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A Special Management Report From

Ag Equipment Intelligence

How New Equipment Technologies are Reshaping Farming

An *Ag Equipment Intelligence* Staff Report

Contents

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Breakthroughs That are Reshaping Agriculture

For decades, farmers equated machine control with having two hands on the steering wheel, navigating their field on instinct and tradition. The onset of GPS guidance and auto-steering more than 20 years ago created profitable efficiencies, which served as the cornerstone of precision farming hardware innovation.

But the next generation of machine automation is imminent, offering the ag industry promising, yet unproven opportunities. Developing technologies, including artificial intelligence (AI), autonomous vehicles and progressive engine systems are expected to redefine production ag in the coming years, for both farmers and dealers.

No longer will self-driving machines, robotic sensing tools or electric engines be science fiction. These advancements, and others, are on the cusp of commercial production.

Farm Equipment interviewed manufacturers and academic experts who shared their outlook for a special report on the breakthrough technologies that will define the future of agricultural production. The pages that follow answer some of the pressing questions — while raising a few more — about how the application of these new innovations will impact farm equipment dealers and their customers.

When Will Artificial Intelligence Become a Natural Ingredient in Ag Equipment?

Manufacturers, educators and engineers weigh in on where AI technology is now, where it's going and how it'll change the ag industry's production processes.

For many, considering the effects artificial intelligence (AI) may soon have on society is a source of both anxiety and wonder. Agriculture, as much as any industry, is in line for big changes. Farm equipment may soon have a mind of its own.

The term AI, as it relates to agriculture, is often lumped in with other emergent technologies like autonomous equipment and field sensors. But, AI-based equipment is distinct in that rather than being programed to perform a function, it's being designed to interpret data pulled from the field, act on it and teach itself best practices in the process.

The reason the terms are conflated is because AI will likely provide the foundation on which truly autonomous equipment is built and fields sensors will be its eyes and ears.

The first step to incorporating a new technology is understanding it. To this end, *Farm Equipment* asked manufacturers, educators and engineers how AI is reshaping the agricultural industry. Where is the technology today? Where is it all headed? And what are the major obstacles that will need to be overcome for effectively adopting these advancements?

Why Is AI Important?

Just because you can do something doesn't always mean you should. AI is meeting this argument in many of the industries it's beginning to penetrate. Kraig Schulz, president of Autonomous Tractor Corp., thinks the agricultural industry will embrace AI and the resulting autonomous equipment because farmers' margins are becoming razor-thin. He claims that if the average price of a bushel of corn is stacked against the average cost of producing it since 1980, the average income is negative $0.01 per bushel.

"Costs are up 60%, prices are only up 40% on average over that time period," he says. "If you talk to the pundits, most don't think this situation is going to get a lot better in the foreseeable future. Our view is that we have to keep trying to cut costs."

Labor and equipment account for about 25% of farmers' expenses, he says. Smarter, more efficient equipment can stretch the dollar in both categories.

If AI-based equipment results in smarter farming, it can cut costs in inputs as well. Scott Shearer, an Ohio State University ag engineering professor, says this is already being done with herbicide application. He points to the example of Blue River Technology, recently acquired by John Deere, and its development of machine learning in agricultural spraying equipment.

"They're recognizing weeds and only treating the weeds in a field rather than a blanket application," says Shearer. "This is a technology that really could change and reshape plant genetics and how some companies are focused. Tests have also shown about a 95% reduction in herbicide usage and being able to still control the weeds using only 5% of chemicals that we've traditionally used."

Where is AI Today?

It's a misconception to say that AI is coming to farm fields because, to some extent, it's already there. Alex Purdy, the head of John Deere Labs, based in San Francisco, says the equipment manufacturer has already been using machine learning to make real-time decisions in the field for several years. Purdy points to Deere's interactive combine adjustment capabilities as an example.

"The Interactive Combine Adjust product we have today takes information from cameras that are embedded in the combine that sense things like grain damage and quality, straw condition, engine settings and operational characteristics," he says. "Then, it runs an algorithm to make recommendations to the operator to change certain settings to maximize the growers' desired outcomes whether that's to increase fan speed or make another important combine adjustment. That process is already impactful today and affects the final yield. You get a lot less waste in the grain tank and you get less lost corn. That's an example of this technology already at work."

In short order, Purdy expects to see added computing power and more sensors on combines lead to further improvements such as feeding the farmer setting recommendations that significantly improve grain quality and machine productivity during harvest. He also speculates that the pace of advancement in agricultural AI is about to quicken as driverless car technology paves the way.

"Graphic processing units and sensors are becoming much more affordable, and that trend will continue being led by the driverless car segment," says Purdy. "With the increased availability, decreased cost and growing strength of the related technologies, I think AI and machine learning will be incredibly transformative in agriculture going forward."

Also championing Blue River Technology, Purdy claims that their sprayer solution allows farmers to go beyond making decisions at a field and sub-field level all the way down to the individual plant level. He notes that although Deere is still "a ways" from being able to employ this at "scale across the entire production system," cotton farmers are already using the technology with some success.

"Using the same kind of AI technology that phones do for facial recognition, Blue River is helping cotton farmers identify individual plants like identifying palmer amaranth apart from cotton plants," he says. "Then, the machine can go and take an action based on that information. I think that's a clear example, but only the tip of the iceberg on ways that we can enhance the farmer's ability to execute the job very effectively in the field at a plant-by-plant level."

In addition to the implications this has for input costs, Purdy says less experienced operators could still be ensured optimal results if they're supported by a battery of AI-based equipment that has its own experiences.

"You can have someone who's new or who has a hired laborer in the cab and you can have confidence that they're going to be doing the right thing because they're backed up by a system that has traveled hundreds of thousands of acres and has that expe-

Blue River Technology and John Deere have developed "see and spray" technology that identifies individual plants to determine whether they are weeds or the crop, and then takes action based on that information, says Alex Purdy, the head of John Deere Labs, based in San Francisco.

rience behind it," he says.

Purdy says the technology today is already on the cusp of unlocking new efficiencies from "seedbed preparation to harvest." The real-time sensing equipment on the market already does a good job of determining field specifications such as required down force during planting, he says. But, with AI analyzing conditions and teaching itself the optimum responses, equipment will soon be able to offer the farmer highly informed suggestions.

"Today we set the specification once and then run the equipment at that," Purdy says. "We think there's an opportunity to adjust the specs continuously based on real-time conditions. There is significant opportunity for optimization there."

What's On the Horizon?

Industry leaders seem to agree that we're still years away from a swarm of light-weight fully-autonomous planters and combines rolling across the field 24/7 with crop scouting and spraying drones buzzing overhead.

Shearer says the industry will likely first see "supervised autonomy" as AI creeps into agricultural equipment.

"These are going to be machines that have a human watching over them," he says. "But, hopefully we get to a point where that human watches maybe 10-15 machines at once. I think that's going to be the progression. As we learn more about how to give that machine in the field intelligence, we'll reduce our reliance on the human monitor."

Matt Rushing, AGCO's vice president of the Global ATS product line, also believes the slide into AI-based agricultural equipment will be a slow progressive one. He says advances in sensors are already laying the groundwork and that eventually, data pulled from the field will be fed into algorithms and real-time analytics engines that will calculate the optimum response to field conditions and act automatically.

Universal Data Exhange Platform Offers Broad Potential for Mixing & Matching Ag Systems

Some of the most vexing issues with the adoption and expanded use of new ag technologies are compatibility and connectivity of different components and applications. Farmers and dealers alike have shared the frustration of getting equipment and software produced by different manufacturers to get along with each other.

To overcome this roadblock, several manufacturers launched a joint effort in 2010, called iGreen, to develop a "neutral" way for farmers, dealers and contractors (custom operators) to exchange data between machinery and agricultural software applications from a wide range of manufacturers. That effort has resulted in the agrirouter. This is an internet-based data exchange platform developed to help resolve the problems with mixing and matching various agricultural systems and applications.

"This will connect up machinery and agricultural software from a wide range of manufacturers," say the developers. "It's an open approach that will also allow other market players (e.g. producers of farming resources, agricultural trade, etc.) to make their digital products available in the global marketplace for the purposes of optimizing agricultural production processes," they say.

The new platform was rolled out by DKE-Data at Agritechnica 2017, and it was awarded a silver medal by a committee of European experts at the German show. Software supplier for the agrirouter is SAP, based in Walldorf, Germany, one of the largest developers of enterprise software worldwide. Agrirouter is considered a major step in the development of "Smart Farming" or what the Europeans call "Farming 4.0."

Solving a Fundamental Problem

"The reason we developed the agrirouter was to solve the major problem of apps and all farm management systems having different interfaces. Nothing was compatible. Another big advantage is the customer or the contractor can decide what data to use and where the data goes," says Jan Horstmann, head of electronics & product IT research and development for Maschinenfabrik Bernard Krone GmbH & Co.

He says agrirouter is an interface that can be used for nearly any farming operation and management system. "But DKE only sells the links to agrirouter because we don't want to get into the commercial part of selling apps," he says. "Agrirouter has no real agricultural function for the farmer and contractor. It does not store data. It's like the postman. It's only transporting data, taking care that the right data gets to the right recipients. That's the whole principle of this."

Horstmann goes on to explain the impetus for the development of the interface. "We have multi-color fleets, and farmers had to use multiple software solutions because there was no single software that was able to cope with all of the machines. This problem is overcome by the agrirouter.

"It's now possible to use data from multiple machines with one single software. That's the first advantage," says Horstmann. "The second advantage is that of data flow involved with planting, harvesting, mapping, application and all these things. Farmers had all of these hurdles to get the data back. This is also overcome because the apps now have a standard interface through the agrirouter. It is connected to the machines and the postman puts the data in the right format on the machines."

Because it is only an interface, agrirouter can be configured to each machine in use. It simply allows the data owner to control his or her own data and apply it as needed and to use the apps they prefer, says Horstmann.

He also emphasizes that the user defines what happens to his or her data. To alleviate security concerns, all data transfer activity complies with or surpasses current European data protection directives.

Commercializing Agrirouter

Horstmann says the final release of agrirouter would take place in Europe in 2018. "We have very precise plans to roll it out in different countries and North America is high on our priority list. It should be in the states by 2019."

According to the developers, usage fees for the data transfer via the agrirouter are low, since DKE-Data GmbH & Co. KG operates as a non-profit company. The fees will be charged to the user by his or her agricultural software provider. In addition, mobile phone fees are incurred for the transfer of data between machinery and the agrirouter. In the future, agrirouter users will be able to register free of charge before setting up their personal agrirouter on their personal computer, tablet or smartphone.

The project is supported by a consortium of agricultural engineering companies, but membership is also open to others. The developers say, the basis for membership is that the company "recognizes that Farming 4.0 will only work if its change of data is made possible." Currently the consortium includes AGCO, Amazone, Deutz-Fahr, Grimme, Horsch, Krone, Kuhn, Lemken, Pöttinger and Rauch. Regardless of their size, say the developers, every member of the consortium has a single vote.

"In the future, we're going to see additional expansions with sensor technologies and the algorithms supporting them so eventually a human doesn't have to even see the raw data or recognize that something's happening before an action is taken in the field," he says. "If sensors show there's better moisture or organic matter in an area of the field, the technology will determine that a planter should raise its seeding population and notify the operator that it has done so.

"Or maybe a sensor will detect a pest on a leaf, and instantly apply pesticide? The sensors will supply the information and through the technology on-board, the equipment will react with an appropriate course of action."

Shearer believes as AI in farm equipment improves, it'll likely help transform drones into the valuable crop scouts the industry has always hoped they'd become.

"I truly believe there are going to be opportunities with AI to get closer to identifying what some of the crop health problems are with fly-overs," he says. "That's not going to be the only thing though. We still rely heavily on our crop scout to go into the field and walk it, looking in the crop canopy to make their assessment. How do we position machines in the future to do the same thing?

"A lot is going on with rapid infield phenotyping right now. People are looking at putting robots within the canopy if you want to think of it that way. But again, how can we do this in a practical manner and how can we be cost effective? Those are going to be the important things to consider in the process of adopting AI."

As to where AI innovations will come from in the future, Shearer thinks that tech startups from Silicon Valley in the mold of Blue River Technology will help lead the charge. But, he suggests that it may take an understanding of large scale farming to drive adoption.

Adoption Hurdles

Naturally, some of the biggest hurdles AI-based equipment will have to overcome are technological ones. New solutions will need to be rigorously field-tested and polished until they're mature enough for widespread commercial use. Purdy even suggests that the large amount of computing power AI solutions will require may necessitate more electrification on field implements.

"Electrification generally is going to be required for smarter equipment," he says. "The Blue River Technology that is pulled behind a tractor today requires electrical power and we expect the electrification of implements will continue to be an important requirement and enabler of tomorrow's smart machines."

Perhaps an equally large hurdle is a psychological one. Rushing notes that farmers are skeptical and not likely to leap out of the cab at the first mention of a smart machine that claims to know their farm better than they do. However, provable return on investment has a way of changing minds.

"Farmers can be the biggest skeptics in the world, especially when it comes to new technology," says Rushing. "So I think you've got to have something that's demonstrable and you have to have provable facts to back it up. I think once you have that, though, and can prove the waste and yield benefits, you'll see more and more farmers adopt it."

How Will Business Change?

Farmers still have a crop to grow and dealerships still have equipment to sell, but what effects will AI have on their business relationship? In terms of selling the equipment, Rushing says, not much. Proving the value of a purchase to the farmer will remain the golden rule as long as there is equipment to sell.

"If you can show the farmer that there's value there, and it's got to be a value that's not just focused on waste, but more on yield, because they have realized they can't cost reduce their way to prosperity," says Rushing. "They're looking for ways that they're going to be able to somehow increase yields. If you can demonstrate the value of the sensors and technologies, farmers will use them and realize the benefits."

Rushing also believes AI-based equipment will likely add revenue to dealerships' service departments.

"Most of the revenue in a dealership is generated through parts and service," he says. "All these new capabilities realized on the machine will be coupled with additional value added services that you can include at the time of purchase. In the future, in addition to buying a new planter with all these valuable sensors and technology, they're also purchasing a recurring service package that ensures the machine and technology is optimized and available when it is needed. There will be more reliance on equipment dealers and technology specialists to make sure everything is working the way it should."

What AI-based equipment may mean for the industry long term is as unknown as the technology's applications themselves. Although, Shearer speculates that rapid advances and shrinking equipment may mean a shorter shelf life.

"We're probably going to go to a different service life for implements and tractors," he says. "Many of the tractors being built today probably have a life of 20,000 hours. I would expect to see that reduced to something like 5,000 to 6,000 hours. This is where technical obsolescence will meet mechanical life. I think farmers in the future will purchase technology on agricultural field machinery to do specific jobs. But, newer technology may render the previous technologies obsolete."

Forecasting further, Shearer envisions a future where less equipment ownership is necessary on the farmer's end. That could come in the form of leasing equipment or contracting for the service of AI-enabled equipment, he says. Either way, he feels that it's likely more manufacturers may end up marketing their equipment directly to the end user.

He says those changes could have a serious effect on how dealerships operate, but the need for specialized service isn't going anywhere — even if it changes shape.

"It's going to be essential as AI makes supervised autonomous equipment possible to have service available 24/7," Shearer says. "Farmers aren't going to settle for the tractor being

down for two days because they couldn't get someone out to service it. However, with smaller equipment you might be able to warehouse all the parts essentially in the bed of a pickup truck. That changes the dynamic a bit in terms of being able to service the needs of a large fleet of smaller equipment. There's going to be some interesting opportunities in rural America for new businesses, and these are going to be technology-based."

What is Driving the Driverless Momentum in the Ag Equipment Industry?

Robots won't yet be doing all of the field work, but electric powered equipment and smaller, self-propelled implements are making their way to a field near you.

Ask someone in agriculture what comes to mind when they think of autonomy and they'll likely say a driverless tractor.

But many experts in precision farming say that simply removing the farmer from the cab may not be the best purpose of autonomy.

"Building an autonomous robot that moves through the field is interesting," says Alex Purdy, head of John Deere Labs. "But if it can't go and execute the jobs like spraying or planting that a grower needs to do in the field it doesn't achieve what a grower actually needs and is more like a toy."

And while full autonomy may not exist yet in agriculture, it's not a new development to the industry — in fact, it's been around for decades, says Matt Rushing.

"We've automated so many things over the years, even though farmers don't necessarily recognize it as that. Too many people think that autonomy means removing the driver completely," says the vice president of the Global ATS product line, for AGCO.

For example, going from mechanical to electronically programmable hydraulics, manual steering to auto-steering, and manual headland management to automatic headland management are all examples of autonomy in agriculture.

There's still a lot of progress to be made before farmers can have their equipment do all the work for them, but companies are making headway with autonomous solutions, which may have profound impacts on both farmers' and dealers' operations.

Replacing Tractors, Shrinking Footprints

Kraig Schulz, CEO and president of Autonomous Tractor Corp., says the true definition of autonomy is when a piece of equipment is on its own, driving and functioning completely separately, and all you have to do is observe the results of the work. But that's not likely to happen anytime soon.

"Autonomy works really well in repetitive, mundane tasks," he says. "I don't think you would get many farmers to say that it's the same thing every single time they go out; it changes every time. And that's what makes true autonomy extremely difficult. And not even necessarily the answer."

Schulz explains that data from Iowa State University Extension shows that for corn following soybeans, labor only makes up 5% of the total cost of production, which means that removing the farmer from the field isn't going to make a big difference to the profitability of an operation.

Instead, he says the problem with labor in a corn-soybean operation is having the right people on hand at the right time. And that's where he sees semi-autonomous equipment coming in.

"It doesn't have to go out while we're filling up our second cup of coffee and come back. It has to operate independently enough while we're within a reasonable distance of that vehicle, so that we can take care of all exceptions like we would if we had a driver.

"One might imagine that you wouldn't actually need as many tractors because you could have self-powered, self-propelled semi-autonomous implements doing the work alongside you in the field during the key seasons where you don't have enough labor."

AGCO already has one such solution that is now up to series-production readiness for its Fendt brand, Project Xaver — a swarm of small, autonomous seeding units.

The manufacturer first started the project by thinking about how to remove the driver from the tractor but realized there were still plenty of agronomic and logistic problems to solve, Rushing says, such as soil compaction caused by the tractor weight. It would also be inconvenient to transport.

"We looked at the whole planting process and thought, 'So what does it take to plant corn?'" Rushing says. "Well, you need a tractor, you need a planter bar, you need the row units that actually hang on the bar and that's what does the planting. But in reality, what really does the planting? It's the row unit itself. Everything else is just a necessity to propel the row unit through the field."

By replacing one 8 row planter and tractor with a dozen or so autonomous row units, Project Xaver not only reduces compaction, but is also designed so that if one row unit goes down, another one can step in to finish the job, reducing downtime. Unveiled at Agritechnica 2017, a swarm of 10 Xaver prototype units can plant about 2.5 acres per

hour and are automated to refill and recharge batteries, which takes about a half-hour.

"Years ago we had lots of little machines going through the field and they were all manned," Rushing says. "Then all of a sudden we went bigger because it was harder to find labor to operate them. But then if we see a significant failure on one big machine, the farmer may have a significant downtime issue."

Ohio State University ag engineering professor Scott Shearer sees soil compaction being a big driver for smaller autonomous equipment.

"A lot of farmers today don't realize the compaction penalty as it applies to profitability of their operations," he explains. "I'm not going to disagree with the fact that farmers buy larger equipment to be timely, and that's a very important aspect in terms of profitability. But the other side of the coin is, I don't think they recognize the amount of yield reduction that is occurring because of the larger equipment."

He points to another company working on this, SwarmFarm Robotics, based in Australia. The company is also moving away from large equipment to swarms of small, autonomous equipment, such as sprayers and mowers.

With these developments, he believes that "supervised autonomy" will be the first adoption of autonomous equipment, where a human is monitoring a fleet of small machines, until artificial intelligence can replace that person.

"We're going to go from one person sitting on a machine to one person sitting in an office monitoring a machine, to a person in an office maybe monitoring a dozen or two dozen machines," he says. "And as we learn more about how to give that machine in the field intelligence, we'll reduce our reliance on the human monitor."

Automation Before Autonomy

As for the immediate future, Purdy believes more automation has to occur before agriculture starts seeing broad-based autonomy.

"Our group is focusing most of our attention on automating the tasks in the field to give the grower all of the tools to automate and improve the accuracy of important in-cab decisions. Not only will this increase precision and profitability for growers, it will allow for less-skilled labor to be in the cab and be as effective as a skilled laborer," he says. "We actually think that those automation questions instead of autonomy questions are more difficult to achieve and will be eventually required to get to a full autonomous solution."

He adds that John Deere Labs, a part of the company's Intelligent Solutions Group, based in San Franciso, is looking at what they think growers are going to want and need in the next 10-15 years. He believes that automation is the most important and critical piece of the puzzle.

"We're pretty excited for some of the automotive companies to really drive down some of the costs in full autonomy and drive down some of the challenges we're going to run into in full autonomy," he says.

During Agritechnica in Hannover, Germany, AGCO's Fendt brand introduced Project Xaver, a swarm of a dozen or so small, autonomous seeding units, replacing one 8-row planter. The small autonomous units reduce compaction and are also designed so that if one goes down, another unit can step in to finish the job.

Fuel of the Future

One development the automotive industry is driving with autonomous vehicles that experts believe will make a big impact in agriculture is electric motors.

Schulz, Rushing and Purdy all say that autonomous equipment will likely be electric due to the amount of power the equipment will require, as well as the precision capabilities it will provide.

For example, Schulz says there are some farmers pulling trains of equipment through their fields and overpowering their tractors. With electricity, those implements could have their own supportive power systems.

"You have greater precision of the implements because you're directly steering them," Schulz says. "Think about that from a precision standpoint. No longer are you dragging stuff through the field, you're carrying it. You can control and power the entire system, creating huge efficiencies on the precision side."

Rushing adds that in addition to precision control, electric would eliminate a lot of mechanical and service issues as well.

"The need for power is even higher than it used to be," he says. "So now we will have to either go to bigger alternators, generators and motors and all these other things, or we can focus on making the whole vehicle electric."

Purdy notes that the artificial intelligence equipment they have from Blue River Technologies, which Deere acquired in September 2017, requires a power source and agrees that electricity and electrification of implements will probably be necessary as we move to smarter equipment.

Moving to electric isn't without challenges, though, the primary one being the cost of batteries.

"All the systems that are out there for electric cars are based off the premise that you're going to use a battery," Schulz says. "They don't like running off of generators, so we use batteries."

The problem is the amount of energy a tractor requires is much higher than an electric car. For a 200 horsepower tractor to run for 10 hours would require 1,500 kilowatt hours, Schulz says. That would cost $350,000 in lithium batteries alone and would weigh more than the tractor itself.

Schulz thinks the better option for agriculture is to find a way to couple a generator to the engine and use electric wheel motors without batteries to power the tractor.

But there are agriculture companies introducing battery-powered vehicles. Rushing says AGCO released its E100 tractor that uses a lithium battery, noting that it can run for about 5-6 hours without a recharge and recharges to about 80% within an hour.

"This stuff is coming," Schulz says. "The world is moving to electric vehicles, and I fundamentally believe it's going to have a huge impact on dealers' businesses because the traditional model is slowly going away."

Changes for Dealers

Part of the reason Schulz believes electric-powered vehicles and equipment will make its way to agriculture — and that it will have a profound impact on dealerships' business — is due to the simplicity of it.

"I was talking to a friend who bought a Tesla and the dealer was 400 miles away. He said, 'Well, what am I going back to the dealer for? Why do I need that?'" he says. "That's a challenge when you start thinking about this. If we start moving toward electric systems and the longevity goes up and simplicity is improved, how does that change your business models? Farmers aren't coming in for repairs and new parts all the time."

For example, he explains that a tractor could go from having at least 20 ECUs to less than 5 because it can be monitored and controlled digitally. Several wires could be replaced with one fiber optic cable.

"You're going to have multiple ones running different places, but you can literally take all the communications you have and boil it down to one line," Schulz says. "You know how you check that line? You stick a flashlight in one end and if light comes out the other end, it's good. That's simplicity."

Electric motors also last longer. The U.S. Department of Energy's average expected lifespan for an electric motor greater than 100 horsepower is 29 years, or 200,000 hours of use.

They're also more efficient. Statistics from the U.S. Energy Information Administration show that going from a gasoline-powered vehicle with a mechanical drivetrain to one that's gasoline-powered with an electric platform increases fuel efficiency by about 30%, Schulz says.

Because of these advantages, Rushing thinks dealers will start bundling services with the cost of a piece of equipment to make up for the loss of income from parts and repair.

"Most of the revenue generated in a dealership is through their parts and service capabilities," he says. "So I think you'll see is new capabilities on a machine, coupled with additional value-added services that you purchase at the point of sale."

For example, the dealer could offer to include an annual pre-season inspection, load their prescriptions for them or provide additional uptime and technology optimization services.

"Farmers like that," Rushing says. "It's like buying an additional insurance policy because now they can depend on their dealer or service provider to ensure the technology's working, through the service they purchased it and they also got this service at the point of sale.

"There's going to be more reliance on equipment dealers and technology specialists to make sure the technology is working the way it should, and these services will be offered as part of the purchase."

Rushing also thinks that as more "swarm" equipment like Project Xaver's autonomous row units and SwarmFarm Robotics' autonomous spraying solutions become available, ag service providers may begin offering these units as a service.

While dealers' parts and repairs business may decrease, Shearer suspects that farmers may trade their equipment out more frequently as new technology continues to render previous technologies obsolete. For example, instead of using equipment for 20,000 hours, a farmer may only use it for 5,000 hours.

"We buy new smartphones

because they do more. We don't necessarily buy new smartphones because the previous one quit working," he explains. "So I think some alignment of mechanical life and technical obsolescence will be a key consideration when designing."

Acceptance & Adoption of Autonomous Equipment

A major factor in the advancement of autonomous equipment and other smart technologies is adoption by growers.

Rushing doesn't think we'll see every farmer running out to buy something like Project Xaver because it's a different concept than what they're used to. But, in time, they will accept it as a tool to solve specific agronomic and logistic problems on the farm.

"You hear farmers say all the time, 'Hey, I like to drive my machine,' even though many haven't been driving for 15 years due to auto-guidance technology,'" he says. "But similarly, farmers in the early 1900s said, 'How could anything replace my mule?' But this was then disrupted by early mechanization. Similar adoption reservations and concerns will be seen as we move into the autonomous era."

Safety regulations will also play a role, but Shearer doesn't think it will be too big of a challenge.

"There are a lot of companies right now focused on automation in transportation," he says. "My attitude is if you can manage the liability on public thoroughfares in downtown Los Angeles, we can probably learn to manage the liability in the middle of a corn field in Nebraska."

While there are companies coming out with their own technology, such as AGCO, or acquiring Silicon Valley-type companies like Deere did with Blue River Technologies, Shearer questions whether some of the immediate autonomous technologies would be applicable to the Midwest.

"I'm not certain that Silicon Valley, if you would, understands Midwestern agriculture," he says. "That's not meant to be critical, it's just a fact of reality. I think they see things at times from a California perspective, and that's all well and good because there are a lot of high value crops out there.

"But I'm talking about the 200 million acres in the heartland, the corn and soybean type row crops, and that's going to take a bit of a different mindset. It's a much tighter margin in terms of profitability, but the acreage is there to support a decent market in terms of machine numbers. So are you going to build a few machines for very specialized markets or are you going to build a lot of machines for the more traditional row crops? It's going to be interesting to see how some of that unfolds."

Is Diesel's Half Century Farm Reign Ebbing?

Electric power, alternative fuels and imaginative innovations with internal combustion engine design promises a diverse stable of farm power in coming decades.

For 50 years diesel power has ruled the roost on the world's farms, providing fuel-efficient, rugged power plants that operate dependably at nearly full power throughout seasons of use.

Driven largely by clean air concerns, however, today's diesels have taken on added weight, girth, complexity and expense as regulators on both sides of the Atlantic mandate ever-tighter exhaust emission rules. Those mandates first drove billions of dollars into a massive overhaul of diesel fuel formulations in Europe and the U.S. to limit sulfur content to under 15 ppm. The cleaner fuel was necessary to launch the on-going series of phased-in emission controls on the engines themselves to remove sulfur-dioxide and particulate matter from the exhaust stream.

Today, that quest for even cleaner exhaust air continues, with 5th generation mandates being implemented in Europe in 2019 to further limit CO2 and nitrous oxide and other so-called "greenhouse gasses."

Throughout, OEMs have rallied to meet the government mandates and continue to plan for further tightening of limits on what can exit the stack of a diesel. Still, the escalating cost of eliminating ever-smaller amounts of exhaust stream impurities to comply with regulations, plus political pressure in Britain and France for an outright ban on diesel engines for highway use, has engine builders eager to explore alternatives.

Enter engines that burn natural gas (both compressed and liquefied), electric drives (both hybrid and battery power), spark-ignited gasoline engines, exotic automotive designs that combine both compression-ignition and spark-ignition, and one 2 Stroke diesel that uses opposed pistons and two crankshafts.

A Move to Electricity?

History shows regulations that affect commercial transportation and the automotive industry ultimately have an impact on agricultural equipment. Clean air standards are no exception.

Navigant Research reports bus and truck builders worldwide see a move to electric drives by 2030 that will make them the second most pop-

John Deere's all-electric 6R prototype tractor swaps the diesel engine for a pair of 150 kW electric motors and a 130 kilowatt-hour lithium-ion battery pack to produce 402 horsepower. Although draft performance of the electric tractor is equivalent to its diesel counterpart, current battery technology limits fieldwork to 4 hours between charges or ready access to charging infrastructure and swap-out battery packs.

ular powertrain in medium and heavy duty commercial vehicles — surpassing those using alternative fuels.

In its recent Transportation Forecast: Medium and Heavy Duty Vehicles, the research firm says advances in electric drives in the automotive industry are encouraging commercial adoption of electricity as a prime mover. "While electric powertrains are expected to remain under 25% of total truck and bus sales, electric drive vehicles are finally reaping the benefits of significant investments made for their use in automobiles," says Lisa Jerram, Navigant research analyst.

Most markets for electric drive vehicles remain in a trial or early adoption phase of plug-in electric trucks and buses, but cost reduction and improvements in battery technology are increasing interest from fleets and municipalities, she adds.

Navigant says alternative fuel applications such as natural gas (CNG and LNG) and propane are still expected to outsell electric drive powertrains through 2035, but electric drive options will have much higher growth rates — even excluding China with its dominate share of electric drive commercial vehicles.

An American Prototype

John Deere's SESAM tractor (Sustainable Energy Supply for Agricultural Machinery) unveiled in 2016 gives a glimpse of how electric-drive technology might appear in the farm field.

The prototype tractor is powered with a 130 kilowatt-hour (approx. 175 horsepower) lithium-ion battery pack and is based on Deere's 6R platform. The 6R's diesel engine has been replaced with a pair of 150 kW (approx. 200 horsepower) electric motors generating a total 402 horsepower running torque through a mechanical transmission. Power from the motors can be dedicated to drive the tractor, to the PTO shaft, or split with each motor taking on a separate duty.

Published reports indicate the battery life of the prototype under field conditions is about 4 hours with a 3 hour recharge period, meaning the current machine (with today's battery technology) would require several power packs and on-farm charging infrastructure to operate continuously.

Deere officials say they retained a mechanical transmission for torque-to-wheel distribution to avoid the cost of an electrical transmission for high power.

In North Dakota, Autonomous Tractor Corporation (ATC) took an alternate route from the mechanical gear train Deere installed in the SESAM. CEO Kraig Schulz says ATC's current work on driverless farm equipment led his company to develop its eDrive system that uses proprietary electric wheel motors and an electronic torque controller.

"Much of today's electric drive technology didn't really work because of high starting torque needed," he explains. "Tractors use their transmissions to basically transfer all their horsepower to the ground at 0 rpm wheel speed, and the industry didn't have an electric motor drive system to do that."

ATC's eDrive system replaces a tractor's differential and axles with 4 simple motors powered by a 400 horsepower diesel-electric power plant (think railroad locomotive), and provides 20-30% better fuel efficiency, simplified repair and quieter operation than an equivalent diesel-powered tractor using a mechanical transmission.

Improved efficiency in diesel-electric power stems from matching a generator with a consistent speed, fuel efficient engine.

Manufacturers explain that a smaller tractor, such as a 125 horsepower model, may only use full engine power 20-25% of the time. The same tractor usually operates at minimum load 30-40% of the time including idling. This allows a smaller engine to be used to drive a generator which charges large battery packs during low load cycles with energy that can be drawn upon when the tractor is required to perform high load duties. During idling, the diesel engine can be stopped while auxiliary systems continue to be powered by batteries — reducing fuel consumption and emissions.

A number of manufacturers including Deere, AGCO, Caterpillar and Belarus have demonstrated various prototypes of diesel-electric farm equipment over the last decade.

Meanwhile, the race is on by major global equipment manufacturers — many with indirect ties to agricultural equipment — to develop or buy electric power expertise and technology with a flurry of acquisitions announced over the past year.

Cummins Inc. is acquiring Europe's Brammo Inc., which designs

New Holland's biomethane-powered concept tractor builds on CNH Industrial's 2 decades of experience in producing spark-ignited natural gas burning engines. The 180 horsepower machine is designed to use compressed biomethane produced from farm residues and wastes for extremely low overall emission levels.

FPT Industrial recently introduced its 2018 line of spark-ignited engines capable of burning CNG or LNG and designed to perform comparably to like-size diesel engines. The latest of the new line is the Cursor 13 NG, a 460 horsepower, 6 cylinder model.

and develops battery packs for mobile and stationary applications. "To be a leading provider of electrified power systems, just as we are with diesel and natural gas driven powertrains, we must own key elements and subsystems of the electrification work," says Cummins CEO Tom Linebarger. "When the markets are ready, Cummins will bring our customers the right power solution at the right time."The company recently introduced the Aeos all-electric truck in the EU.

In Germany, engine maker Deutz has its eye on electric and hybrid drive systems for agricultural applications and bought Torqeedo GmbH, a leading German manufacturer of electric propulsion equipment for leisure and commercial boats.

Deutz Chairman Frank Hiller says buying the company launches the E-Deutz strategy and will enhance Deutz electrification knowledge and the introduction of new products quicker than starting from scratch. Torqeedo has extensive experience with electric motors, battery management, power electronics and system integration.

Royal Dutch Shell, already a player in developing liquefied natural gas vehicles and fueling infrastructure in selected markets around the world, recently purchased NewMotion, the owner of one of Europe's largest electric vehicle charging networks. The acquisition is Shell's first venture into electric mobility.

AxleTech International of Troy, Mich., is entering a partnership with TM4, Coucherville, Que., to develop integrated electric axles for heavy duty vehicles used in transportation and off-highway applications.

California's Efficient Drivetrains Inc., manufacturer of hybrid and electric drivetrain systems and components has announced it will be collaborating with Master Transportation, a bus manufacturer in Taiwan. Lightning Systems of Loveland, Colo., is unveiling a full electric drive system for Ford Transit passenger wagons and vans it has developed in partnership with New Eagle.

And, Ford is entering a $750 million joint venture with Chinese automaker Anhui Zotye to build battery powered cars for sale in China, the world's largest market for electric cars.The move comes in the wake of announcements by Ford that it plans to offer electric versions of 70% of its models sold in China by 2025.

Daimler AG's Mercedes Benz also makes an electric car with a Chinese partner, and General Motors, Volvo and Volkswagen AG have announced or are exploring similar ventures.

Internal Combustion Resilience

While electric and variations of hybrid-electric power will likely make inroads against the piston and crankshaft crowd over the next several decades, the internal combustion engine is far from retirement age — particularly with the recent emergence of the U.S. as a major producer and exporter of natural gas.

Advanced drilling techniques have unearthed vast quantities of clean burning natural gas, which encourages continued use of existing fuel infrastructure along with spark-ignited engine technology.The combination allows OEMs to meet stringent emission controls with much simpler pollution control equipment than is required by diesel technology.

CNH Industrial has fielded more than 30,000 natural gas engines running on CNG and LNG since entering the market more than 20 years ago. Throughout Europe nearly 22,000 natural gas powered trucks and buses operate with IVECO engines produced by FPT Industrial, CNH's powertrain brand.

An offshoot of that technology spawned New Holland's recent biomethane powered concept tractor designed to operate in a "closed loop" cycle that powers tractors with energy produced on a farmer's own land using waste products.

The tractor sports a 180 horsepower FPT Industrial spark-ignited engine that produces maximum torque identical to an equivalent diesel power plant and better fuel economy. If powered by farm-grown energy crops, crop residue and other

waste products used to make biomethane, the resulting fuel has virtually no CO2 profile and delivers an 80% reduction in overall emissions.

The tractor features a front mounted fuel storage structure and a pair of similar internally mounted tanks to provide a full day of farm work autonomy and can be refilled as easily and quickly as its diesel powered counterparts. The machine also can be powered with traditional CNG.

In late 2017, FTP Industrial also unveiled its Cursor 13 NG engine, a 460 horsepower 6 cylinder engine capable of burning CNG or LNG and benchmarked against a similarly sized diesel.

"To make natural gas appealing we needed to provide performance, ability and total cost of ownership equivalent or better than diesel," explains Pierpaolo Biffali, FPT head of product engineering.

Biffali says the spark ignition engine relies on a single fuel technology, reducing the number of tanks required and uses only one emission technology, a 3-way catalyst. "That single emission system is much better than the four required by diesels. That translates into compactness, lightness and overall reductions in complexity," he says.

IVECO, the commercial vehicles brand of CNH Industrial, is busy filling orders for its Stralis NP (Natural Power) engine designed to run on LNG in a deal with Jost Group, a pan-European transport and logistics company. The agreement calls for a fleet of 500 Stralis NP trucks with the first 150 vehicles entering operation in 2018. The order will replace 4-5 year old, pre-Euro VI diesel powered vehicles in the company's fleet of 1,400 trucks.

CNH says the Stralis NP running on LNG emits 10% fewer CO2 emissions than a comparably sized diesel powered engine, and up to 95% lower when fueled with biomethane.

Meanwhile, the German Ministry of Transport and Digital Infrastructure has identified LNG as the best solution for long distance road transport over the next 10-15 years, a testament to the rapidly growing demand for LNG on the Continent.

Another OEM seeking relief from the expense of "global diesel red tape" is Kubota. The Japanese manufacturer recently introduced the WG line of spark-ignited engines based on the same block architecture as the company's 0.74-3.8 liter diesel engines.

The engines are capable of operating on gasoline, CNG or propane for nearly identical power output as the diesels they can replace. Kubota designed the WG line as a "drop-in" replacement

Farm Equipment Dealership Could Soon be Printing 3-D Parts

3-D printing will grow exponentially and as costs come down, dealers could start adopting the technology for parts in as soon as 3 years.

Could 3-D printing revolutionize the parts and service department in the dealership of tomorrow? 3-D printing, also known as additive manufacturing, refers to the processes used to create a three-dimensional object in which layers of material are formed under computer control. It is already being used in a number of industries, and it's likely that agriculture could be next. Robert Saik, author of The Agriculture Manifesto and founder of The Agri-Trend Group, thinks 3-D printing is one of the drivers that will shape agriculture in the next decade. He says the growth and adoption is going to be exponential, meaning adoption will start off slowly before it quickly becomes mainstream.

"The thing about exponential growth is it is sub-linear in its early stages. In other words, people dismiss exponential technologies because at early stage, the growth rate is actually sub-linear. It will have a huge, huge impact on agriculture but right now it's sub-linear. Not many people are aware of its impact or that it's even on the radar screen," Saik says.

A good example of a product that had exponential growth is the smartphone. Ten years ago when the iPhone first hit the market, very few people had one. "Its growth curve was exponential. At first, people said, 'What are you going to do with that?'" he explains. Today, nearly everyone has some type of smartphone.

An agriculture example, Saik says, is auto-steer. "Farmers, for a long time said, 'I don't need that. I can steer straight. What the heck would a guy need that for?' Auto-steer is an example of exponential growth. Trimble retrofitted hundreds of thousands of tractors with auto-steer. Today, it's very rare to find anybody who doesn't have it to the point where the word is ubiquitous. It's everywhere. It's coming now embedded inside of all the equipment," he says.

3-D Printed Food?

Saik says there are a number of companies who are working on technology to 3-D print food. He says there are going to be a large number of 3-D type food printers coming on the marketplace. "In Holland right now, I came across a hospital that was using 3-D printing to make food for patients based on their blood type," he says.

"My question has been, what's the ink in the cartridge? What is going to be the food ink? What will be the substrates be that are going into the ink cartridges? You have to think about the commodity, the crops that we grow. You'd have to give pretty high marks to crops like soy, corn, wheat and canola, because they're going to lend themselves to the extraction of substrates. We may be growing crops in the future, not for wheat's sake alone, but actually the substrates that we extract out of the wheat that go into ink cartridges, that go into 3-D food printers. That's a little bit of a wild thought, but some people are doing that today."

Advancing the Technology

There are a number of 3-D printer manufacturers and there are a number of different types of printers. Saik says right now the 3-D printer market is experiencing a Moore's Law like phenomenon. Moore's Law states that the rate and speed of the microchip doubles every 12-18 months, and as a result the cost comes down by half as well in that period.

"Much of that is going on right now in the 3-D printer world. This leads to two things. One of the problems right now with deposition modeling or fused printing is that they lay down the materials in layers. You could get two-dimensional layering that's quite strong, but you get the third dimension between the layers is a weak point. Those early iterations of 3-D printers may not have lent themselves to really good strength with respect to parts and that sort of thing. But where we're headed with 3-D printing in the future would allow us to gain strength through that third dimension. That's really where it gets really interesting."

Currently most 3-D printing is done with plastics because plastic can be heated, melted, reformulated and ink-jetted in a two-dimensional fashion, Saik explains. But, he adds that the number of possible materials that will be used in the future are infinite. "Just as we've seen amazing growth in our understanding of biology because of genomics. There are people out

for the counterpart diesels.

Likewise, Cummins Westport continues to shine in the high power, low emission truck and bus category with its spark-ignited natural gas engines ranging from 6.7-12 liters for 2018.

Exotic Designs

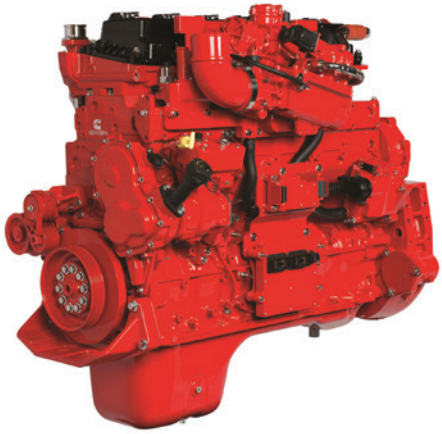
Clearly, alternative fuels such as CNG, LNG and biomethane offer clean burning power from traditional spark-ignited engines and are readily available when market and political conditions signal their need and economy. Still, some manufacturers are unveiling imaginative upgrades of existing engine technology for emission compliance and more power from smaller packages with both gasoline and diesel fuel.

For instance, Mazda, Japan's smallest automaker, plans to equip some of its 2019 vehicles with its SkyActiv-X gasoline engine that combines both compression ignition of diesel fame and spark-ignition in what it calls Spark Controlled Compression Ignition.

The computer laden SkyActiv-X engine is the third iteration of Mazda's SkyActiv power plant series and boasts a 20-30% boost in fuel economy over earlier similar size models. Pollution control comes from a proven, off-the-shelf, catalytic system.

Car and Driver reports say the new 2.0 liter engine produces 190 horsepower and 207 foot-pounds of torque compared with 155 horsepower and 150 foot-pounds of torque for the previous model.

So is it a gasoline fueled diesel? No. Although at times it does operate solely with compression ignition, throughout much of its duty cycle it will use a spark plug to eliminate noisy and destructive pre-ignition "knock."



Cummins Westport's 2018 lineup of spark-ignited natural gas engines include models from 6.7 liter to its newest 12 liter ISX12N. The California company is a leading supplier of truck and bus engines.

Performance improvements for the "X" engine stem from improved air flow through a super charged intake that is boosted not so much

there working on material genomics right now, where they're breaking apart a molecular structure of different substrates to form new compounds that have never been formed before. This is going to lend itself to 3-D printing," he says.

One new substrate Saik thinks will proliferate in agriculture is graphene, a material similar to graphite. Graphene is strong and a tremendous electrical conductor and insulator. "There's a lot we're going to be able to do with graphene. I think graphene is absolutely going to revolutionize how we grow materials. That'll actually dovetail right into 3-D printing," he says.

Printing 3-D Parts

While Saik says the opportunity for 3-D parts generation — either on the farm or at the dealership level — is still pretty small it will come over time, especially once the technology gets to the point where the strength of the third dimension is increased. "There are a number of 3-D companies that are already working with steel and different metal substrates to create the ability to 3-D print in metal. The interesting thing is where you can fuse two different materials together, like a metal and a Teflon, to actually build whole parts with different materials, all 3-D printed together," he says.

The time will come when the farmer won't go to the dealership for a part or the dealership won't go to the OEM for the part, Saik says. Instead, the manufacturer would send out an email with the 3-D drawing or pattern for the part. Then, the part would be printed at the dealership or at the farm. "This really starts to impact one area of our business, which is oddball parts, very strange parts or parts that are very unique to a piece of equipment. Or when you start thinking of vintage automobiles and vintage tractors and equipment that the manufacturers don't want to keep stocking," he says. "Eventually, the manufacturers will simply stock CAD drawings, 3-D printing templates, of these parts and send them out to 3-D shops for printing.

So how far in the future is "eventually?" Saik says in the next 3-5 years. He also says that the place it might all start is with obsolete parts that manufacturers simply don't want to stock any more for two reasons. "One is that nobody wants to stock and make those parts anymore [because of low volumes]. Secondly, the failure of a part on a vintage automobile or a vintage tractor isn't of as significantly economic importance as it is on a combine that's in the middle of harvest," he explains.

"I would probably guess that in 3 years, a lot of dealerships will start to experiment with the 3-D printed parts in their dealerships," Saik says. "The more progressive dealerships and parts departments are already paying attention to this technology."

One possible roadblock that has been suggested to 3-D printing parts is the unwillingness of OEMs or parts suppliers to provide dealers or farmers with the CAD drawings. However, Saik says while this is a valid point, what will happen is third parties could scan the part with a laser scanner and creates a replica that way. "There's ways around it, and the other side of it is just think about the profit attached to sending an email with a 3-D printed pattern, as opposed to making the part and shipping that. Where are you going to make more money?" he says.

Overcoming Costs

Depending on the machine, the material being used and the object's size, this process can take a few hours or a few days. 3-D printer manufacturer 3D Systems added direct metal 3-D printing to its portfolio a few years ago. But, direct metal 3-D printing comes with a higher price tag, says Cathy Lewis of 3D Systems. The company offers three printer sizes ranging in cost from $250,000-$800,000.

Lewis says some of the plastics that 3-D printers use have the same longevity and mechanical properties as some metals and are much lighter weight. Plastic printers can cost as little as $5,000, but most that are used in end-use manufacturing range from $300,000-$700,000.

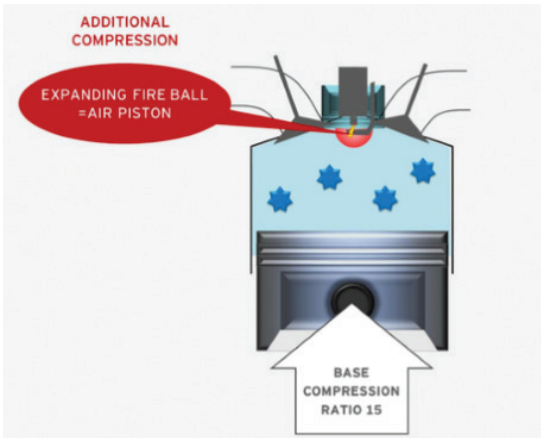
However, as Saik points out those prices will drop once the adoption of the technology starts to catch on. "I think that there's going to be a natural progression as costs come down initially. I still remember back when we brought the first fax machine into our town. We advertised in the paper that we had a fax machine at our fertilizer dealership. People would come in and use it. Can you imagine?

"But you can see that regionally, either a state or province, people would set up companies with 3-D printers, and they would print out stuff. That'll be the first level, and eventually, it'll be at dealerships. Then eventually, because of Moore's Law, prices will continue to drop to the point where farmers have it in their own shop."

Mazda's new for 2019 SkyActiv-X engine combines diesel-like compression ignition with computer controlled high pressure direct fuel injection and spark ignition to boost power and cut emissions. The innovative engineering is sure to be noticed by engine OEM's around the world.

for power but for a dependable air supply across a wide range of engine speeds. Also, bumping the compression ratio to 16:1 and adding a high pressure direct fuel-injection system that continually monitors in-cylinder conditions allows Mazda to vary the fuel mixture within the cylinder with each stroke.

On intake, the "X" engine cylinder is charged with a cyclonic swirl of an ultra-lean gasoline/air mixture (too lean to ignite by mechanical compression heat alone). As the piston moves upward in compression, Mazda uses a high-pressure injector to accurately time a localized enriched fuel mixture into the "eye" of the swirling super-lean cylinder charge. The spark plug then lights the second charge which creates a fireball that acts as a "virtual piston" moving downward to further compress the lean mixture below, triggering complete ignition of the cylinder charge. The result is no pre-ignition "knock," extremely efficient fuel combustion, lower emissions because of effective use of EGR to lower cylinder temperatures and most importantly — more power.



Taking cues from proprietary software, Mazda's SkyActiv-X engine uses an ultra-lean gasoline/air fuel mixture compressed 16:1 and ignited by an accurately timed fuel injection and spark. The spark-ignited fireball in the top of the cylinder acts as a "virtual piston" and further compresses the lean fuel/air mixture in the cylinder for a controlled compression ignition event.

Mazda says the engine's impressive fuel economy is apparent across a wide rpm and load range, uncoupling fuel efficiency from engine speed. Such characteristics likely could allow simpler transmissions since higher engine speeds don't necessarily equate to reduced fuel economy.

Mazda's 2019 use of the "X" engine will certainly be in commuter cars and limited to overall highway use, but engineers in the U.S. and Europe are taking note of company's blending of diesel technology with that of 4 stroke spark ignition engines. Lessons learned with this engine could conceivably find their way into heavy equipment of the future.

2 Stroke Diesel

Another interesting engine design currently being developed by Achates Power and Cummins is a 2 stroke diesel engine that uses opposed pistons in a long cylinder and two crankshafts. During the 1930s German engineers produced a number of compact, efficient Junkers Jumo diesel engines of this design for powering cargo aircraft, some of which successfully flew regular 5,000 mile mail routes between Germany and Brazil. After World War II, however, the rapid development of jet engines eclipsed interest in the opposed-piston aircraft engine.

Although the proven design involves two crankshafts, it eliminates a heavy cylinder head and complicated valve train to gain

California's Achates Power has revived a 1930s German aircraft engine design that uses opposed pistons in a long cylinder driving two crankshafts. The 2 stroke diesel gains thermal efficiency and power-to-weight advantages by eliminating a mechanical valve train and a heavy cylinder head.

power-to-weight and thermal efficiency. Those attributes have driven California's Achates Power to continue development of the non-traditional engine over the past 14 years.

Achates officials are currently working with Cummins on a 3.0 liter 3 cylinder version of the opposed piston engine as a possible power plant for future U.S. combat vehicles.

David Johnson, CEO of Achates, says work on the "Advanced Combat Engine" under a $47.4 million contract through the National Advanced Mobility Consortium could provide a test bed for transportation and industrial engines of the future. Johnson says while the current models of the Achates engine are diesel-powered, developers are confident they can configure the compression-ignited engine to use gasoline to meet current and future emission standards despite their "two-stroke" design.

Future Power: A Mixed Bag

Current electric drive research and further innovation with various internal-combustion engine designs and digital controls are sure signs mid-Century farming will be done with a variety of power sources.

While electric (battery-dependent) alternatives continue to rely on a power grid not designed for widespread vehicular use, improvements to the infrastructure are occurring, as

well as rapid development of more efficient battery technology. Those factors, and the "no emissions while in use" argument for battery-powered equipment, likely will continue to be selling points for moving away from internal combustion power plants, but the changes will come gradually.

The ready access to an infrastructure that currently supplies liquid and natural gas fuels to end users on a day-to-day basis will provide strong impetus for continued use of fossil fuels in farm equipment — particularly because of the need for remote autonomy of tractors and harvesters. Also, as OEM's turn their attention back to spark-ignited engines, which are being shown capable of competing with diesels in performance, they likely will readily adopt these power plants and their significantly less complex pollution control systems.

Given the abundance of fossil fuel alternatives and infrastructure, it's likely the ultimate mix of electric and fossil fuel power on the farm will be shaped by political decisions and not insurmountable engineering challenges.

Which Has More Potential, Autonomous or Electric Tractors?

The rollout of their autonomous tractors at the 2016 Farm Progress Show in Boone, Iowa, garnered Case IH and New Holland a lot of attention for several weeks. *(See Ag Equipment Intelligence, September 2016.)* The Case IH version is a cabless vehicle utilizing the brand's Magnum tractor platform. New Holland's model, called the T8 NHDrive, is outfitted with a cab, but is fully autonomous.

In quieter fashion, Deere began offering glimpses of its new all-electric tractor called SESAM, later in the year. Its major debut came at the SIMA show in Paris, France, in late February 2017. SESAM is short for Sustainable Energy Supply for Agricultural Machinery. Deere calls it the industry's first fully battery-powered tractor.

The SESAM prototype produces 130 kW (174 horsepower) of continuous power and is based on the 6R Series tractor chassis, using an adapted DirectDrive stepless transmission, with a speed range from 3-50 kph (2-30 mph) at full power. The tractor is emission-free and develops high torque at low speeds and a maximum output of around 400 horsepower.

The introduction of these technically advanced farm vehicles begs the question: In the long run, which of these tractors holds more possibilities for farmers, dealers and the manufacturers?

No estimates for potential growth and revenue have been offered for electric tractors, but according to Tractica, a market intelligence firm that focuses on human interaction with technology, revenue from driverless tractors would reach $30.7 billion by 2024.

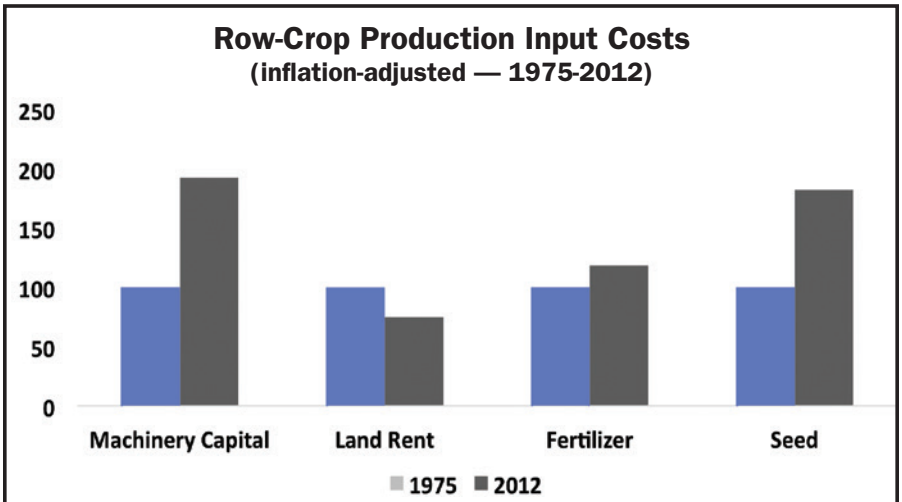
Autonomous vs. Electric?

When it comes to self-driving vehicles, Kraig Schulz, cofounder, president and CEO of Autonomous Tractor Corp., says the real question is what level of autonomy do farmers really need? He believes a "Tesla for tractors," is the best bet for the ag industry; most likely a semi-autonomous, electrically powered vehicle.

Speaking at the 2017 Precision Farming Dealer Summit, a conference organized by *Precision Farming Dealer,* a sister publication of *Ag Equipment Intelligence*, Schulz says, autonomy is a spectrum.

"Rudimentary autonomy that must be observed or managed by someone in the vehicle is on one end, and more complex, self-sufficient autonomy is on the other. Maybe down the road we will see tractors that have already gone out and plowed the field and come back while you're still getting your second cup of coffee, but for now the autonomy we see in farming still requires a certain level of supervision.

"The world is moving to electric vehicles. It might be more gradual, but it will make its way to farms and change the industry ..."



Between 1975-2012, the cost of machinery and repair have about doubled. Use of electric farm vehicles could help reduce these costs.

Source: Kansas State University

Autonomy in the truest sense is something that functions completely on its own — something I don't think we will see broadly adopted among row-crop producers any time soon."

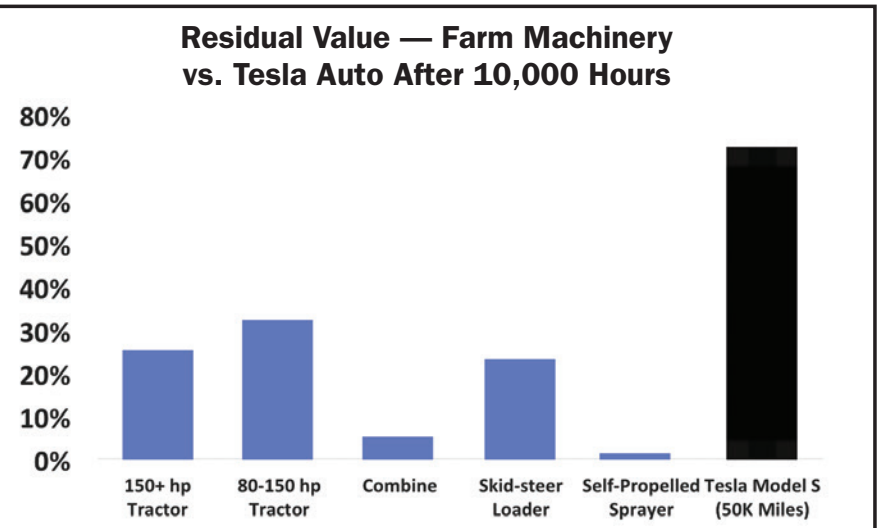
Driving Costs Down

According to Schulz, between 1975 and 2012, the purchase cost of machinery and its repair have both about doubled. "These rising costs in equipment and maintenance, and limited improvement in fuel efficiency have led to almost continuously rising production costs for farmers over the last 25 years," he says.

Schulz believes electrification might be an answer to rising equipment costs. "Electric tractors would get better fuel economy, have an increased longevity and reduced repair costs — all facts that have been proven by the automotive world.

Electric drive technology has been adopted by the marine, locomotive and mining industries, but not in ag. Isn't it about time our industry started moving to a more cost-effective solution like electric drivetrains?"

He says Tesla automobiles are a good example that demonstrates how electric tractors would be an improvement for farmers. "An electric vehicle has only a small fraction of the moving parts of a mechanical or hydraulic vehicle," Schulz explains. "Since the whole system becomes digitized, the communications systems can be dramatically simplified, eliminating hundreds of wire connections. Using fiber optic cables alone can reduce most of the wires in a tractor to just one cable."



Average expected lifespan of an electric motor is 29 years, which is two times the average lifespan of a traditional tractor.

Source: University of Minnesota, Machinery Cost Estimates, 2015 Electrek, 2016 — Tesla Model S residual value after 50,000 miles, U.S. DOE

Long Life Motors

He adds that advances like these can translate into real dollars for producers. According to Schulz, a Tesla retains better than 70% of its value after 50,000 miles while traditional cars lose 70% of their value. Part of the reason, but not the only reason, for this disparity is the average expected lifespan of an electric motor is 29 years, which is two times the average lifespan of a traditional tractor. "Farmers would benefit greatly from equipment with longer lifespans and less frequent need for repair."

He points to the improved fuel efficiency with electric vehicles as another benefit. A gasoline-powered vehicle gets roughly 35 miles per gallon, Schulz says. A hybrid gasoline and electric platform would increase efficiency by about 30%, and moving it to a completely electric platform would increase it significantly more. "Simply put, transmissions aren't that efficient and electricity is a much more efficient way to transfer power."

"Autonomy in the truest sense is something that functions completely on its own — something I don't think we will see broadly adopted among row-crop producers any time soon ..."

Challenge of Batteries

Like the Tesla, the biggest drawback to electric drive platforms is the vast majority of electric systems use batteries.

"This works well for the Tesla design since most of the time a driver will only use the Tesla at a fraction of its full horsepower and is used only a few hours each day," Schulz says.

"Teslas today carry about 100 kilowatt hours of batteries, but even just a 200 horsepower electric tractor would need about 1,500 to work for a full day. Batteries alone would cost farmers about $350,000 for this hypothetical electric tractor, not to mention the battery pack would also weigh more than the tractor.

"The world is moving to electric vehicles. It might be more gradual, but it will make its way to farms and change the industry," Schulz predicts.

Semi-Autonomous & Electric Machines

"Semi-autonomous equipment seems to be the answer," he adds. "Equipment that operates independently enough that the farmer can be within reasonable distance to intervene when a problem occurs is more realistic than fully autonomous equipment."

Further, Schulz explains, if the equipment is semi-autonomous, a tractor may not be needed to pull it. And it probably would not need a cab. "Why wouldn't the power and mobility be integrated into the implement itself in a modular fashion that can be moved from implement to implement?

"With an electric drivetrain this is possible — providing even better control of the implement and driving down even further the cost of equipment. Fully autonomous equipment might not be as necessary as we think it is," Schulz says. AEI