Pioneering MTU C&I diesel engines for U.S. EPA Tier 4

For more than 100 years, diesel engines have been a popular prime mover in a variety of nonroad applications, such as marine and railway propulsion, and as special drives for mobile cranes, mine haul trucks and military vehicles. Although modern diesel engines are efficient and clean energy converters, increasingly stringent emissions regulations require further improvements in controlling constituents in diesel exhaust—primarily nitrogen oxides (NOx) and particulates (PM). MTU’s C&I engine portfolio covers a power range from 100 to 3,000 kW (135 to 4,020 bhp).

Key technologies for clean, economical and powerful engines

Emissions guidelines for mobile machines and equipment in North America are becoming ever more stringent. The introduction of Tier 4 interim (Tier 4i) in 2011 marks a significant tightening of the limits which have been in force since 2006. For drives below 560 kW (750 bhp) output, the limit for nitrogen oxides has been halved and the permitted particulate level is a full 90 % lower. In the case of drives with an output above 560 kW (750 bhp), permissible nitrogen oxide levels will be reduced by 45 % whilst particulate limits will be decreased by 50 %. Following this, the next step, Tier 4 final (Tier 4f), is already planned for 2014 when the nitrogen oxide limits for engines below 560 kW (750 bhp) will be cut by a further 80 % as compared to Tier 4i. For engines above 560 kW (750 bhp), Tier 4f will be introduced in 2015 and will involve a further 60 % decrease in particulate emissions to 0.04 g/kWh.
### U.S. emission limits for nonroad mobile machinery

<table>
<thead>
<tr>
<th>Year</th>
<th>below 560 kW (750 bhp)</th>
<th>above 560 kW (750 bhp)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009</td>
<td>Tier 3 4.0/0.2</td>
<td>Tier 2 6.4/0.2</td>
</tr>
<tr>
<td>2010</td>
<td>Tier 4i 2.0+0.19/0.02</td>
<td>Tier 4i 3.5+0.4/0.1</td>
</tr>
<tr>
<td>2011</td>
<td>Tier 4f 0.4+0.19/0.02</td>
<td>Tier 4f 3.5+0.19/0.04</td>
</tr>
<tr>
<td>2012</td>
<td>Tier 4f 0.4+0.19/0.02</td>
<td>Tier 4f 3.5+0.19/0.04</td>
</tr>
<tr>
<td>2013</td>
<td>Tier 4f 0.4+0.19/0.02</td>
<td>Tier 4f 3.5+0.19/0.04</td>
</tr>
<tr>
<td>2014</td>
<td>Tier 4f 0.4+0.19/0.02</td>
<td>Tier 4f 3.5+0.19/0.04</td>
</tr>
<tr>
<td>2015</td>
<td>Tier 4f 0.4+0.19/0.02</td>
<td>Tier 4f 3.5+0.19/0.04</td>
</tr>
</tbody>
</table>

NOx + HC (hydrocarbon) / PM in g/kWh
(NOx: nitrogen oxides, HC: hydrocarbon, PM: particulate matters)

The initial step in the process of achieving compliance with ever tighter emissions regulations involves in-engine optimization—for example, by increasing injection pressure, improving combustion or utilizing exhaust gas recirculation techniques (EGR) to keep raw emissions as low as possible. These measures can significantly reduce the complexity and cost associated with downstream exhaust aftertreatment technology and in many cases, they can make exhaust aftertreatment completely unnecessary. As a result, the customer needs less installation space and benefits from lower maintenance requirements and reduced complexity.

There is, however, an inherent conflict of aims between lowering diesel particulate levels and reducing nitrogen oxides. Very few in-engine techniques make it possible to reduce both pollutants simultaneously. It is far more often the case that an improvement in one of the emissions components will initially result in a worsening of the other. Where emissions limits can no longer be met using in-engine technology, exhaust aftertreatment involving selective catalytic reduction (SCR) is needed to reduce nitrogen oxide and/or diesel particulate filtration (DPF) is required to lower particulate levels.

### Series 400, 500 and 900 for Tier 4i below 560 kW (750 bhp)

In the power range up to 560 kW (750 bhp), the MTU program includes Series 400, 500 and 900 engines for Tier 4i. These units are used, for example, in dockside and mobile cranes, container stackers, wheel loaders, construction machines, road millers, underground mine vehicles, excavators and even in self-propelled harvesters. The engines have been developed from Mercedes-Benz commercial vehicle drive units and span the 100 to 480 kW (135 to 645 bhp) power range. The new engines mean that OEMs can convert their applications to operation
with a Tier 4i drive without extensive modifications because their dimensions and cooling requirements (which determine the size of the cooler) largely match those of their predecessors. The engines have an SCR exhaust aftertreatment system to reduce nitrogen oxide emissions in exhaust gases. The SCR catalyzer replaces the exhaust muffler so that only minimal additional installation space is needed. The OEM mainly has to integrate the supplementary tank for the SCR reducing agent. As Series 400, 500 and 900 units are certificated on the same constructional design for US Tier 4i zones as for areas covered by the European EU III B standard, customers can export their equipment from one region to the other without drive modifications.

High-pressure injection and optimized combustion mean that these engines meet Tier 4i particulate specifications without diesel particulate filters. These enhancements also achieve a fuel saving of up to 5 % as compared to previous engine models and engine load behaviour has also been further improved. The SCR system was derived from the commercial vehicle sector where its functional reliability and straightforward maintenance requirements were proven in day-to-day operation. With the exception of the catalyzers, all SCR system components are identical and interchangeable for Series 400, 500 and 900 units which considerably simplifies spare parts provisioning for the operator.

Series 1000, 1100, 1300 and 1500 for Tier 4 below 560 kW (750 bhp)

From 2014, MTU will be marketing new 4-cylinder and 6-cylinder in-line engines for Tier 4f in its Series 1000, 1100, 1300 and 1500 programs covering the 100 to 460 kW (135 to 620 bhp) range. These units are based on the coming generation of Mercedes-Benz commercial vehicle engines and are specially adapted by MTU for specific C&I applications. The 4 and 6-cylinder Series 1000 models cover the 100 to 260 kW (135 to 350 bhp) range. The 6-cylinder Series 1100, 1300 and 1500 engines produce 280 to 320 kW (375 to 430 bhp; Series 1100), 340 to 380 kW (455 to 510 bhp; Series 1300) and 400 to 460 kW (535 to 620 bhp; Series 1500). MTU is thus one of the first engine manufacturers already able to present an entire engine family for Tier 4f below 560 kW (750 bhp), giving customers ample time to adapt their applications for the new engines.
To achieve compliance with the stringent emissions specifications laid down by Tier 4f for nitrogen oxides and particulate, MTU equips these engines with exhaust gas recirculation, SCR units and diesel particulate filters. MTU’s development goal, however, is to fulfill Tier 4f without diesel particulate filters which would be a major advantage concerning space requirements and also weight. A modern common rail injection system generating up to 2,500 bar injection pressure ensures low raw particulate emissions and efficient combustion. All technology for exhaust aftertreatment is incorporated in a single module. This “one-box” system makes it easy for customers to integrate the module in their equipment. They simply need to connect it up to the reducing agent supply and the engine electronics. The one-box system also incorporates the acoustic muffler function.

**Engines above 560 kW (750 bhp)**

For Tier 4i and Tier 4f engines above 560 kW (750 bhp), MTU has developed a technology package incorporating high-pressure injection, 2-stage controlled turbocharging and exhaust gas recirculation. This facilitates particularly low-particulate and low-NOx combustion which makes exhaust aftertreatment systems largely unnecessary.

Here, MTU utilizes common rail injection technology. A high-pressure pump generates injection pressures up to 2,500 bar independent of engine speed and injection volume. Fuel is fed through pipelines to the injectors where it is precisely metered and injected into the combustion chambers as a fine vapor. The result is extremely efficient and low-particulate fuel combustion in the cylinder. Because exhaust gas recirculation simultaneously reduces the temperature in the combustion chamber, less nitrogen oxide is produced during combustion.

A 2-stage, controlled turbocharging system supplies the engine with combustion air and ensures maximum performance and engine dynamics even with uneven speed increases. With this turbocharging concept, air is initially compressed in the first turbocharger. It is then cooled and subsequently further compressed before being cooled once more. All engine and turbocharging functions are centrally controlled by the powerful ADEC (Advanced Diesel Engine Control) engine management system developed by MTU.
Series 1600

From 2014, MTU’s Series 1600 will also be available for C&I applications. With a cylinder displacement of 1.75 liters, the 10 and 12-cylinder engines produce between 567 and 730 kW (760 to 980 bhp). They are designed for diesel-mechanical and diesel-hydraulic drive systems and suitable applications include haul trucks, wheel loaders, excavators, cranes and mining plant. To achieve compliance with Tier 4f limits due to come into force in 2015, these engines will be equipped with in-engine exhaust gas recirculation technology and a diesel oxidation catalyst. MTU’s development goal, however, is to fulfill Tier 4f without any aftertreatment equipment. Benefits for the customer include low fuel consumption, low installation space requirements and low conversion and operating costs. The cooling system on these engines is also designed so that application-side systems which require cooling can be easily integrated. This reduces the complexity and cost of systems integration, minimizes the number of connection points and simplifies maintenance.

Series 2000

MTU’s Series 2000 engines have enjoyed widespread success since 1997 in applications such as excavators, haul trucks, wheel loaders, heavy drilling units as well as dockside cranes and mobile cranes.

For Tier 4i, MTU has undertaken fundamental redevelopment of its Series 2000 engines. With a cylinder displacement of 2.23 liters, the 12 and 16-cylinder versions cover a power range from 561 kW to 1,163 kW. These are the first series-production engines in their performance class worldwide to achieve Tier 4i compliance using only in-engine technology and without diesel particulate filters and without SCR catalyzers. The cooler needs to be adapted to suit the engine’s increased cooling requirements. From 2015, the Series 2000 will be available in a Tier 4f version. Even for this emission stage MTU plans to fulfill the emission limits using only in-engine technology. In addition to emissions reductions, fuel consumption has also been substantially cut by up to 10 % in comparison with Tier 2 engines and combustion noise has also been reduced.

A powerful ADEC system at the latest stage of development (ECU9) safeguards control of the engine and its sub-assemblies. With its 2-
stage, controlled turbocharging system, the engine is able to deliver constant power even under extreme conditions including high air temperatures up to 55 °C (131 °F) or high altitudes up to 3,100 meters (10,200 ft)—this is currently the only drive unit in its class on the market to achieve this.

Further development of the Series 2000 is currently underway to ensure compliance with Tier 4f regulations which will apply for this performance range from 2015. MTU also plans to achieve the tighter specifications laid down by this emissions standard exclusively with in-engine technology and without diesel particulate filters or SCR systems.

Series 4000

MTU will be introducing the new Series 4000 mining engines for Tier 4f onto the US market 2015. On customer request the new Tier 4i or Tier 4f compliant engines will be available even before 2015. With a per-cylinder displacement of 4.77 liters, the 8, 12, 16 and 20-cylinder versions cover the power range from 800 kW to 3,000 kW (1,070 to 4,020 bhp). These powerful Series 4000 drives have earned a reputation for themselves in mining applications throughout the world and can be found primarily in heavy mine vehicles, wheel loaders and excavators in quarries and open-cast mines.

MTU plans to fulfill the emission limits using only in-engine technology. To this end, the combustion process has been developed to achieve particularly low pollutant levels. Alongside exhaust gas recirculation technology, MTU has implemented Miller valve control for NOx-reduction. This method involves closing the inlet valves earlier than is otherwise usual and results in lower combustion temperatures and consequently in a reduction of nitrogen oxides in the exhaust. MTU has also optimized the common rail injection system and increased injection pressure. Control of the engine and all sub-functions is carried out by MTU’s powerful ADEC (Stage ECU9). The engines will consume up to 3 % less fuel than today’s Tier 2 engines.

MTU has equipped the Series 4000 engines with a 2-stage turbocharging system involving three turbochargers. As a result, the new engines develop even greater torque and deliver constant power up to a working altitude of 3,200 meters (10,500 ft).
One-stop certification

As a systems manufacturer providing complete drive solutions, MTU supplies engines for C&I applications with full EPA Tier certification so that customers can integrate MTU drive systems in their applications quickly, simply and economically.

MTU product line-up for C&I applications

<table>
<thead>
<tr>
<th>Power Range</th>
<th>Tier 2</th>
<th>Tier 3</th>
<th>Tier 4i</th>
<th>Tier 4f</th>
</tr>
</thead>
<tbody>
<tr>
<td>135 - 350 bhp / 100 - 260 kW</td>
<td>4R, 6R Series 900 (up to 240 kW/320 bhp)</td>
<td>4R, 6R Series 900 (2011) SCR (up to 240 kW/320 bhp)</td>
<td>4R, 6R Series 1000 (2014) EGR, SCR, DPF*</td>
<td></td>
</tr>
<tr>
<td>455 - 510 bhp / 340 - 380 kW</td>
<td>6R S60 Series 400 (up to 360 kW/480 bhp)</td>
<td>6R Series 400 (2011) SCR (up to 360 kW/480 bhp)</td>
<td>6R Series 1300 (2014) EGR, SCR, DPF*</td>
<td></td>
</tr>
<tr>
<td>535 - 620 bhp / 400 - 460 kW</td>
<td>6R S60 Series 500 (up to 480 kW/645 bhp)</td>
<td>8V Series 500 (2011) SCR (up to 480 kW/645 bhp)</td>
<td>6R Series 1500 (2014) EGR, SCR, DPF*</td>
<td></td>
</tr>
</tbody>
</table>

* Development without diesel particulate filters (DPF) in progress
** Development without diesel oxidation catalyst (DOC) in progress

EGR: Exhaust Gas Recirculation
SCR: Selective Catalytic Reduction
DPF: Diesel Particulate Filter
DOC: Diesel Oxidation Catalyst

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