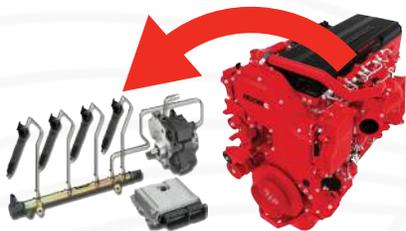


**Russ T. Bretell, Manager, Education and Technical Sales, Cummins Filtration**

*Russ has been with Cummins Filtration for 23 years and has had the opportunity to have fun in the diesel equipment industry for 36 years.*

Today’s diesel engines are enjoying the optimum in performance, fuel economy, driver satisfaction, and long life while also meeting strict emission requirements. The underlying driver in fuel system evolution comes from the need to meet ever-stringent emission regulations. These regulations have led to the introduction of many technologies, from EGR to DPF and DOC and then SCR, and the subsequent changes of fuels, from LSD to ULSD and then the addition of Bio-Diesel.



In a multitude of applications, from long haul trucks, to off road equipment, to vocational and recreational vehicles, many of these engines share one thing in common—technologically advanced High Pressure Common Rail (HPCR) fuel systems. While these fuel injection systems are critical to an engine’s ability to deliver the high level of performance and fuel economy seen today, they are subject to challenges not experienced by earlier fuel system designs.

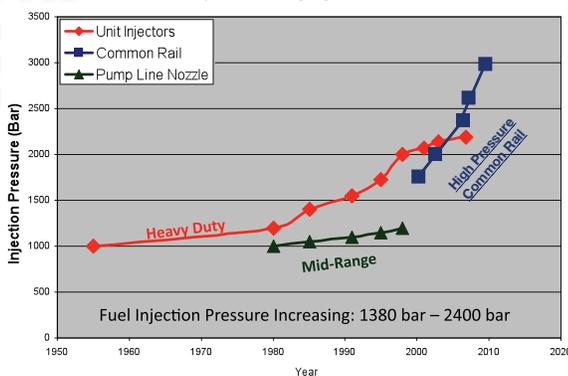
The X-axis of the graph above shows the change over time, from 1950 to today, and the Y-axis shows the injection pressure, measured in BAR (as a reference, 14.5 psi = 1 bar). As the graph indicates, fuel injection pressure with the HPCR systems is in the range of 40,000 psi, increased from 20,000 psi only a few short years ago.

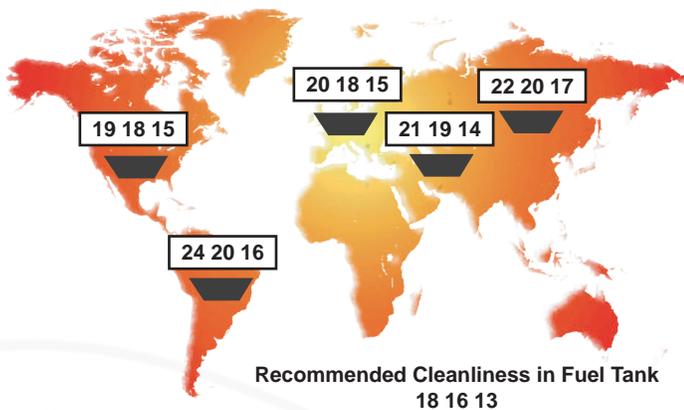
While extremely effective at fuel delivery, atomization, performance and fuel economy, herein lies the route of our challenges—higher pressures. Increased fuel injection pressures causes tighter tolerances between components, meaning that smaller contamination can cause increased wear on the fuel injection system components.

A single fuel tank fill-up can be enough to damage the fuel system with contaminant particles as small as 4 microns—roughly ten to twelve times smaller than a human hair. These particles, although invisible to the human eye, can prematurely wear down critical internal components of the fuel injectors, resulting decreased engine performance, higher fuel consumption and costly damage.

Consequently, HPCR systems require extremely clean diesel fuel; however, poor fuel quality caused by transport and delivery makes the challenges of HPCR fuel injection systems even more difficult. The World Wide Fuel Charter has stated that a full 50% of the diesel fuel dispensed around the world does not meet the International Standards Organization, or ISO codes for cleanliness.

**Fuel Injector Equipment Evolution**





As diesel fuel is transported from the refinery to the end user destination, it is pumped through pipelines, moved by barge, shipped by truck and stored in tank farms. During this delivery process, changes in temperature throughout any given day and exposure to the atmosphere can cause condensation and water to form in these storage systems, measurably diminishing fuel quality.



Additionally, by the time this fuel is ready to be burned during combustion, it has been exposed to the heat and pressure of engine injection systems, centrifuges, pumps, and heaters causing an increase in asphaltene agglomerations, negatively impacting combustion efficiency and emissions.

All of these factors increase the likelihood of contaminated fuel entering the HPCR fuel injection system. Now that we have reviewed the requirements of the HPCR injection system, as well as quality and delivery of the fuel source, let's consider the challenge that today's filtration systems face. There are additional dynamics taking place within the fuel filter itself that must be addressed, such as filter loading, engine/filter vibration and pressure surges.

Unlike air filters, fuel filters become less efficient over time. In other words, fuel filters are not removing as many particles of contamination toward the end of their service life as they did at the beginning of it. As the filter fills with contaminant, and fluid flow continues, it actually can push some contamination through the filter; this condition is referred to as filter loading. Additionally, fuel filter efficiency is affected by fuel system pressure surges. This condition typically occurs upon engine start-up as higher initial pressures can force previously held contaminant through the filter.

Finally, engine and filter vibration enables a greater amount of originally trapped contaminants to work loose and pass through the filter. To help visualize this behavior, think of the way a flour sifter works. When flour is poured into the sifter, the flour particles do not pass through the holes in the screen, even though the particles are much smaller than the holes. Only when you shake or agitate the sifter with the handle will the flour particles pass through the screen. In a similar way, contamination particles may not pass through the filter media in a static environment, but when vibration is introduced, the particles can then shake their way loose to pass through.

Fuel quality and cleanliness, fuel delivery and transfer, filter loading, pressure surges, and filter vibration all come together to present a serious dilemma for today's engines. Furthermore, even with all these challenges present, Industry Standards for real-world, actual in-service testing, with filter loading, pressure surges and vibration, do not exist. Many current filters can meet the parameters for the laboratory testing, but how many of your engines operate in a lab?

As the only filter manufacturer that is also part of an engine company, Cummins Filtration is able to develop, test and refine filter performance using the expertise and data of Cummins engines in a wide range of real-world operating conditions. The result of this research and development has led to the latest

technology that can combat these HPCR fuel system challenges— patented Fleetguard® NanoNet® advanced filtration media.



Through a science to technology approach, with many years of research and development, Cummins Filtration thoroughly analyzed the challenges with which operators and engines faced. Over 30,000 hours of off-highway equipment testing, 2.2 million miles of on-highway testing, and over 71,000 hours of test cell experience has led to the development of NanoNet media.

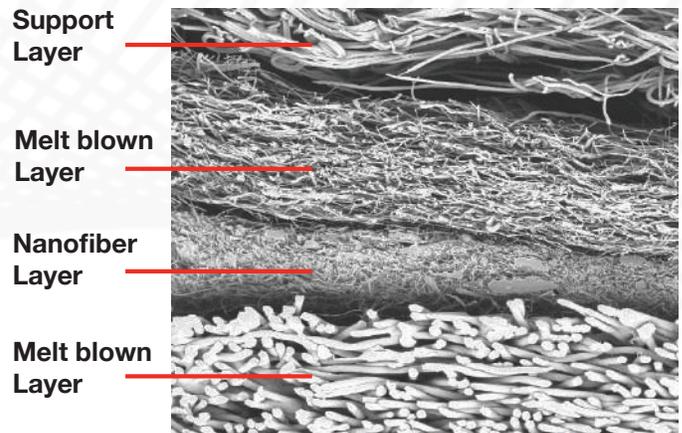
Before we explore further into NanoNet technology, let's quickly review the previous proprietary media technology from Cummins Filtration— StrataPore®. StrataPore gets its name from the fact that it's a multi-layer media; it's also a gradient density media, meaning, each of the layers has a different density or efficiency. The individual layers are manufactured in what's known as a "melt blow" process where small pellets of various polymers are melted down and force-sprayed through tiny holes into a single layer sheet of media using high pressures. These different sheets of media are then layered together, and along with backing layers of a substrate, give us the total media package known as StrataPore.

NanoNet technology incorporates a combination of proven StrataPore layers with new nanofiber media layers. The

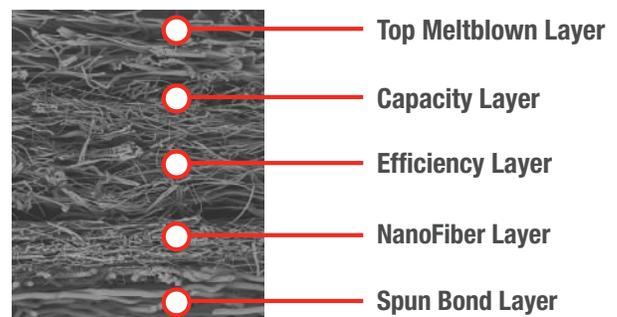
result is a fully synthetic, multilayered media capable of removing the smallest particles of contamination, even down to 4 microns, with very high efficiency. Additionally, the fully synthetic composition means that NanoNet is not susceptible to damage or saturation from liquids as traditional media can be.

The image shown below shows the various layers that make up NanoNet media. The first layer is a substrate, or support layer, followed by the second which is melt-blown. The third layer is the nanofiber layer and the fourth is an additional melt blown layer. The total package of each gradient layer working together is what makes NanoNet effective.

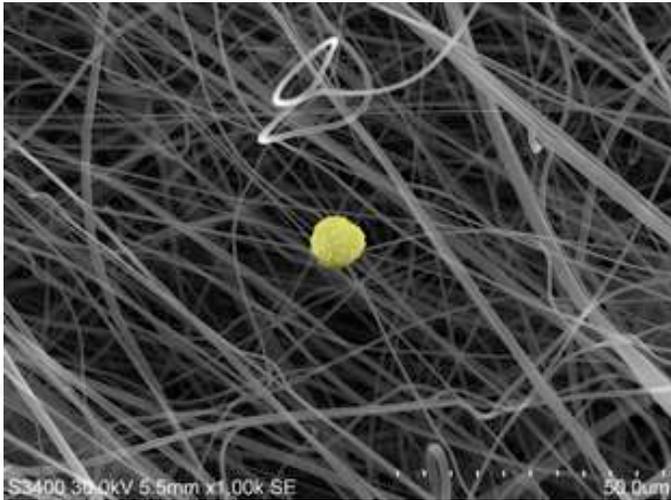
## Example of Four Layer NanoNet®



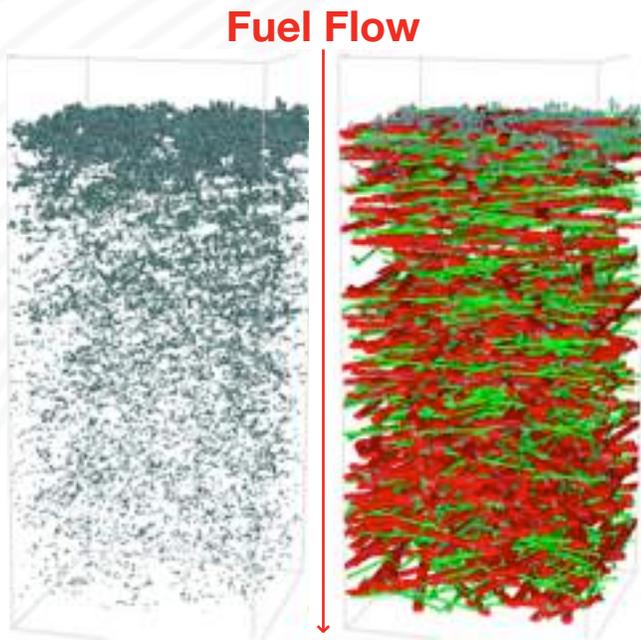
The image below shows another example of NanoNet media, this time in a five layer configuration. The nanofiber layer of NanoNet provides the highest efficiency and holds contaminant even with pressure surges, filter loading and engine and filter vibration thanks to the extremely small fibers.



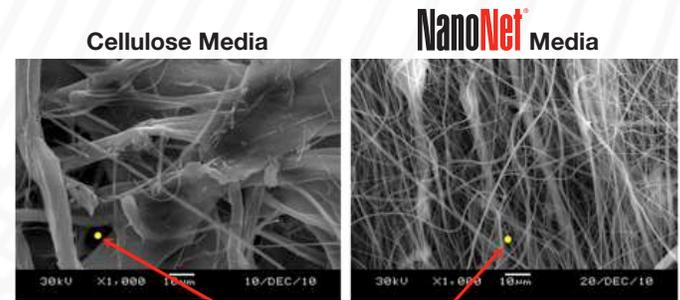
The photo below shows another view of the nanofiber layer, demonstrating the small size of the fibers. For reference, the yellow circle represents a 10 micron size particle. These small size of these fibers allows for removal of single digit micron particles, but also reduces restriction for high flow and high capacity. To further illustrate the difference between



In this computer aided drawing, the red and green coloration (shown left) represents fibers within the nanofiber layer of NanoNet media, magnified many times. If we remove the fibers (shown right), notice how the contamination particles are retained with very few even reaching near the bottom of the nanofiber layer.

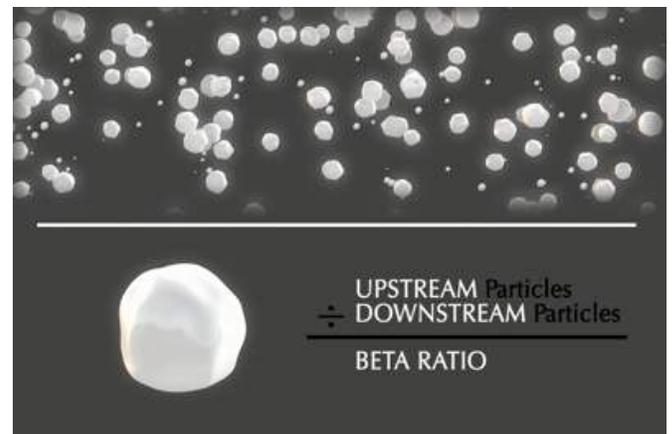


nanofiber media and traditional cellulose media, consider this magnified image of cellulose, or paper media, (shown left) compared to the nanofiber media (shown right). Notice the yellow circles, which represent a 3 micron size particle. With the cellulose media, it is clear to see that the particle will likely pass through the large openings in the media, meaning it is not very efficient; however, the tight pattern of the nanofiber media ensures that the particle will have a much more difficult time passing through, meaning it is much more efficient than the cellulose media.



3-5 Micron Sized Particle

Beta ratio measurements more clearly distinguish the performance gaps between NanoNet media and traditional media. Stated simply, a beta ratio compares the number of particles of contamination introduced to the filter to the number of particles of contamination that pass through the filter. This ratio gives us a true indication of a filter's efficiency for a given size particle.



For example, let's target 4 micron sized particles. If 100,000 particles enter the filter and 1,333 make it through, then the filter's

efficiency is 98.7% (removes 4 micron size particles 98.7% of the time) and has a ratio of Beta 75. That's 100,000, divided by 1,333 to equal Beta 75 and 98.7% efficiency; this type of performance is actually quite good and typical of our StrataPore media. However, NanoNet media can remove the same 4 micron size particles 99.9% of the time. While that's only a 1.2% improvement, in reality it means that of the same 100,000 particles flowing into the filter, only 100 particles are able to get through the media. A 1.2% improvement in efficiency is actually a thirteen times improvement over traditional filtration.

This particular example compares the Fleetguard high-horsepower FF5644 fuel filter to the NanoNet upgrade version, the FF5782. The FF5782's higher level of efficiency translates into longer injector life, reduced down time and repair costs, as well as increased uptime and revenue potential. Fleetguard NanoNet filters ensure the engine's HPCR fuel injection system performs like new over time, minimizing repair costs and maximizing fuel system efficiency and performance.

NanoNet technology is available in many products today, with more on the horizon. For applications from high horsepower, all the way down to the RAM® and TITAN® diesel pickup trucks, NanoNet filters provide optimum protection. Look for the NanoNet logo and you're your engines are being protected.

### **For Additional Information, Contact:**

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615-986-9008

*Diesel Fuel Challenges and Nanofiber Media Filtration Solutions (03/2015)*

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