Off-Road Trends: Driving Cleaner, More Efficient and Connected Machinery

Parker

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Off-road machinery encompasses a wide variety of large, specialized equipment for some of the world's largest industries: construction, agriculture, mining, forestry, material handling and lawn and turf maintenance.

Despite the industries' broad range, they are driven by many of the same economic, social and technological issues: shortages of skilled labor, stricter environmental regulations, increasing productivity while reducing costs, advances in automation and incorporating the latest digital technologies.

Because much of this heavy machinery is mobile, its progress is influenced by many of the same trends as the transportation industry, such as reducing diesel emissions by embracing new battery technologies, designing connected machines with predictive analytics and continuing the path toward fully autonomous equipment.

This white paper includes both global and U.S. market trends that are driving new thinking, designs and technologies in this already advanced machinery.

Construction Equipment Trends

Many American construction projects were slowed or halted in March 2020 due to the coronavirus pandemic. While existing projects in most states eventually resumed, new project activity is expected to remain sluggish. The result—equipment sales has slowed considerably, while rental and leasing have grown.

Many of today's construction equipment trends are the result of **advancements in digital technology,** some of which reduce skilled labor requirements:

- **Autonomous heavy equipment** is now used to excavate, grade and perform a growing amount of work on construction sites.
- **Autonomous drones and rovers** use cameras and LiDAR to perform scans of a job site; then use **artificial intelligence** to determine daily progress against the schedule and to identify any errors.
- **Specialized robots** under human supervision can perform repetitive construction tasks such as bricklaying, painting, loading and tying rebar, with the ability to work nonstop.
- **The Internet of Things (IoT) enables a digitally integrated construction process and job site.** It includes smart construction machines with sensors that collect and transmit data to each other and with their home base.
- **Predictive telematics and analytics** send machine diagnostics alerts and other vital information to fleet managers and equipment owners for off-site management.

Growing demand for machine electrification in construction and other types of equipment continues to drive global development of new battery technologies.

- OEMs are converting equipment from lead-acid to lithium batteries, which are 20%-30% more efficient.
- Battery chargers are moving toward integration into the equipment they power.
- One leading manufacturer recently introduced the first fully electric backhoe loader at CONEXPO 2020. This machine is powered by a 480V, 90kWh lithium-ion battery pack, capable of working a typical 8-hour day on a single charge.

The global market for compact construction equipment is forecast to grow from more than $10 billion in 2017 to more than $15 billion in 2025.

The electrification of these machines is easier than on large construction equipment and is a growing trend.

One global OEM has announced that it will stop producing its diesel-powered versions, converting to an all-electric product line. The company is promoting them as **small, quiet, zero-emissions machines for use in cities and densely populated areas.**

Outlook

Industry analysts predict that the global construction industry will nearly double by 2030, from $8 trillion to $15.5 trillion. This will be led by the U.S., China and India, which will represent 57% of the total growth.

In the U.S. there has been mounting political pressure for major investments in the country's infrastructure. This includes repairs and new construction of roads, bridges, transit systems, schools, affordable housing, broadband internet, sewer systems and the electrical grid. If Congress passes a new infrastructure bill, it could be a major boon to the nation's construction industry.

Agricultural Machinery Trends

The global agricultural industry faces the critical challenge of increasing productivity to feed a world population expected to grow 24% from 7.8 billion currently to 9.7 billion by 2050. An essential way the industry is addressing the challenge is through deploying automation technology.

Autonomous farm equipment is now used for mowing, plowing, planting, weeding, spraying and harvesting crops without direct human control. These machines employ sensors based on LiDAR, radar and digital video technology.

Robots, including drones, are a major trend in agriculture. By 2025, the value of global robot shipments designed for agricultural use are forecast to reach $87.9 billion.

The greatest barrier for farmers to adopt robotics technology is its high cost, including repairs, especially on smaller farms and in developing countries. Affordability is especially challenging when prices are low on farm commodities and when sales to global customers are disrupted.

Precision agriculture is a growing trend that relies on a variety of digital technologies. It identifies, targets and applies needed treatments to specific locations, whether in different fields or in different areas of the same field, rather than treating the entire area the same.

This greatly reduces the quantities of chemicals and water used while also increasing crop yields, both of which increase profitability and sustainability. The digital technologies used in precision agriculture include:

- **Robots** that use vision, guidance and machine learning technology; weed-killing robots can identify and spray individual weeds.
- **Drones & other UAVs** that monitor fields in real time, gathering a variety of data. Advanced drones can selectively apply insecticides, herbicides and fertilizers where needed.
- Geographic Information Systems can show variables such as soil properties, average rainfall and elevation.
- **Farming software and online data** are used for crop monitoring based on satellite imagery, field condition analysis, weather analytics, predictive analytics, field task assignments and record keeping.

The U.S. Federal Communications Commission recently announced plans to allocate $1 billion for precision agriculture, with digital farming technologies a key component, to improve and secure the American food supply.

Smart machinery is another aspect of precision agriculture. It includes: **smart irrigation systems, GPS-guided auto-steer systems, satellite-guided precision seeders** and **auto-steer systems.**

Electric motors have not replaced diesel engines in the largest farm equipment due to insufficient battery power for torque required. They are also difficult to charge due to the remote locations and long hours this equipment typically works.

Electric motors can, however, electrify these diesel-powered machines' auxiliaries and implements, rather than having them powered by the engine. This can reduce the size of engine required, which saves fuel. The external implements are frequently powered by hydraulics, driven by a hydraulic pump. A recent trend has been to replace these hydraulic systems with electric motors, resulting in greater precision control.

Electric motors also are suitable as stationary motors on the farm for powering machines that perform low-duty and low torque tasks, and for running smaller autonomous equipment.

The OEMs of large diesel-powered farm equipment were able to design new diesel engines meeting the U.S. EPA's most recent Tier 4 emissions standards when these regulations went into effect in 2015. The new rules apply only to new engines, with existing equipment up to 30 years old exempt. As a result, this segment in the U.S. is not currently under environmental pressure to switch to battery-powered propulsion.

Outlook

One of the major consulting firms forecasts the global agricultural industry will experience a strong rebound in the post-COVID-19 recovery, followed by growth in the long term. This will be due, in part, to countries dependent upon food imports supporting their agricultural sectors to better secure their food supplies. In addition, the global industry will continue to be pushed to improve sustainability and to implement new technologies.

Mining Equipment Trends

The global mining equipment market will likely decline in 2020, the result of economic recession caused by COVID-19. It is forecast to increase in 2021, growing 1%-3% annually to reach $154 billion in 2025. The largest segment will be surface mining equipment, driven by increasing global demand for metals and minerals. Asia Pacific will lead other regions due to growing exploration for coal and metal needed for power generation and metals used in numerous large infrastructure projects.

A growing global trend in this industry is **mining company stakeholders demanding that the companies be responsible and sustainable.** In addition to their stockholders, companies are being pressured by their workers and by local communities, consumers

and governments to reduce their greenhouse gas emissions, use lower carbon fuels and protect the health and safety of their workers and the communities in which they operate. An increasing number of companies that purchase mined materials, such as jewelers, electronics companies and automakers, want assurances that the minerals they buy are mined responsibly.

Automation is a key component in many mining companies' digital transformation strategies because it improves safety, increases productivity and reduces labor costs. In a 2020 survey of global mining leaders, 75% said they view technological disruption as more of an opportunity than a threat, with 36% identifying innovation and technological transformation as one of their company's top two growth strategies.

Autonomous mining equipment includes haulage trucks, excavators, shovels, dozers, wheel loaders, graders and drills. Some OEMs now offer **autonomous haulage systems,** which control fleets of vehicles that load, haul and dump. They have onboard controllers, high precision GPS obstacle detection and avoidance systems, and they are integrated with other vehicles on the mine site. These systems typically interact with personnel in a remote command center. It should be noted that **despite the mining industry being an early adopter of autonomy, and after 15 years of development, less than 3% of today's mobile mining equipment is autonomous.**

Artificial intelligence (AI) is being used in a variety of applications including **drones with 3D modeling, advanced data analytics** and **virtual and stimulated reality.**

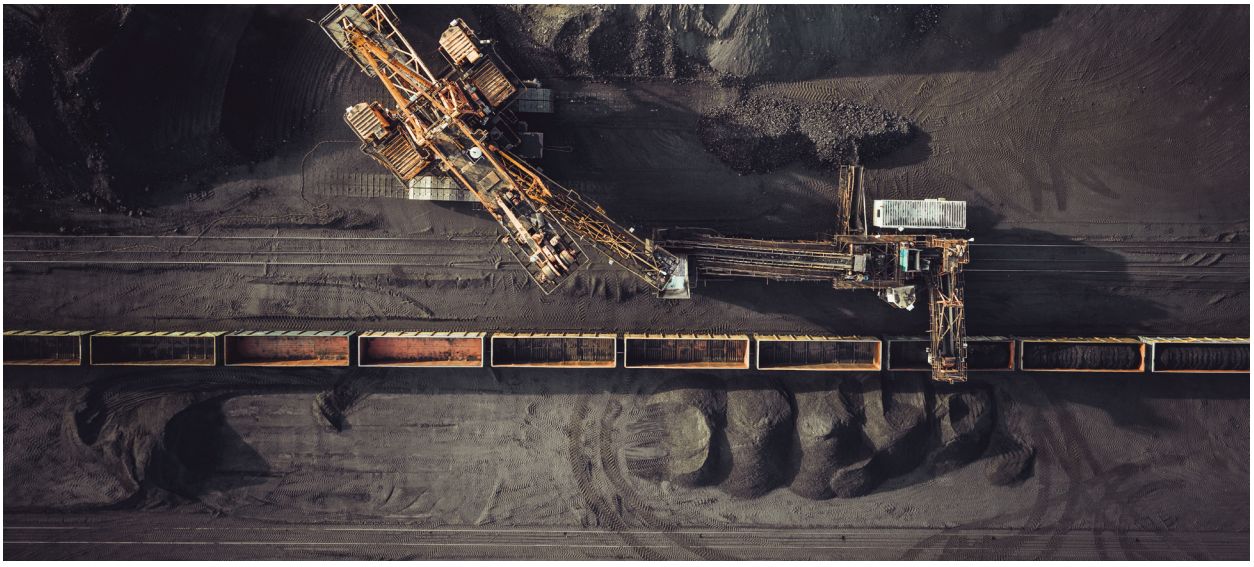
Other technological trends include:

- **VR & AR** (virtual and augmented reality) used to provide immersive training for employees.
- **Increased connectivity via IoT (the Internet of Things)**—smart equipment carries sensors that monitor equipment performance and enable predictive maintenance before equipment failure.
- **5G connectivity** enabling instant communication between people and machines, as well as machine-to-machine communications.

Electric vehicles (EVs) are replacing many diesel-powered mining vehicles, particularly the smaller ones, and electric motors are replacing their hydraulics. The benefits of electric conversion are zero emissions and better reliability, longevity, precision and performance. Zero emissions is the most important driver for underground mines converting to electric vehicles because industry regulations require the installation of expensive ventilation systems to protect workers when diesel-powered equipment is used.

Open pit mines and quarries are not subject to underground mine regulations, but their diesel-powered machines must adhere to the same strict **environmental regulations** as construction and agricultural equipment. These operations are also converting from diesel to electric power.

In this industry, **advancements in battery technology** have focused on powering successively larger equipment. This includes converting kinetic energy to electricity from different areas of the vehicle and storing it in supercapacitors.



Material Handling Machinery Trends

Definition and End Use Industries

The global market for all material handling equipment was valued at $130 billion in 2017 and is forecast to grow 5.5% per year through 2024 to about $180 billion.

Material handling machinery for this report includes conveyors and monorails, industrial hoists and cranes, industrial trucks (including forklifts and automated guided vehicles), material handling robots and automated storage & retrieval systems (AS/RS).

Manufacturing and e-Commerce

Global manufacturing began a gradual recovery in the second half of 2020 following a contraction of nearly 50% in the first half of the year because of the pandemic. In the U.S., manufacturing growth has accompanied new orders, increased exports, low customer inventories and rising prices for manufactured goods. As further growth extends into 2021 and 2022, manufacturers are expected to resume investing in **robotic material handling** for common processes such as pick and place applications using programmable, 3D vision-guided robots, machine tending (loading and unloading stationary machines), palletizing and parts transfer. The primary benefits of robotic material handling in manufacturing are its ability to work nearly 24/7 with reduced cycle time and greater consistency compared to manual labor.

E-commerce is another major end use industry for material handling machinery, which had been growing steadily and automating prior to 2020; then the pandemic boosted its sales. With consumers staying home, online sales jumped to more than 16% of total U.S. retail sales by mid-2020 versus 10.8% the year before. E-commerce fulfillment centers were suddenly challenged to process significantly higher volumes of merchandise at an accelerated pace. With unemployed workers plentiful in 2020, the fulfillment centers were able to hire the extra labor they needed.

With the ending of the pandemic, however, some of this workforce will likely leave for other jobs, driving further industry demand for **automated material handling systems in 2021.** This is because a larger percentage of U.S. consumers, including seniors, are expected to continue purchasing online at higher volumes than they did pre-pandemic. Also driving the demand for automated systems is the aging material handling workforce, with retirements leaving positions vacant and difficult to fill.

Machinery Trends and New Products

- Shift from mechanical to computer-controlled equipment and systems
- Demand from manufacturers for automated material handling systems including Automated Storage and Retrieval Systems (AS/RS), AGVs, robots and automated transporting and conveying systems.
- Newer battery technologies

Lawn and Turf Equipment Trends

This section focuses on motorized commercial lawn and turf equipment used to maintain the grounds of golf courses, sports arenas, municipal playing fields, public parks and other non-residential greenspaces. This power equipment group includes mowers, sprayers, spreaders, aerators and related machinery.

Emissions Regulations

Unlike large off-road diesel-powered equipment, U.S. environmental emissions standards have not changed for gasoline-powered lawn and turf equipment since the EPA's Phase 3 standards, passed in 2008 and implemented on new models beginning in 2011 and 2012. These regulations apply to all new gas-powered equipment with up to 19kW of power (25 hp). New lawn and turf equipment with "large spark-ignition engines" (over 25 hp; non-diesel) are still subject to the EPA's older Tier 2 standards that apply to 2004 and later models.

Equipment Trends

Battery-powered equipment is still resisted by lawn contractors and other professionals who view its weight, power, cost and length of continuous operation inferior to gasoline-powered machines. It is gaining market share, however, in segments that value its comparative benefits: significant noise reduction, zero emissions, no carbon fuels and less maintenance. A growing number of "green zones" and environmentally motivated cities, schools, golf courses and commercial properties are opting for battery-powered outdoor equipment.

- Battery-powered riding mowers currently use lithium-ion and Absorbed Glass Mat (AGM), or Flooded Lead-Acid (FLA) batteries. **Lithium-ion batteries are more expensive but last longer, are smaller, lighter and maintain the same power throughout their discharge cycle.** Also, unlike lead-acid batteries, they can be discharged down to 20% repeatedly without damage.
    - One OEM offers lithium-powered commercial mowers which, if used with interchangeable high-capacity battery packs, can operate all day.
- **Improved rotary mowers** are able to cut grass cleanly at 1" tall that previously required using reel mowers.
- **Newer models of stand-on combination sprayer/spreaders** for applying liquid or granular materials such as fertilizer are faster, easier to maneuver, maintain consistent application rates and have larger capacities.
- **OEMs are designing equipment for greater operator comfort,** including better cushioning, suspension and more ergonomic controls. This improves productivity (operators take fewer breaks) and contributes to higher employee retention.
- **Improved designs for colder climates** are incorporating large batteries, reliable engines and well-sealed electrical systems.
- **Triplex mowers,** while expensive, are being promoted by the USGA for mowing golf course greens. By replacing walking mowers, they free up 3-4 employees, making them cost effective.

- **New lawn aerators** feature rear-wheel control and are more versatile and maneuverable.

Machine Automation

Cost is the primary deterrent to the adoption of new automation technologies, especially for smaller operations such as individual golf courses and budget-strapped municipalities. Current technologies include:

- Autonomous mower navigation and telemetry
- Smart sensors and cameras
- Connected equipment that communicates problems through an app
- Cloud-based robotic operations centers and apps

- **GPS precision sprayers** that are self-steering (but with operator on board) based on boundary mapping, to precisely apply products only where they're needed, eliminating or reducing overlap and widespread application.

Fully Autonomous Equipment

The total number of autonomous mowers in Europe, including residential lawn mowers, is on the verge of surpassing traditional mowers, but this trend is just beginning in North America.

For commercial equipment, a major inhibitor is the **reluctance of business owners and turf managers to use driverless equipment** on playing surfaces where it could come in contact with the public.

In January 2020, the American National Standards Institute (ANSI) and the Outdoor Power Equipment Institute (OPEI) published the **first standard for battery-powered robotic lawn mowers.** This is expected to increase the number of products offered by manufacturers, who can now design equipment to the new industry standard.

One company has developed two battery-powered driverless robots designed for North America's **growing number of golf practice driving ranges.** One is a mower with adjustable heights and the other collects, cleans and dispenses the golf balls.

Forestry Equipment Trends

A century ago, a logging crew in a forest might number 80 men, but that same logging operation today can be performed by two or three skilled workers operating highly automated machines.

Modern forestry equipment used to harvest, process and transport trees and logs in high volumes is commonly found in both natural and industrial plantation forest operations.

Equipment Trends and New Technology

Digital technologies are being used to increase productivity and sustainability in managing and harvesting forests. This includes the use of GPS navigation, satellite imaging, Big Data, 3D simulations via GIS spatial mapping, telematics with remote diagnostics and digitalization of the supply chain. Logging operations frequently work in remote locations with poor or no cellular service so when they can, they download needed information in advance and take it to the job site stored on rugged mobile devices.

Forestry machines are collecting an increasing amount of data about their work environments and their own performance, but **transmitting this information to a remote owner or OEM** is a challenge. To enable machine communications, two basic solutions have emerged. The first, favored by some major equipment manufacturers, is to communicate via cellular networks when they're available and automatically switch to satellite communications when the machine is out of range. The second solution is offered by some third-party service providers. One offers an app for downloading data from a harvester's or forwarder's computer via an external mini-computer; then transmitting and storing it in the cloud as soon it comes within cellular range.

Other Trends Include:

- Improved operator comfort and safety including fatigue monitoring systems, ergonomic cab designs and better seat suspension systems.
- **Harvesters built using low-cost excavators as a base** are popular throughout Asia and South America. While the price and maintenance costs are much lower than purpose-built harvesters, they consume significantly more fuel.
- **Linear (electric) actuators** are replacing bulkier hydraulic actuators and pneumatic systems in forestry equipment. They enable highly precise movement, reduce the need for fluids, work well in extreme environments and are resistant to high loads.
- **Computer controlled processing heads** for harvesters can be programmed to automate their tasks based on the species of tree and other variables.
- One new **processing head for harvesters can fell a tree and then convert it into chips** for biomass; **another new head can remove the bark** from some species, increasing their value, rather than this task being done at the sawmill.
- A European forestry machine manufacturer has developed a hybrid harvester with a **diesel engine and electric drivetrain system.** Its software controls each drivetrain component, enabling it to react instantly based on the workload. The result is greater power, torque and hydraulic flow, with lower fuel consumption.

Engine Emissions Standards

U.S. non-road mobile forestry machines are currently regulated by the EPA's Tier 4 emissions standards that took effect in January 2014. They reduced harmful emissions from these engines by 85%-90%. No new Tier 5 standards have been announced and are not expected before 2021.

U.S. equipment manufacturers, however, will likely comply with the new European Stage V standards to sell their equipment in Europe. These standards apply to capturing ultra-fine sub-micron soot generated by diesel engine combustion, which can be met by installing diesel particulate filter (DPF) aftertreatment systems.

Global Timber and Wood Products Industry

The U.S. produces more timber and wood products than any other country, followed by Canada. It leads the world in the production of industrial roundwood, pulp for paper, and wood pellets.

Since the 1960's, **Canada has been the largest supplier of softwood lumber in the U.S.,** which is used for homebuilding. In 2017, the U.S. imposed a 20% tariff on this lumber, amounting to $5 billion annually. This has resulted in higher U.S. lumber prices and increased Canadian exports to China.

China has grown to become one of the world's largest producers and importers of wood products, recently surpassing the U.S. in sawnwood (primarily lumber) production.

In 2020, the FAO (Food & Agriculture Organization of the United Nations) reported 2018 record volumes of wood-based products produced and traded globally, representing an 11% annual increase in international trade value.

Wood pellets are currently experiencing rapid growth due to high demand from the EU, which consumed 75% of global production in 2018. These pellets are being burned as biomass for power generation to meet Europe's 20% renewable energy targets, implemented in 2020. Global wood pellet production grew by 11% in 2018 to 37 million metric tons.

Industrial forestry plantations, first started in the 1960's, comprised an estimated 5% of global forests in 2000 but supplied 35% of the world's roundwood (cut trees). They are now becoming more widespread in South America and Asia and are expected to expand in Southeast Asia and Africa.

Compared to natural forests, plantations are more productive, yielding more harvested trees per acre in a shorter amount of time. The Kyoto Protocol includes proposals in favor of forestry plantations to reduce global CO_2 levels. While the hope is that plantations will help preserve the world's natural forests, they are being carved out of natural forests in some tropical countries. The expected long-term growth of plantations will increase demand for forestry equipment and may change some designs based on what is being harvested.

Conclusion

Off-road machines are among the most highly automated in the world. They have replaced millions of workers in industrialized nations who used to do this work manually, often under dangerous conditions. Their advanced engineering and new digital technologies make them some of the world's most expensive machinery, but their high productivity, efficiency, reliability, and safety have made the benefits outweigh the costs.

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