Manufacturers are busy rolling out solutions to meet Tier 4 Final (T4F) off-road requirements for diesel engine exhaust emissions, and the technologies look very familiar to those already in use in the on-road diesel engine market.

The biggest change from the Tier 4 Interim engines will be the addition of a diesel oxidation catalyst (DOC) and selective catalytic reduction (SCR) technology. SCR has been successfully used in Europe for several years and was introduced to the on-highway diesel engine market to meet the last round of on-road diesel engine emissions regulations in 2010.

The introduction of SCR technology does require the addition of another fluid – diesel exhaust fluid (DEF)—which is injected onto a catalyst to reduce emissions. But there are also many benefits, especially when paired up with the previous exhaust gas recirculation (EGR) technology. “Combining cooled EGR with SCR provides a very effective solution to balance nitrogen oxides (NOx) reduction between the engine combustion and exhaust aftertreatment,” says Kevan Browne, Cummins Inc., Columbus, IN. “This enables the optimum point of fuel efficiency and performance to be maintained in the ‘sweet spot’ for longer than an SCR-only approach can achieve. The engine EGR rate is rebalanced for the Tier 4 Final engines.”

The SCR systems were added to address the need to further reduce NOx emissions. “To meet T4F, it’s not possible without SCR,” says Hakan Sterner, Technical Director for Scania Engines, Södertälje, Sweden. “Since the system is available, it’s the best way to reduce fuel consumption, be less sensitive to sulfur and keep a good transient response. With high EGR rates, which are required for Tier 4 Interim without SCR, it’s not possible to meet the emissions levels without a DPF.”

With SCR, DEF is consumed by injection into the DOC and the dosing rates can vary by the engine supplier. “The fuel cost is so much higher than the cost for DEF [that] it’s almost always a [savings] to reduce the fuel consumption by increasing the DEF consumption,” says Sterner. “But there is a limit

Click here to read industry expert Frank Manfredi’s blog about JCB’s recent announcement that it will meet Tier 4 Final emissions regulations through the use of its patented in-cylinder technology alone.

This 9-liter engine achieves Tier 4 Final standards with an ultra-clean aftertreatment system that combines the Cummins Compact Catalyst with Selective Catalytic Reduction (CCC-SCR).
where increased NOx will give no reduced or very limited reduction of fuel consumption. There are also other limitations which reduce the possibility to just increase the injection of DEF, for example the evaporation of DEF and efficiency in the catalytic converter.”

It is difficult to pinpoint the optimal SCR dosing rate. “This is a complicated formula that varies between engine platforms, the range of exhaust temperatures and the efficiency of the spray pattern,” says Browne. “The design goal is to achieve the best balance of fuel economy with DEF dosing rates, DEF tank sizing and required refilling intervals.”

There has been a lot of work to integrate the EGR and SCR technologies for optimum performance. “Until facing the NOx emissions levels required by T4F, John Deere achieved the mandated NOx levels with its cooled EGR technology,” says Doug Laudick, Manager of Product Planning at John Deere Power Systems, Waterloo, IA. “With the additional 80% NOx reduction required for T4F, we will combine our proven cooled EGR with an optimized SCR technology within the Integrated Emissions Control system to meet the more stringent emissions levels.”

Many of the initial concerns with SCR have been worked out as the technology was adopted for on-highway applications. “SCR is an appropriate technology building block for T4F,” says Laudick. “The DEF supply chain infrastructure is better developed.”

John Deere tracks total fluid economy, diesel fuel consumption plus DEF consumption, and has realized an improvement over Tier 4 Interim engines. “The total fluid economy (diesel fuel and DEF) with T4F engines is expected to meet or improve upon that of proven Tier 4 Interim engines with cooled EGR and exhaust filters operating on diesel fuel only,” says Laudick.

**Possible without a DPF**

Some companies have proven that it is possible to meet T4F without use of a DPF. According to Jeff Wilke, Product Manager, Kohler Engines, Kohler, WI, this required a combination of technologies for the company’s direct injection engine. “High-pressure common rail fuel injection was a big contributor. We went to a four-valve head and we centrally located the fuel injector in that four-valve head. A lot of work was done on the injector in terms of the spray pattern and the nozzle.”

An electronic control unit (ECU) drives the fuel injection system. “We did a lot of work on the mapping of that ECU so that we have the right fuel ratio at all times to get the best fuel burn,” says Wilke. “We do a cooled EGR which is electronically controlled by the ECU. Turbocharging is also necessary, and it has to be intercooled.”

The engine block design itself is also a big contributor to eliminating the DPF. “A lot of work was done to reduce oil consumption because oil is definitely a contributor to particulate matter,” explains Wilke. “The block design helps the cylinders stay in the proper shape. We have a web structure that helps with the structure of the crankcase as well.”

Scania has also been able to meet T4F without a DPF. “Low smoke has been a strategic decision for Scania for many years,” says Sterner. “This has forced us to continuously improve our engine. Our common rail system can have up to 2,400 bar injection pressure; our single cylinder concept [allows us to] put a lot of development in one piston bowl; and our completely own developed engine and aftertreatment management system. The DOC also helps us reduce particles for T4F.”

**Scania’s scalable approach**

Scania will use a common system to meet emissions throughout its engine range. “The system we have for Tier 4 Interim is our new engine platform (5-, 6- and 8-cylinder) with common rail (XPI) and SCR,” says Sterner. “For T4F, we will add some EGR to reduce the NOx before the SCR system. This is to ensure that we have the required emission margin, including deterioration, to meet the emissions in all possible conditions taking in use compliance (IUC) into consideration.”

Sterner adds, “To improve the efficiency in the SCR catalyst we will also add a DOC. The system will be equal on all our engines, but there will be different sizes of the catalysts. It’s important to meet any duty cycle with the same engine since it’s sometimes difficult to predict the use.”

While there is a price for the technology, fuel consumption should remain about the same. “Since one more system is added, there will be
a price increase,” says Sterner. Differences in fuel consumption will be minimal. “In some cases lower and in some cases a bit higher, but very small changes. This depends on how we use EGR in combination with the variable vane geometry turbocharger (VGT) and SCR system.”

**John Deere continues ‘building block’ approach**

To meet increasingly stringent emissions regulations, John Deere has followed a building block approach in which technologies have been systematically adopted to meet each regulatory Tier. The Integrated Emissions Control system encompasses any combination of aftermarket and emissions-reduction components integrated in that building-block approach.

Solutions depend upon engine size. “For engines 75 hp and above, the Integrated Emissions Control system will consist of a DOC, a DPF and a SCR system specifically designed to meet the demands of off-highway applications,” says Laudick. “The DOC/DPF exhaust filter reduces particulate matter while the cooled EGR and optimized SCR system reduce NOx to the regulatory levels of T4F. John Deere T4F engines below 75 hp will meet regulations using an Integrated Emissions Control system consisting of an exhaust filter without cooled EGR or SCR.”

The combination of cooled EGR technology and the Integrated Emissions Control system will enable the engines to utilize minimal DEF. “DEF consumption with our T4F engines will be 1 to 3% of diesel fuel consumption depending upon the application,” says Laudick. “Lower DEF consumption means DEF tanks can be smaller, impact on equipment applications is minimized, DEF filter service intervals can be extended, vehicles can achieve a longer interval between DEF tank refills, and operator involvement is reduced.”

Laudick adds, “Our building-block approach of utilizing cooled EGR, exhaust filter and SCR technologies has ensured that T4F engine performance will meet or exceed that of our Tier 4 Interim engines. With low DEF dosing rates and a higher-pressure fuel delivery system, John Deere T4F engines will meet or improve upon the total fuel economy of our Tier 4 Interim engine models. Our enhanced electronic control unit monitors and controls the engine and the Integrated Emissions Control system components, providing superior fluid efficiency without compromising engine performance or machine productivity.”

**Cummins claims Tier 4 Final is a relatively small step**

The major change for Cummins will be the addition of SCR for T4F. “The technology change for Cummins to move from Tier 4 Interim to T4F is significantly less than that required to move from Tier 3 to Tier 4 Interim,” notes Browne. “Essentially, it is about incorporating SCR within the exhaust aftertreatment system – with no major change required to engine systems. In terms of incremental emissions technology and installation cost, the change to achieve T4F will therefore be lower than from moving from Tier 3 to Tier 4 Interim.”

The same Cummins aftertreatment system will be common from 75 to 400 hp, with modular scaling for engine output (not duty cycle). “Various configurations will also be available to enable greater equipment installation flexibility,” says Browne. The system is fully passive and flow-through without the need for active regeneration or any ash cleaning. “It consists of a DOC, combined with SCR,” says Browne. “Cummins has been utilizing these systems for many years in on-highway applications. We believe this offers the simplest and most effective solution to achieving near-zero emissions.”

Cummins has developed next generation SCR technology with a copper zeolite-based catalyst. “The copper-based catalyst utilized for SCR enables a higher conversion of NOx at a broader exhaust temperature range when combined with a high-efficiency DEF spray pattern ahead of the catalyst in the decomposition pipe,” says Browne.

The result will be similar performance with better fuel efficiency. “We expect Cummins T4F engines to retain—and exceed—all of the performance enhancements achieved for Tier 4 Interim engines,” says Browne. “Engine fuel efficiency will be better for T4F than that achieved for Tier
4 Interim. Our field test work is showing that this improvement will exceed the cost of using DEF to lower overall operating costs. For some engine platforms, peak horsepower and peak torque availability has also increased to increase overall engine power density and productivity.

Caterpillar builds on ACERT

For T4F, Caterpillar will continue to build on its ACERT technology. ACERT uses a building block approach to provide the right technologies to match the application. ACERT technology blends an innovative intake-air management system, using optimized turbocharging, with electronically controlled fuel injection that precisely shapes each combustion cycle through multiple-injection fuel delivery. This meticulous control of combustion parameters yields clean combustion, steady power in all operating conditions and fuel economy.

The Cat NOx-Reduction System continually diverts a small volume of the engine exhaust gases to the combustion chamber. This process reduces cylinder temperatures and lowers NOx formation.

A Cat Clean Emissions Module (CEM) is a compactly packaged aftertreatment unit that includes a DOC, a DPF to remove particulate matter from the exhaust stream and a Cat Regeneration System that removes soot from the DPF. And in some cases an SCR system.

Under most operating conditions the engine exhaust is hot enough to oxidize soot through a passive regeneration process. However, if conditions are such that supplemental regeneration is needed, the Cat Regeneration System is designed to work transparently, operating automatically without any interaction needed from the operator and regenerating when conditions are optimal.

The manufacturers are rolling out T4F solutions, and it appears that there will be no degradation in performance. Fuel economy will be similar or improved depending on the particular make and model of engine, and there may be another fluid for contractors to maintain, DEF.

In addition, many were not willing to share information on pricing at this time, but it does take additional resources to design and develop the additional components required.