# High Efficiency Gas Turbine Air Filters with Nanofibers

## Overview

Global energy demand is estimated to rise between 25 and 30 percent between now and 2040, fueled by growth in economic output and by industries such as data centers and electrical vehicles requiring an ever increasing amount of energy. The rising energy costs around the world has increased demand for more efficient power generation with minimal waste. The electricity generation sector is witnessing the arrival of new, advanced-class, highly efficient natural gas plants and continuing to invest in the use of renewable sources of production.

This backdrop places even greater pressure on the present installed base, consisting of many thousands of gas turbines, to help the electric utilities develop more competitive business models capable of meeting demand with clean, efficient and reliable modes of generation. If operators hope to achieve peak business performance, finding new ways to extract a greater number of megawatt hours at reduced fuel usage rates and with lower overall operational costs has never been more important.

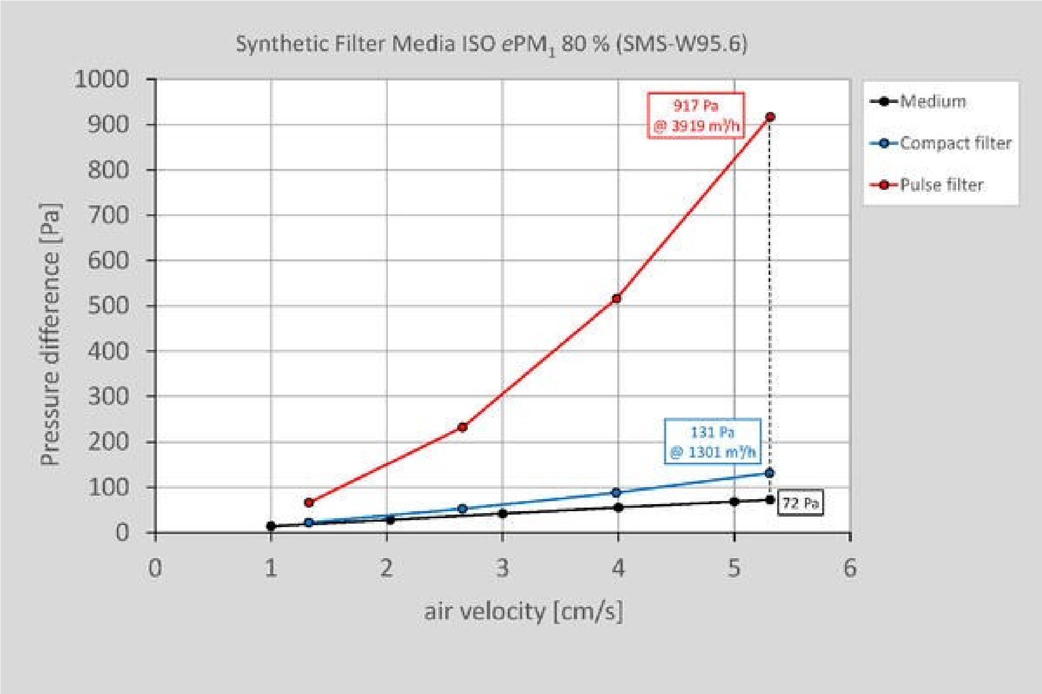
In order to combust fuel, GTs consume vast amounts of atmospheric air heavily contaminated by natural pollutants such as wind-blown dust, agricultural pollution and salt and seawater spray in coastal locations, plus pollutants created by chemical refining, along with hydrocarbon emissions from industry and traffic. As an accumulated mass in fluctuating humidity, these pollutants seriously impact the performance and operating efficiency of precision GT engines. Running gas turbines is costly and improved air filtration systems can help increase runtime, reduce maintenance and improve capacity. There is a need for air filters used in gas turbines help companies minimize downtime, maintain clean engine performance.

To protect the turbine from these pollutants, most GT original equipment manufacturer (OEM) specifications—both past and present—call for air inlet filtration using a final “fine” filter with a classification of MERV 15/F9 (98 grade efficiency) or less. **These are filters that deliver initial particle removal efficiencies of 60% or less at 0.5 microns.**

HEPA (high-efficiency particulate air) filtration, now also known as EPA, was originally developed for clean rooms and pharmaceutical applications. HEPA E12 filters, with efficiency levels thousands of times greater than the MERV 15/F9 classification and capable of removing 99.5% of particles as small as 0.07 microns, are increasingly being used to protect gas turbines. The initial demand for E and H-class filters came from oil companies seeking to maintain a very high level of cleanliness for turbine compressor blades, which eliminates the requirement for offline water wash and, consequently, production downtime.While it would be very attractive to replace current MERV 15 filters with HEPA E12 filters, a significant amount of power is lost due to the increased differential pressure of such high efficiency filters. Inlet systems also may need to be redesigned to accommodate the higher performance filters. **There is therefore a critical need for high efficiency HEPA filters with a pressure drop lower or equal to that of current MERV filters.**

## Pulse vs Compact Filters

Current high efficiency filters used in GTs are typically membranes made from microglass or ePTFE. Furthermore, the very thin media generally has very low dust holding capacity. This required shutting down of the GT for maintenance. Pulse filters are inherently limited in terms of air flow and typically limited to 2 cm/s flow rates or 1500 $m^3/h$ distributed over a 20.5 $m^2$ effective filter area. By comparison current compact filters with a typical MERV 15 (F9) efficiency are capable of handling 5 cm/s air flow speeds and 3,400 $m^3/h$ volume over the same surface area.

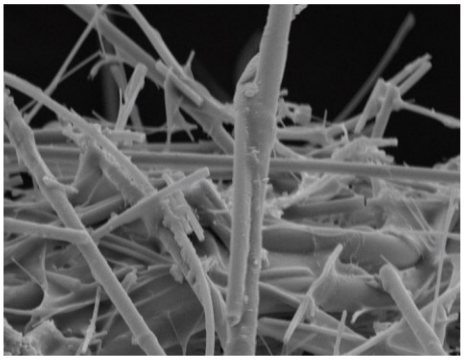



At 2.03 cm/s, the medium has a pressure difference of 28 Pa, the compact filter of 37 Pa and the pulse filter of 140 Pa. This velocity corresponds to a volume flow of 1301 $m^3/h$ for the compact filter. At 5.31 cm/s, the plane medium has a pressure difference of 72 Pa, the compact filter of 131 Pa and the pulse filter of an incredible 917 Pa. The volume flow of the pulse filter corresponds to 3919 $m^3/h$ if its filter medium were to flow at the same speed as the compact filter. The negative influence of the aerodynamic design of the pulse filter including the pleat pack is now 917 - 72 = 845 Pa compared to that of the compact filter with 131 - 72 = 59 Pa.

So, while current compact filter designs are inherently more energy efficient than pulse filters they are limited in performance. MERV filters are generally made from electrostatically charged media. The testing that determines a filter's MERV rating simulates a filter's efficiency only when the filter is new. Airborne particles encountered during use will negate enhancements to the filtration properties of the media, reducing the filter's efficiency and the resulting air quality. Such a drop in filtration efficiency will occur within a fairly short time, and is be as much as several MERV levels.

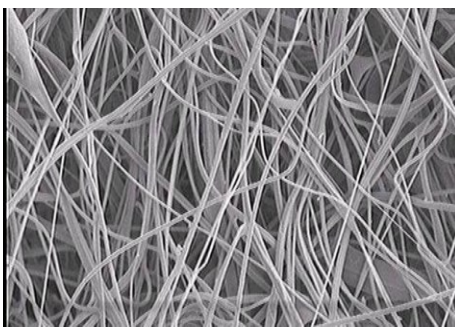
## Current High Efficiency Filtration Technology

### Glass Microfibers



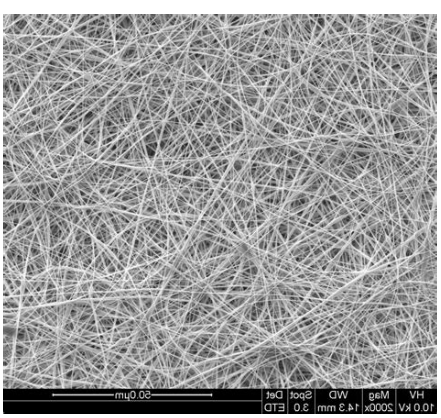
Traditional HEPA filter media has been made from borosilicate glass fibers. The fine fibers in this type of filter media impart high particulate capture efficiencies for HEPA filtration. Wet-laid media production has been in place since the 1950s, and the processes are well established, due to years of experience in operation and optimization of media properties, necessary volumes, and cost. However, microglass HEPA media usually demonstrates low durability. These filters are susceptible to failure that can be caused by various reasons, such as handling, testing and validation, cleaning, and unintended contact.

### Meltblown Microfibers



The melt blown process is a nonwoven manufacturing system involving direct conversion of a polymer into continuous filaments, integrated with the conversion of the filaments into a random laid nonwoven fabric. Using the melt blown technology, the spun filaments are accelerated by means of hot, fast-flowing air that is directly blown onto a moving substrate, creating a self-bonded web. The achieved filament diameter is one magnitude lower compared to the spunbond process, 2–5 μm. The meltblown process has been extensively used in air filtration to produce MERV rated filters. Meltblown media can readily be electrostatically charged to increase collection efficiency. To date the process has not been able to be used for the production of HEPA rated filters.

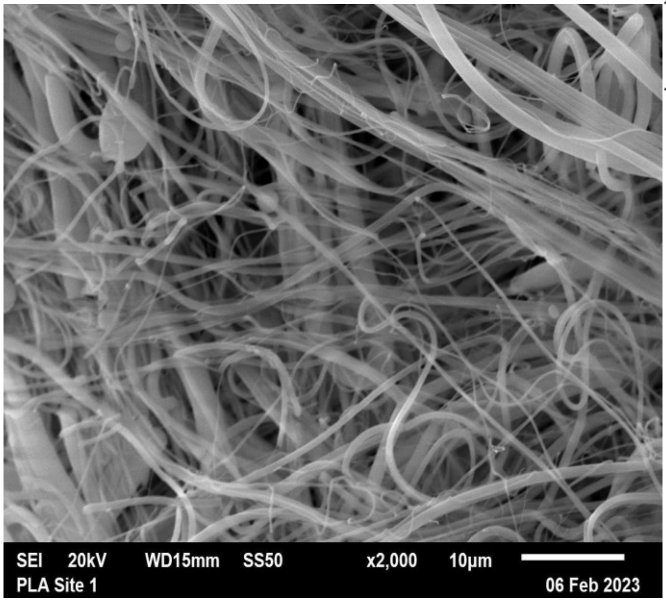
### Electrospun Nanofiber Membranes

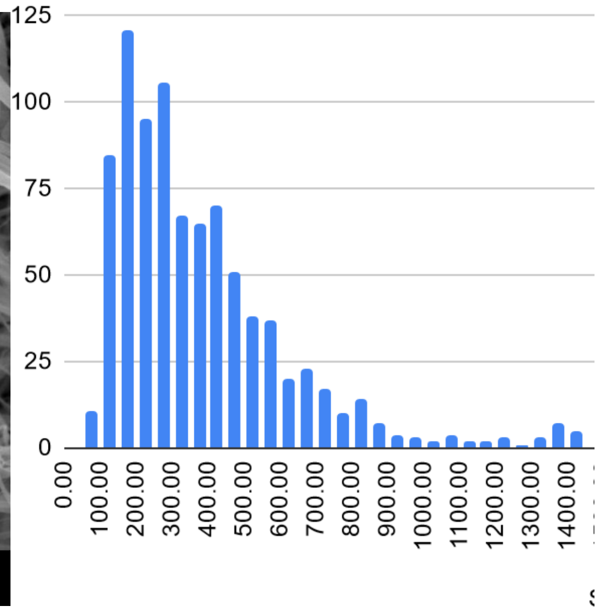


Nanofibers have generated interest in high efficiency air filtration media because of their high specific surface area and small pore sizes. ES nanofibrous membranes (ENMs) have been proposed as alternatives to existing glass filtration media. Experimentation revealed that ENMs have higher filtration efficiency than traditional filtration fabrics, such as meltblown and microfiber filtration materials. While nanofibers can offer high filtration efficiency that stays consistent over the lifetime of the filter, they also tend to plug the media and increase pressure drop very quickly, and require the construction and use of an elaborate and thick pre-filter layer.

## The Verdex Solution

### Melt-Film Fibrillation




Verdex Technologies has developed and patented a highly scalable and green nanofiber manufacturing process called “melt-film fibrillation” to produce advanced filtration materials. The process can produce materials with fibers as small as 100 nm and submicron pore sizes. The process bears some similarity with meltblown but uses a shearing airflow to produce submicron fibers from a thin film. Unlike electrospinning it is entirely solvent free and produces 3D fibers and a very lofty material.

- The median fiber size can be as low as 250 nm or about ten times smaller than typical fibers from meltblown media.
- The fiber surface area is more than 100 times greater than meltblown for particle deposition, resulting in much higher filtration efficiency.
- The fiber size is bimodal with the vast majority of fibers below 500 nm and a small number of larger fibers for structural integrity and mechanical strength. A unique characteristic of the material is the entanglement structure where nanofibers get entangled within the larger microfibers providing high mechanical strength to the finished material.
- Unlike microglass and ePTFE fibers, the Verdex media is directionally homogeneous and is equally strong in the machine and cross directions.
- The media produced has very high porosity (> 95%). This high porosity enhances dust holding capacity and improves service life.
- Virtually any type of thermoplastic polymer can be fibrillated including biodegradable polymers. This material offers high tortuosity and air permeability and is capable of both depth and surface filtration.

## Comparison of Physical Characteristics

| Filtration Media | Meltblown | Microglass | Verdex Fibrillated Nanofibers |
|---|---|---|---|
| Physical Structure | 3D microfibers | 3D microfibers | 3D nanofibers |
| Filtration | Depth Filtration | Depth filtration | Depth and Surface Filtration |
| Dust Holding Capacity | High | Moderate | Very High |
| Porosity | 80-90% | 70-80% | ➢ 90-95% |
| Median Diameter | 2-5μ | 2-5 μ | 300-500 nm |
| Basis Weight gsm | 30-60 | 70 | 30-60 |
| DOP Penetration 0.3μ @ 5.3 cm/s (uncharged) | 65%-40% | 0.01% | 5%-0.01% |
| Pressure drop, Airflow (mm $H_2O$) @ 5.3 cm/s | 20-140 | 250-350 | 20-140 |
| Performance (Alpha) Uncharged | 8-12 | 10-12 | 20-30 |
| Abrasion Resistance | Moderate | Low | High |
| Tensile strength | Moderate | Low | High |

The above table summarizes some of the parameters relevant for high efficiency air filters:

1. **Dust holding capacity:** The Verdex melt-film fibrillation (MFF) media has excellent dust loading and holding capacity. This is critical to removing airborne pathogens.
2. **Penetration:** Microglass (MG) and MFF have much lower penetration than MB.
3. **Pressure drop:** Pressure drops through MG is significantly higher than through MB and MFF.
4. **Abrasion resistance:** Microglass has poor abrasion resistance and meltblown has moderate resistance. Verdex nanofibers have excellent abrasion resistance with a smooth surface.
5. **Tensile strength:** The tensile strength of microglass is very poor while that of meltblown is average. The Verdex nanofiber is a 3D nanofiber web with excellent tensile strength.

## Comparison of of Microglass, Synthetic and Verdex Media

We will use the definition of Quality Factor (alpha) QF = -log(P) /Δp * 100 where P is the penetration at 0.3μ and 5.33 cm/s face velocity and p is the pressure drop in mm $H_20$.

| | Microglass | | | Meltblown or Synthetic | | | Verdex | | |
|---|---|---|---|---|---|---|---|---|---|
| **Class** | **Eff. %** | **PD** | **QF** | **Eff %** | **PD** | **QF** | **Eff %** | **PD** | **QF** |
| **E 10** | 85 | 4.59 | 8 | 90 | 10 | 12.39 | 95 | 4 | 21.41 |
| **E 11** | 96.65 | 16.6 | 8.89 | 95 | 14.24 | 9.14 | 96.65 | 7 | 21.07 |
| **E 12** | 99.64 | 26.11 | 9.36 | | | | 99.65 | 11.4 | 21.54 |
| **H 13** | 99.95 | 29.62 | 11.14 | | | | 99.95 | 17 | 19.42 |

- Overall, the QF (alpha) of the Verdex materials is at least twice that of glass fiber and other synthetic media.

**Proven Verdex Benefits**

GT operational performance, availability and component life are direct functions of the total volume of filtered contaminant deposits. These deposits decrease the air-flow performance of the inlet compressor. Ultimately, the overall performance of the turbine is greatly reduced.

Gas turbines are constant-volume machines, and their performance is affected by:

- Compressor efficiency
- Ambient air temperature
- Ambient pressure
- Inlet pressure drop

Compressor efficiency can be linked to the cleanliness of the compressor blades, which is affected by environmental conditions and air inlet filter performance.

The HEPA level filtration offered by Verdex filters provides the important particle efficiency required to remove large volumes of submicron-sized contaminants, resulting in laboratory-like clean air for engine combustion.

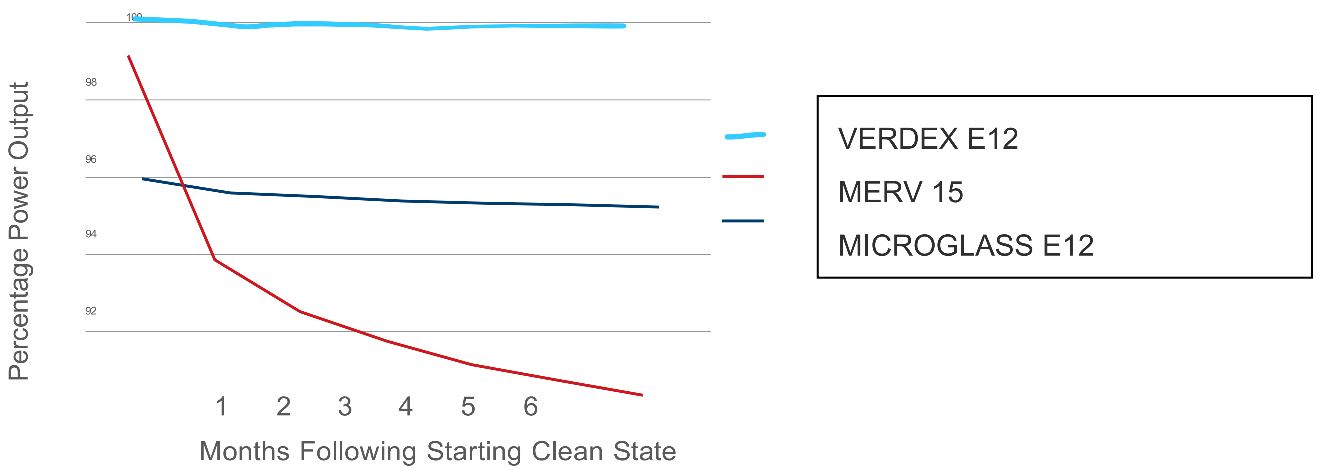
**The primary technical benefits derived from enhanced filtration technology include:**

- Greater machine availability and reliability
- Maintenance of high initial power output
- Improved fuel efficiency
- Increased hot-end component life
- Zero production downtime with elimination of offline water wash
- Lower emissions

**The primary technical benefits derived from lower pressure differential include:**

- Lower energy cost in operating as turbine.
- Greater production yield
- Lower fuel and labor costs
- Lower component spend
- Greener technology use

## Power Savings




As shown above, the effect of using a microglass E12 filter is a significant increase in pressure drop resulting in an initial energy loss compared to the use of a MERV 15 filter with lower pressure drop. In an urban environment with higher levels of hydrocarbons, typical filtration products rated as high as MERV 15/F9 would be insufficient at preventing contamination of the combustion system and power output drops rapidly within a few months.

The VERDEX MFF E12 filter offers a large energy savings compared to MG E12 filters as well as MERV 15 because of the low filter differential pressure throughout the life of the filter.

## Economic Payback

- Microglass HEPA (EPA) filters are more expensive than current MERV 15 filters and the inlet system may have to be redesigned to handle the higher pressure drop.
- The VERDEX MFF filters on the other hand operate at lower or equal differential pressure compared to current MERV 15 filters and can be retrofitted in existing inlet systems without any redesign.
- The much higher dust holding capacity of VERDEX filters from their depth filtration design and high porosity also extends the life of the filters by as much as factor of 4.
- Unlike MG filters which are inherently fragile, MFF filters have very high burst and deformation resistance.

By capitalizing on the innovative nanofiber design, the VERDEX gas turbine filters offer large huge financial and technical benefits for the user, benefits that greatly exceed the additional the cost of the consumable filters.