understand the intricacies of deploying electric fleets on a global or regional scale can help address total cost of ownership concerns from the outset.

Some companies looking to "dip their toe in the water" are utilizing rentals or subscription models to better understand the capabilities and costs before making a larger investment. OEMs and suppliers familiar with these models can help their customers determine which model would best fit their needs.

QUESTION: How do you see collaborations between OEMs, suppliers, and technology companies shaping the future of electrification and electronics in this space?

Dr. Wilfried Aulbur: There are different approaches in the off-highway space regarding new technologies. Some players are leveraging their market might and dominant position to establish de facto independent ecosystems. Others focus on solutions that are more clearly positioned as retrofit options and as "color-blind" options that function across various vehicle brands. Which way is ultimately successful will depend on the value that is created for customers.

Eric Azeroual: Collaboration can make or break an OEM's electrification efforts. While larger OEMs generally have dedicated electrification teams, smaller OEMs may need to extend the capabilities of their internal teams with external support. Suppliers and systems integrators can evaluate vehicle needs and assist with machine design. We work with OEMs not only to design and optimize the electric powertrain, but also the hydraulic architecture to maximize efficiency and performance. As a system supplier, we have a comprehensive understanding of the application. We know how to put everything together in a system. We don't just offer components; we help customers integrate them into their vehicles.

Collaboration extends to buyers, as well. OEM representatives should be ready to assess a customer's facility and power needs, addressing potential infrastructure limitations and guiding them through the complexities of charging infrastructure and integration.

Lloyd Gomm: Given the relative infancy of electrified non-road machinery, cross-industry collaboration is essential to accelerate adoption. The success of these partnerships revolve around:

- Cross-sharing successes and learnings around development, as well as market dynamics, regulations and emerging needs
- Developing greater supply chain resilience across critical materials
- Component standardization and modularization (including software) to reduce cost and improve interoperability
- Supporting charging infrastructure development enabling widespread deployment.

Athan Tsokolas: We connect OEMs to suppliers and technology companies to help drive innovation and accelerate the development of cutting-edge electrification solutions. This integrated approach ensures that OEMs, particularly small- to mid-sized ones, have access to the latest advancements in battery technology and benefit from shared engineering expertise.

Chris Wadsworth: Collaboration is a critical part of making electrification more widespread in the off-highway industry. End users, OEMs, manufacturers and distributors must all communicate

and work together to figure out the best path forward.

QUESTION: What is the projected timeline for widespread electrification in off-highway vehicles?

Dr. Wilfried Aulbur: Widespread electrification of off-highway machines cannot be defined at the overall industry level. As we discussed earlier, some segments and applications lend themselves to electrification and should see significant penetration over the next 5 to 10, in some cases 15 to 20, years.

Eric Azeroual: This really depends on the segment and the machine platform and size. Small lawn and turf will approach 100% electric in the next 10 years. For larger machinery across off-highway segments, widespread electrification depends primarily on the development of charging infrastructure, battery advances, and market conditions, so it's difficult to predict a concrete timeline.

Lloyd Gomm: We see electrification progressing in stages, closely tied to voltage levels and power demands. With continued advancements in battery technology, infrastructure, and policy support, electrification could become the industry norm by 2035.

Brady Lewis: The adoption rate of electric vehicles in a given industry is difficult to estimate now, let alone predict for the future. Like the automotive world, there is a lot of variability across geography, industry and governments.

Athan Tsokolas: Predicting the future is always a challenge, but within the next 5 to 10 years, electrification will be the dominant technology in the compact off-highway sector. This projection is based on key factors, including the growing adoption of electric equipment as end users experience benefits like improved performance, reduced noise and lower emissions. These advantages enhance the operator experience, reduce costs and boost profitability.

Finally, OEMs are playing a crucial role by actively developing and releasing new electric off-highway equipment, further expanding the options available to customers and demonstrating their commitment to this technology. As these benefits become more apparent, the technology matures and the industry continues to embrace electrification, we can expect to see a significant shift toward electric solutions in the off-highway sector.

HOLLAND BELT LOADERS' ROLE

Holland belt loaders were conceived as the next evolution and offered many benefits and advantages over previous models, marking a step forward for the technology.

by Thomas Berry , Archivist, Historical Construction Equipment Association

HOLLAND LOADER COMPANY COLLECTION, HCEA ARCHIVES

One of the four Holland loaders at Perris Dam makes quick work of loading a 110-ton capacity Euclid bottom dump. It's equipped with a vertical cutting edge.

In the last installment, we looked at the Euclid BV and Sierra travelling belt loaders. While these machines were remarkably productive in proper conditions, they were beset by limitations. For the more successful of the two, the BV, the issues were:

- Clogging by material sloughing from the bank behind the towing tractor or at the throat of the conveyor
- Material rolling back down the belt or the belt itself slipping; susceptibility to wear and damage, especially from rocks
- High maintenance costs
- Loss of energy moving it on its own crawlers
- Poor maneuverability and steering
- Difficulty maintaining grade
- Inability to work contours.
- For all their issues, the BVs typically had long service lives, and remained the most efficient means of loading bottom-dump trucks and scrapers. BV owner Francis H. Holland noted in the 1960s, "The old Euclid loader had to be lived with" because it had been discontinued in 1956 — primarily due to large motor scrapers rendering it obsolete — and no comparable replacement was available for its kind of high-volume earthmoving.

Bottom-dump trucks were the cheapest haulers to run, and much larger models were available in the 1960s. Holland realized that costs would be further reduced if larger, more dependable, higher capacity loading equipment was used. So, he began designing his own belt loader, using ideas he had conceived as early as the 1950s; and, in 1969, he founded the Holland Loader Company to manufacture it.

His design was built around increasing and streamlining the flow of material through the loader, with greater power, elimination of the undercarriage, a 72-inch belt, entirely new means of mounting it to the propelling tractors, and more efficient drive for the conveyor.

The loader was introduced circa August 1972, and one of its first major uses was at Perris Dam in southern California. At Perris, moving at three miles per hour between two Cat D9s, a Holland with a 410 hp engine loaded a 110-ton Euclid bottom dump truck with loam and sand in 43 seconds, or with ripped material in 90 seconds, at a rate of 75,000 to 120,000 cubic yards per two-shift workday, more than Euclid's new Super BV and at lower costs.

Despite problems, the Hollands had several benefits such as:

- Nearly 1,500 hp between the loader and two propelling tractors
- Its entire weight rode on the tractors for more efficient movement and flotation
- Smoother operation with no rollback of the belt
- Superior tracking, ground clearance and cutting inside curves
- Reduced clogging; improved breakout of bank material
- Increased discharge height relative to cut
- Overall simplicity of design.

Holland loaders went on to achieve astonishing productivity, loading 180-ton-capacity trucks in less than a minute. They could also be used with traveling transfer and discharge conveyors for direct placement from cut to berm or spoil bank. ■

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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