Gas Turbine Inlet Air Filtration GdPS

A route map and summary of options available and the merits of each based on purchaser's unique circumstances

Modified for AFS April 28 Discussion

Revised 4-8-2015

Table of Contents

Program Overview

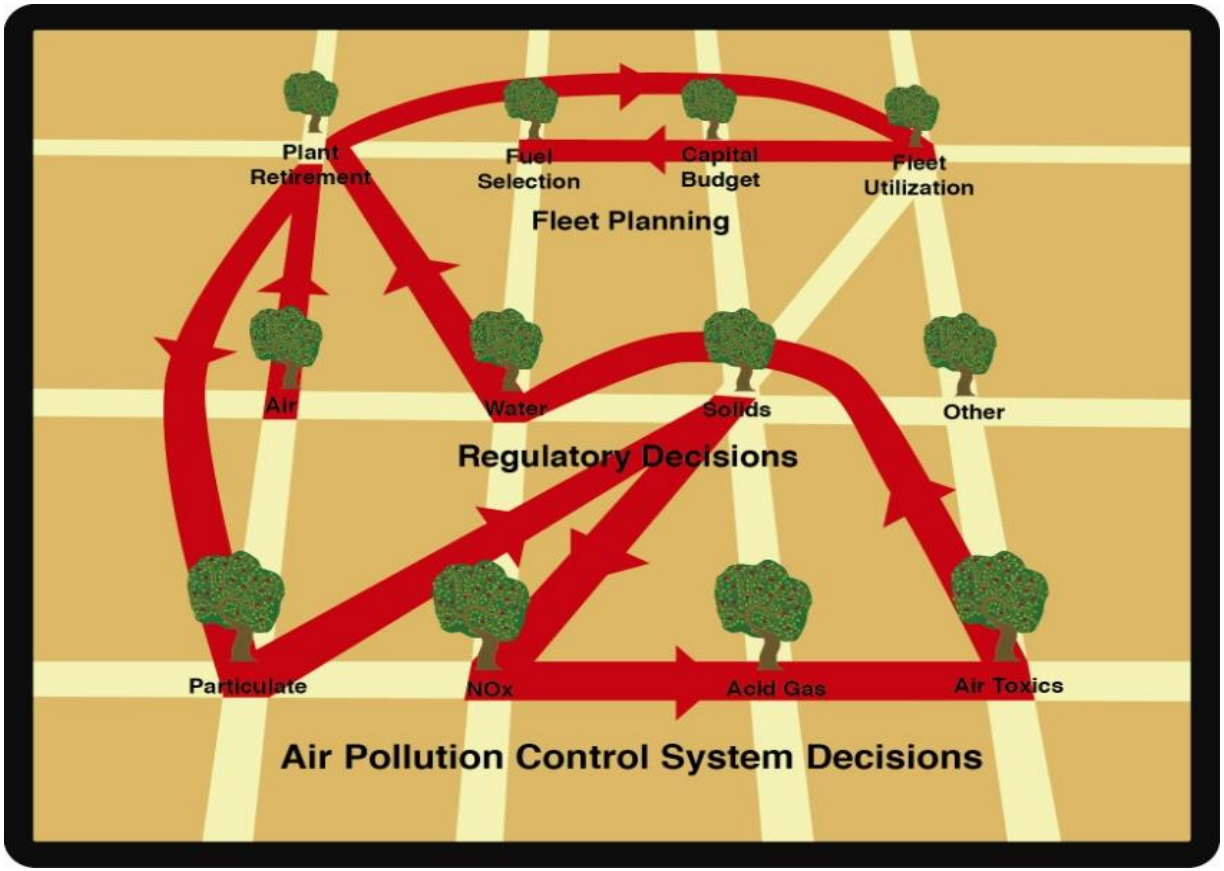
General

- The 90 minute session will be focused on a slide by slide display of the summary power points.
- As each slide is displayed there is the opportunity for discussion. It would start with the slide author if he so wishes.
- Designated panelists as well as the entire group will be encouraged to ask questions and make observations.
- Panelists and participants are encouraged to submit power points to be included in the summary.
- Anyone is encouraged to submit articles and presentations for inclusion in the Power Plant Decision Orchard.
- The Filtration News article in June will be based on the conclusions reached in the session.
- The summary and the intelligence system will be continually updated.

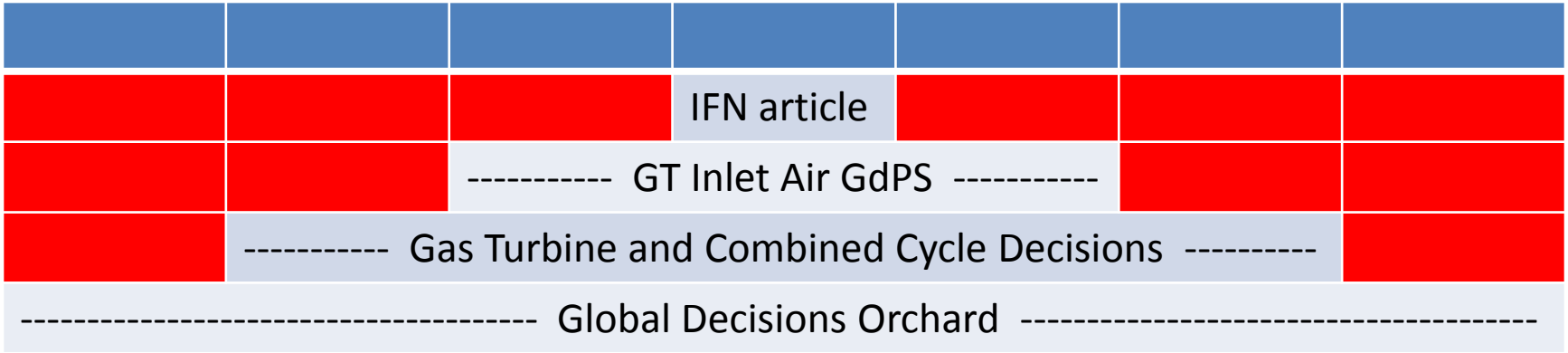
Specific: GT Inlet Air Filters

- Provide access to GT Inlet Air Filter GdPS upon registration
- Provide updated version of GT Inlet Air Filter GdPS prior to the event
- Provide contact among presenters and attendees before, during and after the event
- Conduct the program as a series of panels
- Continue upgrading of GT Inlet Air Filter GdPS and articles in International Filtration News

GT Inlet Air Filter Selection is like a trip with a GPS as a guide – *Global Decisions Positioning System™ (GdPS)*



GT Inlet Air Filter GdPS is part of a whole system



This GdPS is part of a whole system. It is route map to the larger database and a complete service for gas turbine operators – *Gas Turbine and Combined Cycle Decisions.*

The June Filtration news article will be a compressed version of the revised summary as shaped by the AFS session.

Panelists

Company	Name
Donaldson	Eli Ross
Freudenberg	Mike Garnett
Hollingsworth & Vose	Andre Boni Mike Malloy
Lydall	Geoff Crosby
W.L. Gore	Wilson Poon
HOVO	Andrew Shepard

I. Regulatory, Economic and Site Specific Impacts on Filter Choice

Subject	Slide Contributor	Relevant decision
Regulatory Impacts	McIlvaine	Gas and renewable generation will grow as coal and nuclear plants are retired
Priority Ranking	Barilla	What factors must clearly be considered vs. more "grey" factors?
Overview of Environmental Conditions	GE	What challenges are presented by various regional environments?
Coastal, Marine and Offshore Conditions	McIlvaine	What considerations are involved in designing air inlet filtration systems for coastal environments?
Desert Conditions	McIlvaine	Same – for desert environments.
Arctic Conditions	McIlvaine	Same – for arctic environments.
Tropical Conditions	McIlvaine	Same – for tropical environments.
Moisture	Nederman	How should a filter house be designed to address moisture issues?

Regulatory Impacts:
Gas turbine capacity will grow as regulations shift the energy mix away from coal and nuclear generation

Coal plants are being retired worldwide due to environmental concerns and regulations

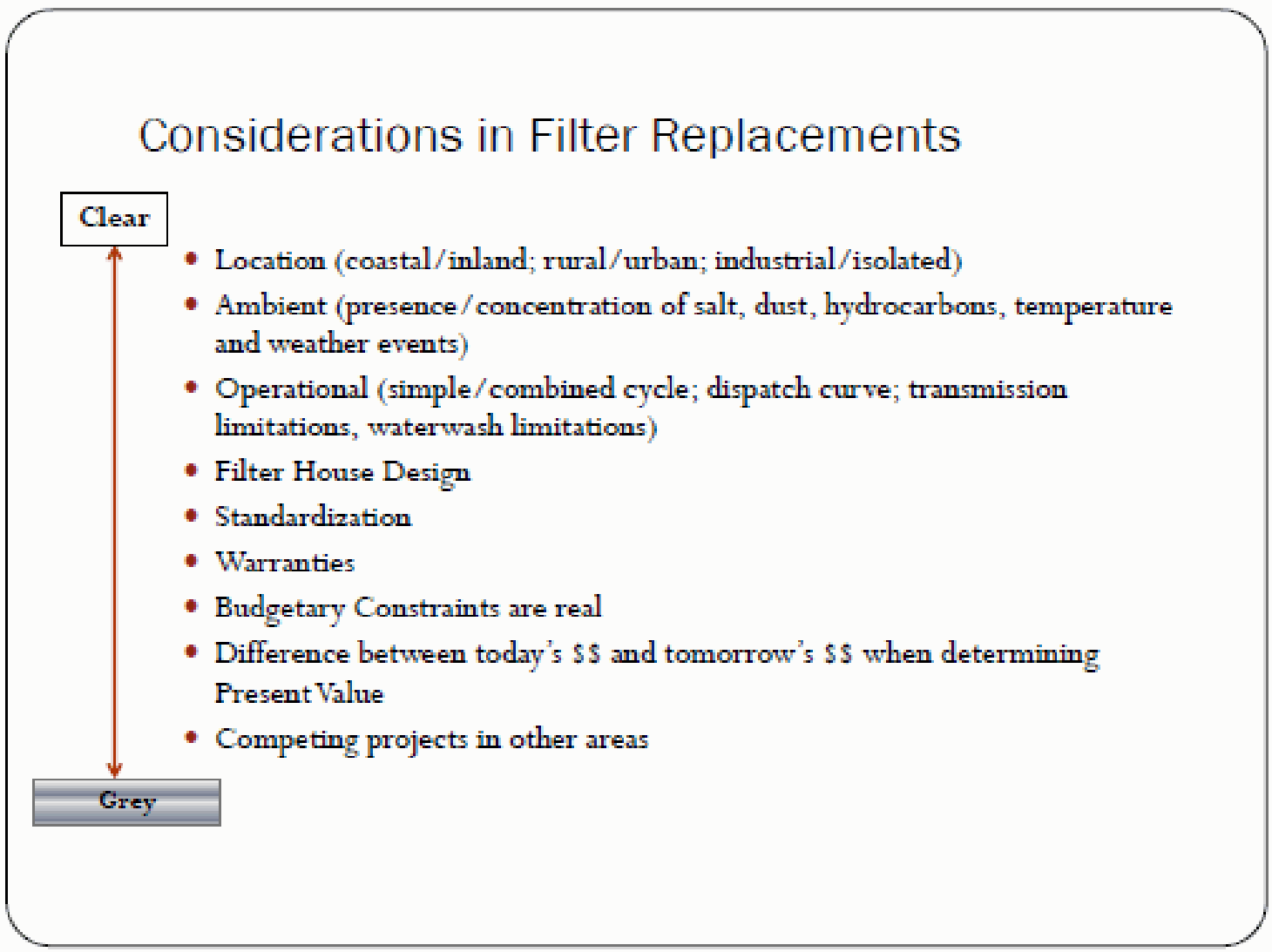
- Mercury, particulates, SO2, NOx
- Greenhouse gas regulations such as New Source Performance Standards (NSPS) for new plants and Clean Power Plant Program for existing plants in the U.S.

Nuclear plants are being retired in Japan, Germany and elsewhere as a consequence of the Fukushima disaster

Gas-fired power generation will increase to fill the gap

In addition, greenhouse gas regulations are promoting ***renewable energy***, which will require quick-start gas-fired units for backup

Priority ranking of filter selection factors (Barilla)



Conditions encountered depending on location (GE)

Environment type	Salt levels	Dust levels	Other challenges
Marine	High	Low	Bulk water
Offshore	High	Medium	Vapors
Coastal	Medium	Medium	Vapors
Dusty	None	High	Vapors
Dusty Coastal	Medium	High	Vapors
Desert	None	Very High	-
Urban	None	Medium	Vapors
Sub... Arctic	-	-	Snow and Ice
Sub… Tropical	-	-	Bulk water

To further evaluate these contaminants, consider the following ad

Coastal, Marine and Offshore Conditions

- The main difference between coastal and land based applications is the concentration of ***salt*** in the atmosphere. Salt is a main contributor to corrosion and can lead to fouling of compressor blades.
- ***Coastal environments*** refer to gas turbines installed on land but within 10 miles of a salt-water shoreline. At 8 to 12 miles from the shoreline, salt concentrations in the air drop to natural background levels.
- ***Marine environments*** refer to gas turbines installed on vessels, where the inlet is generally within 100 feet from the ocean's surface.
- ***Offshore applications*** are typically oil production platforms with gas turbine inlets more that 100 feet from the ocean's surface.
- Air intake filtration systems must be designed to handle moisture and salt and are typically include:
  - Weather protection (such as a weather hood)
  - Vane separators or coalescers to address moisture
  - Pre-filters and/or high efficiency filters to address salt

Desert Conditions

- ***Dust and sand*** are the main contaminants in desert environments. Initial separators can remove the larger dust particles, followed by pre-filters and high efficiency filters to remove the smaller particles.
  - However, modern self-cleaning cartridge filters with pulse cleaning have largely replaced separator/pre-filter/high efficiency filter arrangements, which tend to be more expensive due to the cost of frequent filter change outs.
- Some desert locations experience periods of ***dense fog and high humidity***, particularly in coastal regions in the Middle East. The moisture can collect on the surface of cartridge and self-cleaning filters, causing the dirt to form a cake which reduces the effectiveness of the filter and pulse-cleaning
- mechanism.
- Air intake filtration systems in desert environments typically include:
  - Weather protection (such as a weather hood)
  - Vane separators or coalescers, where appropriate, to address moisture
  - Self-cleaning cartridge filters to address dust and sand

Arctic Conditions

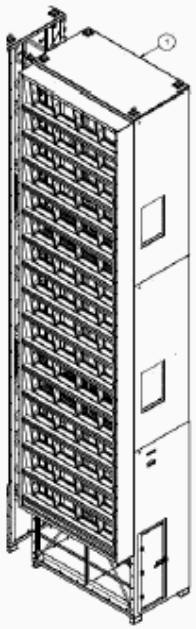
- Arctic environments are characterized by lengthy periods of time with temperatures below 32° F (0° C). The main concern for air intake systems is the ***removal of snow and prevention of ice formation and buildup.***
- Inlet filter housings should be elevated to minimize the ***ingestion of snow and ice***, with consideration given to the expected height of snow in winter months.
- Weather hoods should have a large entrance areas which decreases velocity and the likelihood that show will be pulled into the filtration system.
- Ice can be formed if the temperature of humid air in the inlet system decreases, causing water particles to freeze. Moisture in the air can be due to:
  - ***Cooling tower drift.*** The plant should be laid out to minimize the potential cooling tower aerosols to enter the intake system.
  - ***Ice fog***, which typically starts to form at temperatures below -15° F,
- ***Anti-icing systems*** mix heated air (from compressor bleed or gas turbine exhaust) with cold inlet air. Alternatively, ***pulse cleaning systems*** have been found to be effective in preventing ice build up.
- Air intake filtration systems in artic environments include:
  - Elevated intake structures
  - Weather protection (such as a weather hood or louvers)
  - An anti-icing system with pre-filters OR self-cleaning filters
  - High efficiency filters

Tropical Conditions

- Tropical environments are characterized by high temperatures, high humidity, monsoons, high winds and insect swarms. Due to extensive vegetation, it is considered a low dust environment.
- The primary contaminants are ***water and insects, and salt*** for locations near the shoreline.
- Filtration systems in the topics are specifically built to handle large amounts of rain. Weather hoods are used as a primary defense, typically followed by a vane axial separator and coalescers to reduce water intake.
- Large area insect screens with low inlet velocities are used to block ingestion of insects.
- High temperatures and high humidity lead to the formation of mold fungus and corrosion. Therefore, all metal inlet parts should be made of corrosive resistant materials or coated with ***corrosion protection***.
- Air intake filtration systems in tropical environments include:
  - Weather protection (such as a weather hood)
  - Insect screens
  - Vane axial separator, coalesce
  - Pre-filter and high efficiency filter
  - Corrosion resistant metal parts

Filter house design to reduce moisture (Nederman)

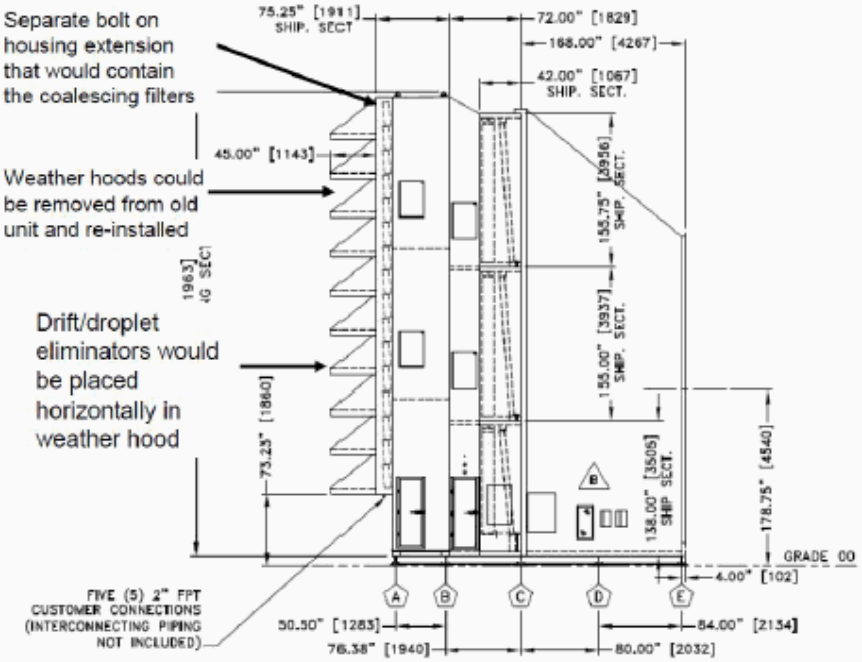
Addressing Moisture Issues



Separate bolt on housing extension that would contain the coalescing filters

Weather hoods could be removed from old unit and re-installed

Drift/droplet eliminators would be placed horizontally in weather hood



PNEUMAFIL

Nederman

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Decision Route – Regulatory, Economic and Site Specific Issues

Webinars (Protected)

Date	Recording Title
February 5, 2015	**Gas Turbine Regulatory Drivers** 120 minutes
May 15, 2014	**Gas Intake Filters: HEPA or Medium Efficiency** 101 minutes

InterWebViews™ (Free)

Date	Topic

Intelligence System Key Words

Search Category	Key Words
By Regulation	Greenhouse gas
By Site Specific Issue	Moisture
By Product	Air filter Air inlet house Coalescer
By Company	General Electric, Nederman
By Person	Barilla

II. Fiber and Media Choices

Subject	Slide Contributor	Relevant decision
Overview of Media Options	McIlvaine	What factors should be considered in selecting the filter media?
Filter Media Options	Ahlstrom	What filter media options are available?
Combo vs Synthetic or Glass	Midwesco	How does the performance of a synthetic/glass combo filter compare to other media?
Nanofibers	Lydall	What are the benefits of nanofibers?

Overview of Filter Media Options

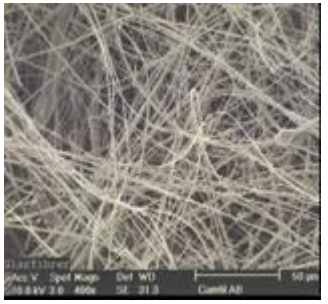
Two primary types of media are available:

- Synthetic, typically with coarser fibers
  - 3.0 to 4.0 µm diameter
- Glass, typically extruded to a smaller fiber diameter
  - 1.0 to 1.3 µm diameter
  - Higher dust holding capacity
  - Stiffer fibers, able to resist higher pressure drops and last longer

Synthetic Media

Fiber selection criteria:

- Efficiency rating
- Fiber size, diameter
- If synthetic, which resins



Glass Media

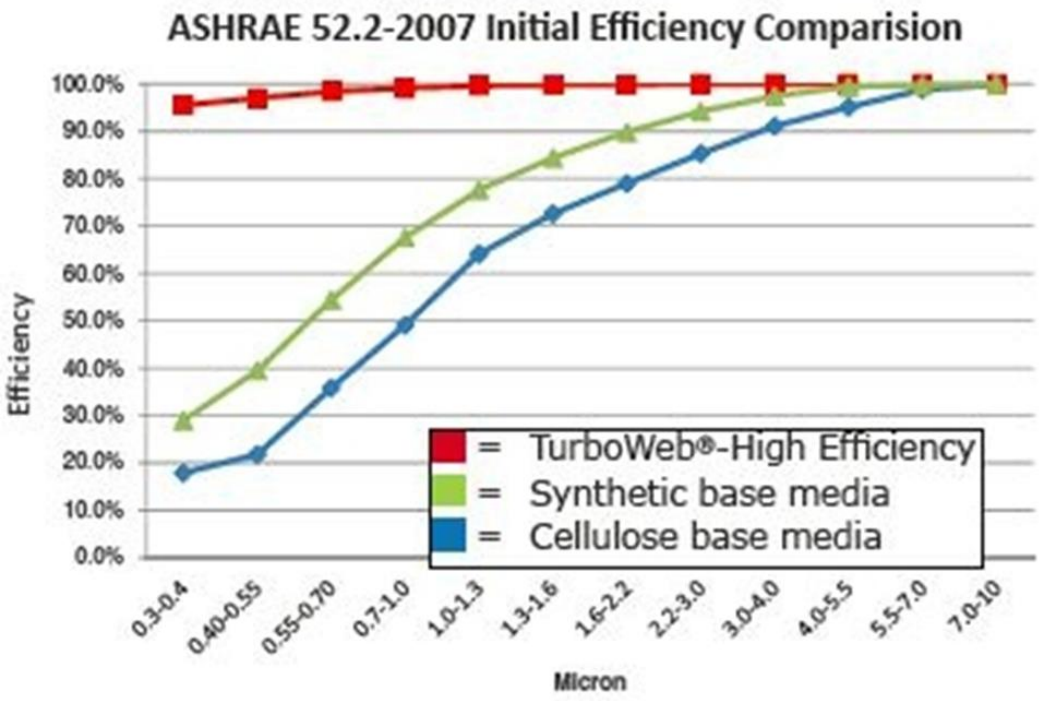
Filter Media Options (Ahlstrom)

Name	Material	Pre filter Static	Pre filer Pulse	Fine filter Static	Fine filter Pulse	HEPA Static	HEPA Pulsed
Trinitex GT	Synthetic	x	x	x	x		
Three layers can be tailored to obtain high strength and superior performance removing diesel soot, high humidity and salt							
Microglass GT				x		x	
possibility of additives and blends with synthetic fibers to enhance strength and pleatability							
Cellulose GT		x	x	x	x		
80 % polyester and 20% cellulose, good pleatability, excellent in dusty environments							
Cellulose fine fiber GT		x	x	x	x		
Layer of fine fiber on cellulose carrier sheet							
Nano GT			x		x		
Nanofiber from electro spinning on cellulose carrier sheet							

TurboWeb™ Filter Compared to Other Media (Midwesco)

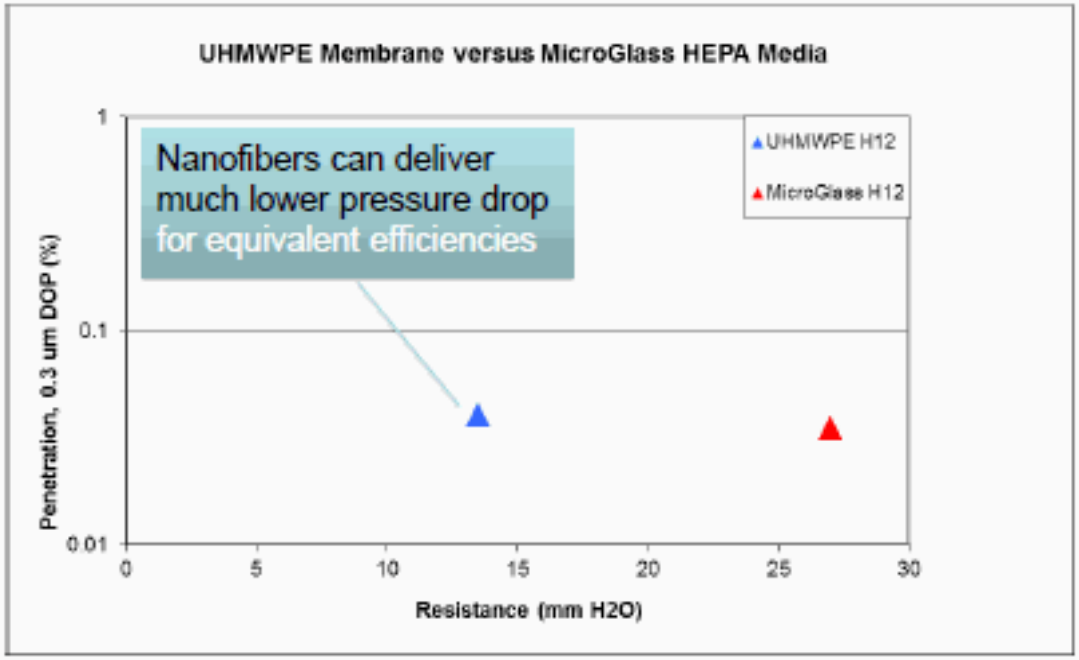
TurboWeb™ is a 3 layer ultra-high efficiency media.

- Layer 1: Proprietary high efficiency laminate
- Layer 2: Special treatment to resist moisture and salt from entering the media
- Layer 3: 100% synthetic



Nanofibers (Lydall)

Nanofibers: Energy Reduction Possibilities



* The efficiency ratings for this test used 0.3 micron DOP particles on a TSI Model 8160 automated test stand on flat sheet media samples at 5.33 cm/second.

Decision Route – Fibers and Media

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February 5, 2015	**Gas Turbine Regulatory Drivers** 120 minutes
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Intelligence System Key Words

Search Category	Key Words
By Product	HEPA Filter Micro-glass Filter
By Company	Ahlstrom, Hollingsworth & Vose, Lydall, Midwesco

III. Filter Choices (page 1)

Subject	Slide Contributor	Relevant decision
Overview	McIlvaine	What options are available?
Pre-filter Options I	AAF	Why should pre-filters be used?
Pre-filter Options II	AAF	Which option is best and when?
Efficiency Levels	Mcilvaine	What are EPA, HEPA and ULPA filters?
Efficiency Levels	Gore	What are the differences between high and very high efficiency filters?
Pressure Losses	Southwest	What are the pressure losses and how can they be reduced?
HEPA Static Design	Southwest	How are rectangular and cartridge filters designed?
Self-Cleaning Filters	Southwest	How do self-cleaning filters work?
Staging	Southwest	Will more than one type of filter be required?
Life Cycle Cost	Southwest	What factors should be considered when calculating the life cycle cost?

III. Filter Choices (page 2)

Subject	Slide Contributor	Relevant decision
Problems with Particulates	Mcilvaine	**Why are filters necessary?**
Static vs. Pulse	GE	**Under what conditions are static and pulse filters most effective?**
Options for Snow and Ice	GE	**What options are most effective in dealing with snow and ice?**
Selection Based on Operating Conditions	GE	**What filter should be selected based on dust loading, remoteness of operation and other conditions?**
Selection Based on Environment	GE	**What filter systems are recommended for each type of environment?**
Selection Based on Environment	GEA	**What filter systems are recommended for each type of environment?**

III. Filter Choices (page 3)

Subject	Slide Contributor	Relevant decision
HEPA Rating	Gore	Why are HEPA ratings important?
Cartridge/Pre-filter	Gore	Gore offers a cartridge filter with an integral pre-filter.
Pulsing for Constant Pressure Drop	Gore	What are the advantages of pulsing over static filters?
Pulsing to Eliminate Off-line Washes	Gore	What are the advantages of pulsing over static filters?

Overview of Filter Options

- Static filter or pulsed
- If static how many stages
- Design shape of filter elements
- Method of preventing leakage round filter element
- Ease of removal and replacement of elements
- Coalescing filter?

Pre-filter Options (AAF)

If a one-stage high efficiency filter is used, the build-up of large and small solid particles can quickly lead to increased pressure loss and filter loading.

Pre-filters are used to increase the life of the downstream high efficiency filter by capturing the larger solid particles.

- Therefore, the high efficiency filter only has to remove the smaller particles from the air stream which increases the filter life.

Pre-filters normally capture solid particles greater than 10 μm, but some pre-filters will also capture the solid particles in the 2 to 5 μm size range.

- These filters usually consist of large diameter synthetic fiber in a disposable frame structure.

Bag filters are also commonly used for pre-filters. These offer higher surface area that reduces the pressure loss across the filter.

Pre-filter options – Which, where? (AAF)

Panel - AmAir 300GT

Bag-V Bank

Three Levels of High Efficiency

The three common types of high efficiency filters are EPA, HEPA, and ULPA, defined as follows:

- EPA filters have a minimum efficiency of 85% for removal of 0.3 µm diameter or larger particles
- HEPA (High Efficiency Particulate Air) filters have a minimum efficiency of 99.97% for removal of 0.3 µm diameter or larger particles
- ULPA (Ultra Low Penetration Air) filters have a minimum efficiency of 99.9995% for removal of 0.12µm diameter or larger particles

Differences Between High and Very High Efficiency Filters (Gore)

Filter Classifications

Filter Class	Efficiency	Particle Size	EN779	ASHRAE 52.2	EN1822 2005/2009
	80% ≤ E_m ≤90% E1 < 75%	0.4µm/ 0.3-1.0 avg.	F7	MERV 13	
Fine Filters	80% ≤ E_m ≤95% 75% ≤ E1 ≤85%	0.4µm/ 0.3-1.0 avg.	F8	MERV 14	
	95% ≤ E_m 85% ≤ E1 ≤95% 95% < E1	0.4µm/ 0.3-1.0 avg.	F9	MERV 15	
	>85%	MPPS		MERV 16	H10/E10
EPA/HEPA Filters	>95%	MPPS			H11/E11
	>99.5%	MPPS			H12/E12

Ventilation Ventilation Cleanroom

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High Efficiency Filter Pressure Losses (Southwest)

- In order to achieve the high filtration efficiency, the flow through the filter fiber is highly restricted which creates a high pressure loss, unless the face velocity is kept low.

- The initial pressure loss on high efficiency filters can be up to 1-in. H_2O (250 Pa) with a final pressure loss in the range of 2.5-in. H_2O (625 Pa) for rectangular filters and 4-in. H_2O (2000 Pa) for cartridge filters.

- High efficiency filters used with gas turbines have pleated media that increase the surface area and reduce the pressure loss.

High Efficiency Static Filter Design (Southwest)

- There are many different constructions of high efficiency-type filters:
  - rectangular,
  - cylindrical/cartridge,
  - bag filters
- Rectangular high efficiency filters are constructed by folding a continuous sheet of media into closely spaced pleats in a rectangular rigid frame.
  - Rectangular filters are depth loaded; therefore, once they reach the maximum allowable pressure loss, they should be replaced.
- Cartridge filters are also made up of closely spaced pleats, but in a circular fashion
  - Air flows radially into the cartridge
  - They can be installed in a horizontal or vertical fashion (hanging downward)
  - Cartridge filters can be depth or surface loaded

Self-Cleaning Cartridge Systems (Southwest)

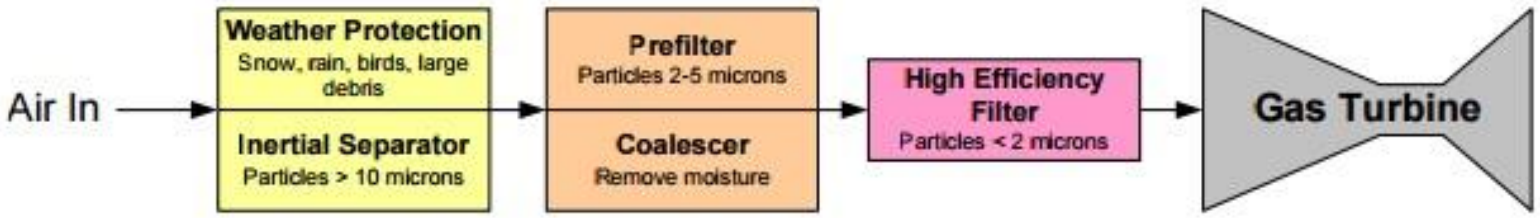
Self-cleaning systems operate primarily with surface loaded high-efficiency cartridge filters.

- Once the pressure loss reaches a pre-defined level, the filter is cleaned with air pulses.
- The pressure of the air pulses ranges from 80 to 100 psig (5.5 to 6.9 barg).
- A reverse jet of compressed air (or pulse) occurs for a length of time between 100 and 200 milliseconds.
- To avoid disturbing the flow, and to limit the need for compressed air, the system typically only pulses 10 percent of the elements at a given time.
- With this type of cleaning, the filter can be brought back to near the original condition

Multi-Stage Filtration Systems (Southwest)

Any gas turbine application typically needs more than one type of filter, and there are no “universal filters” that will serve all needs. So, two-stage or three-stage filtration systems are typically used.

- A weather louver can be used first to remove erosive contaminants, rain and snow.
- The second stage may be a low to medium performance pre-filter selected for the type of finer sized particles present, or a coalescer to remove liquids.
- The third stage is usually a high-performance filter to remove smaller particles less than 2 µm in size from the air.
- The arrangement will very based on site specific environmental considerations.



Filter Life Cycle Cost Considerations (Southwest)

- Initial costs
  - Equipment (filters, filtration system, spares filters, instrumentation)
  - Installation and commissioning (labor, cost of installation equipment such as cranes)
- Energy costs (pulse system for self-cleaning filters)
- Operating costs (labor and inspections)
- Maintenance costs (replacing filters, repairs, and associated labor)
- Downtime (to replace filters, complete offline water washes, anything outside of normal shutdowns for other maintenance)
- Gas turbine effects (degradation, performance loss)
- Decommissioning and disposal (disposal of filters)

Problems with Particulates

Corrosion

- Loss of material caused by a chemical reaction between machine components and contaminants, which can enter the gas turbine through the gas stream, fuel system or water/steam injection system.
- Salts, mineral acids, elements such as sodium, vanadium, and gas, including chlorine and sulphur oxides in combination with water, can cause corrosion.

Erosion

- Erosion is the abrasive removal of material by hard particles suspended in the gas stream.
- Particles causing erosion are normally 10 microns or larger in diameter. Particles with diameters between 5 and 10 microns fall in a transition zone between fouling and erosion.
- Erosion damage increases with increasing particle diameter and density, flow turning and gas velocity, and with decreasing blade size.
- Turbine and compressor manufacturers minimize erosion by increasing trailing edge thickness, installing field replaceable shields and using improved alloys.
- Nevertheless, they all recommend fine inlet filtration to prevent hard particles from entering the turbines.

Fouling

- Fouling is the adherence of particles and droplets to the surface of the turbomachine blading. This degrades flow capacity and reduces efficiency in a short period of time.
- Fouling can normally be reversed by cleaning, but it often requires downtime. Fouling is a serious problem, particularly in the oil and gas industry where sticky hydrocarbon aerosols are universally present.
- Traditionally, no accommodation has been made in designing turbines to tolerate deposition tendencies of particulate-laden gas streams. Although the deposition trajectories can be predicted for some turbine blades, the actual fouling is very much dependent on inlet gas cleanliness which varies unless it is controlled.

Static vs. Pulse Filter Options (GE)

Benefit	Static	Standard Pulse	Upflow Pulse
Initial dust efficiency	+	-	-
Filter life	-	0	+
Sensitivity to fog / mist	+	-	-
Compactness	+	0	-
Cost	+	0	-

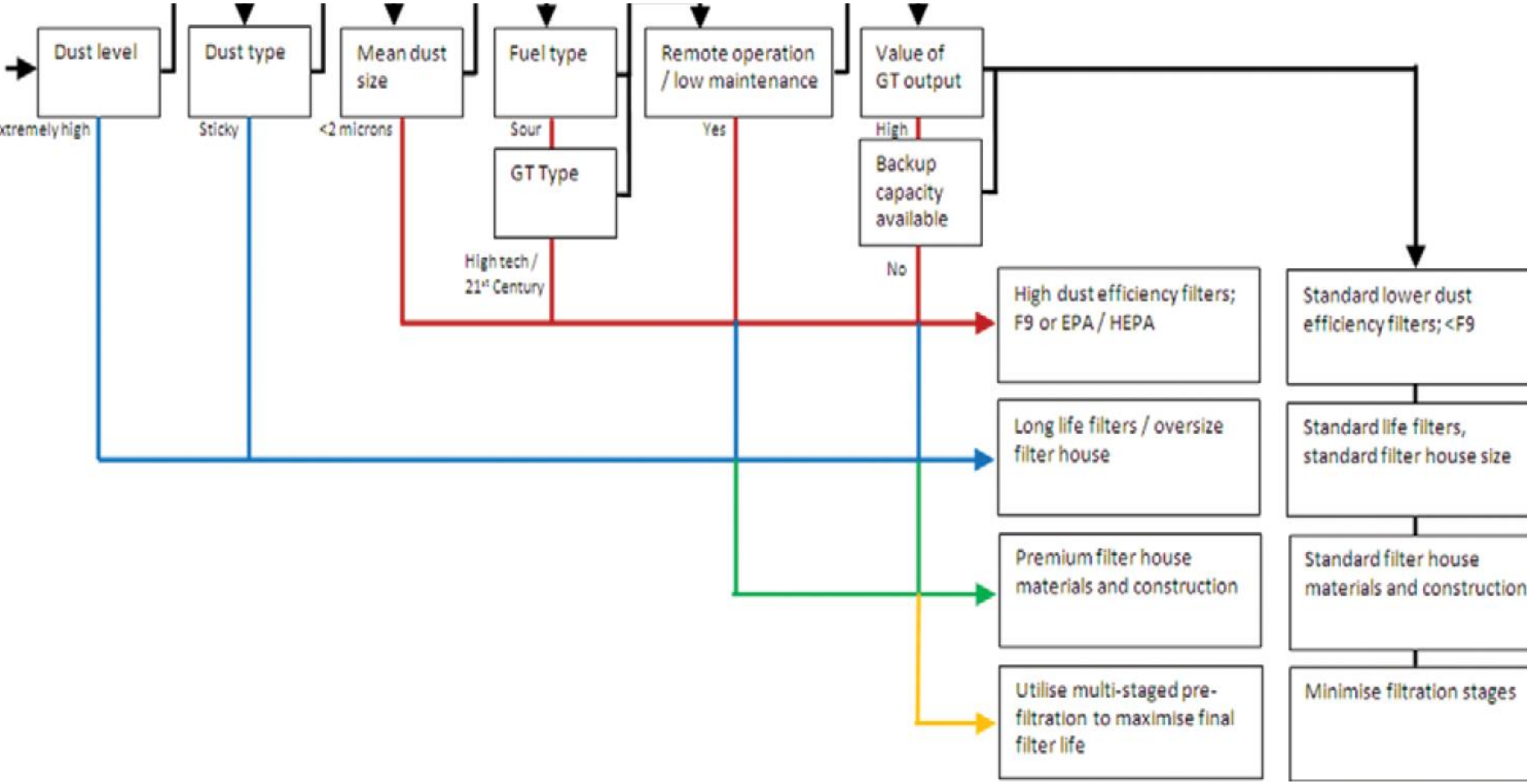
+ (Most favorable)
0 (Unbiased)
– (Least favorable)

Options for Snow and Ice (GE)

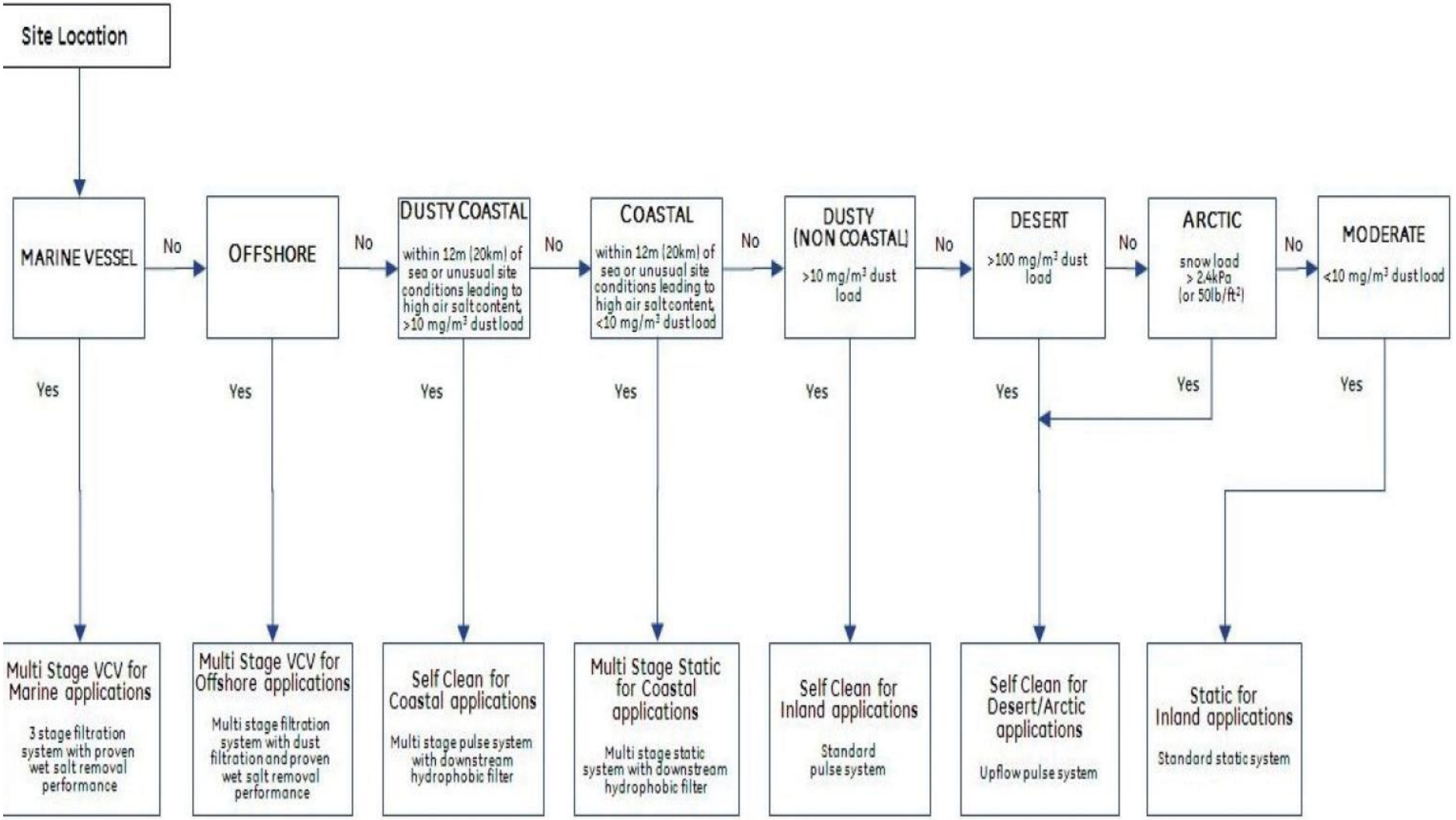
Benefit	Snow Hood	Upflow Pulse	Inlet Heating
Effectiveness vs. Ice	-	0	+
Effectiveness vs. Snow	-	0	+
Cost	+	-	-

+ (Most favorable)
0 (Unbiased)
– (Least favorable)

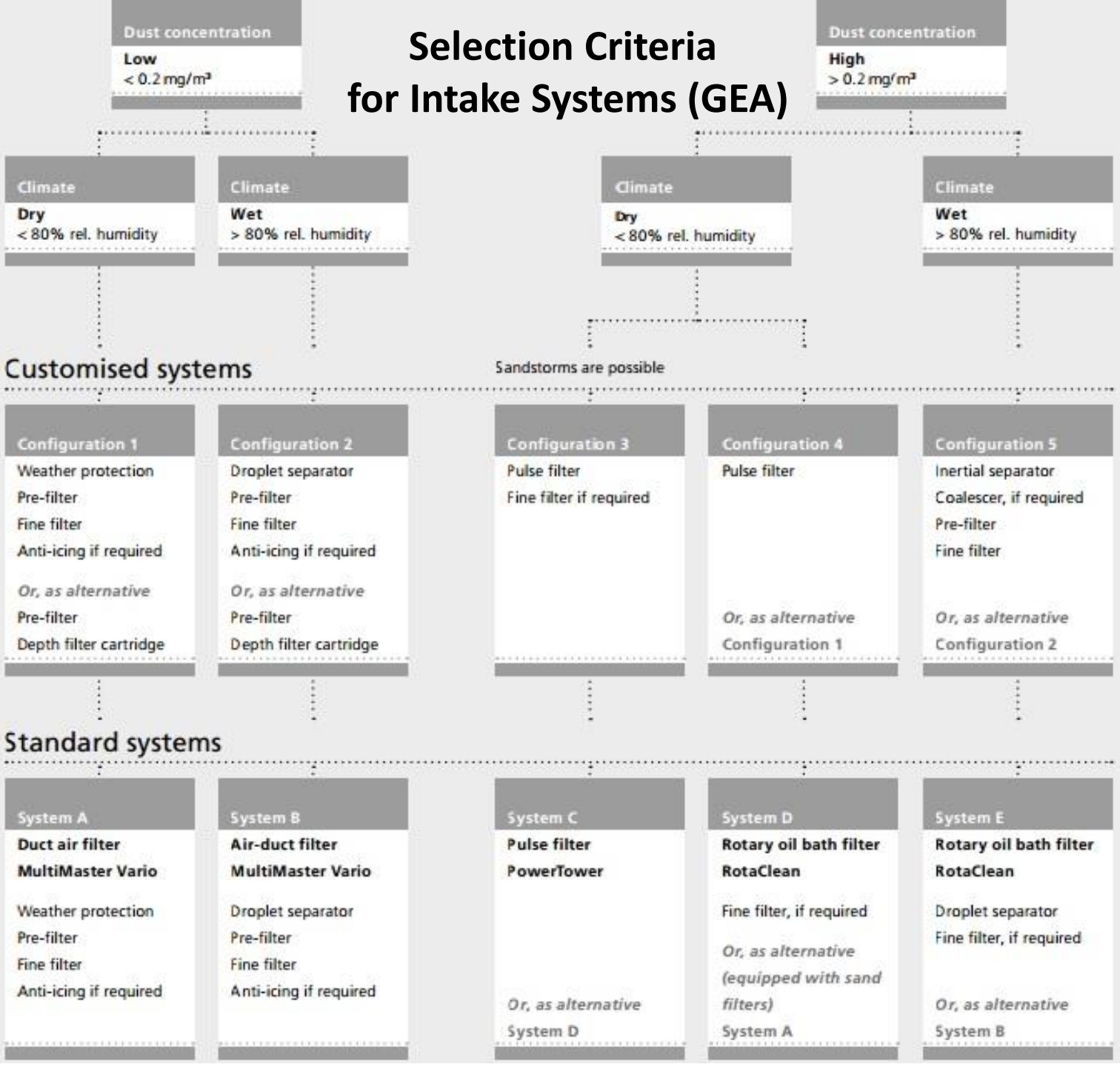
Filter Recommendations
Based on Operating Conditions (GE)



Filter Recommendations Depending on Environment (GE)

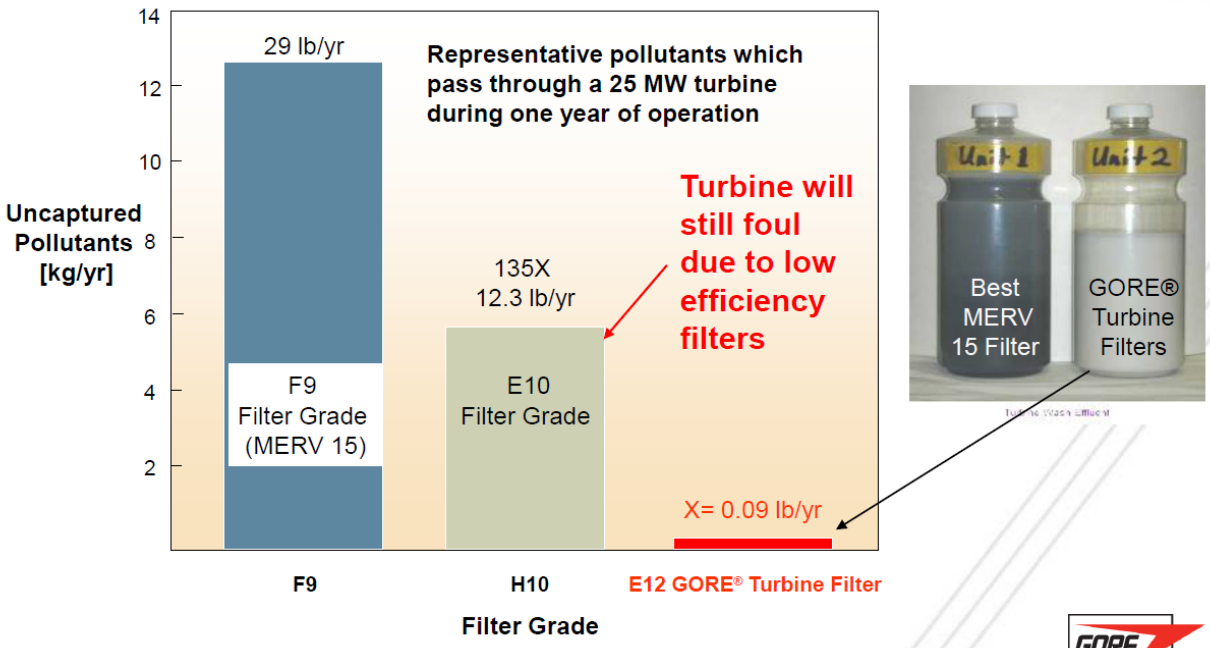


Selection Criteria for Intake Systems (GEA)



Make Sure to Use Relevant HEPA Rating (Gore)

There Are Different HEPA Ratings For a Reason



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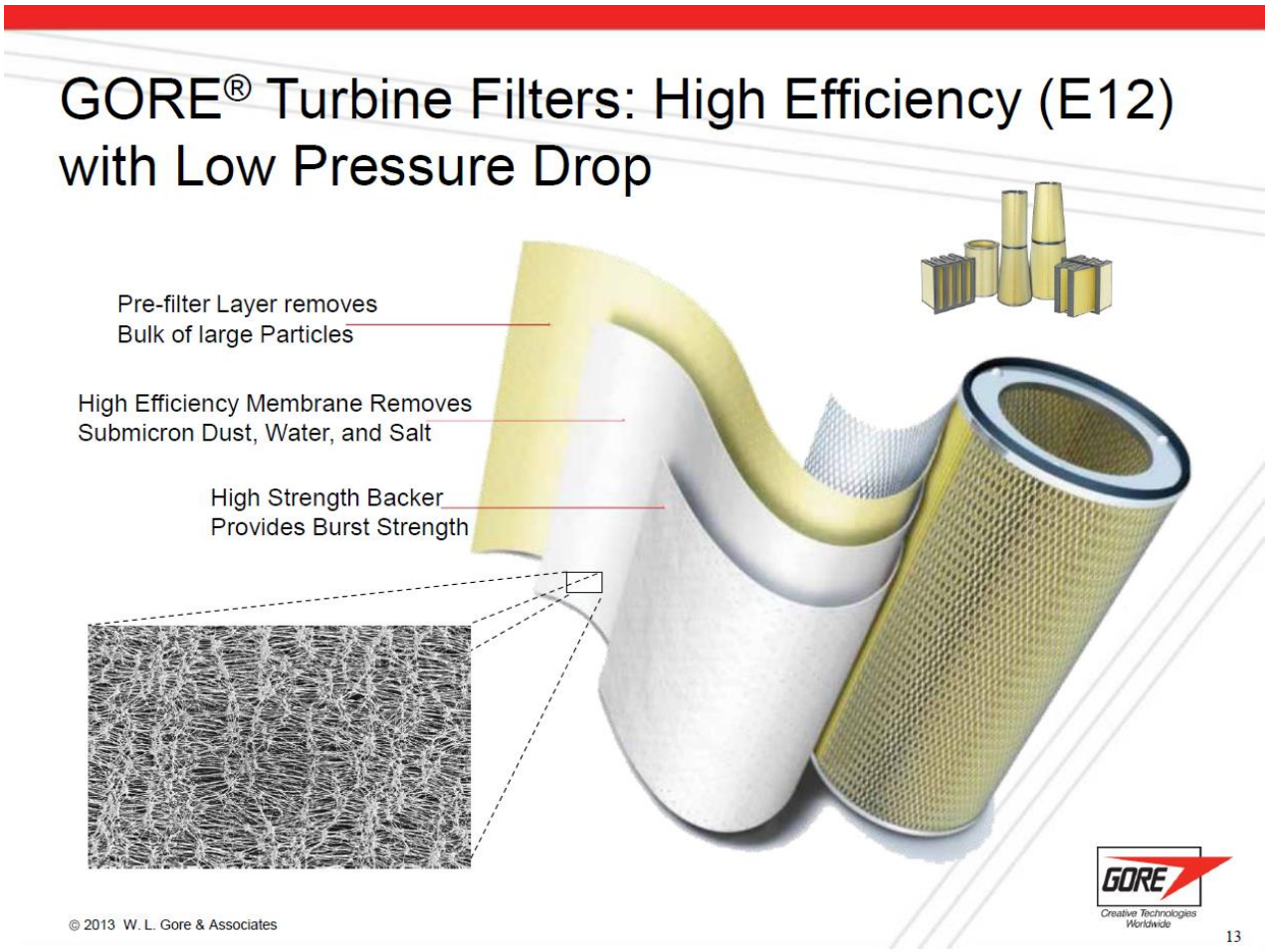
Cartridges with Integral Pre-filters (Gore)



Pulsing Prevents Pressure Peaks (Gore)

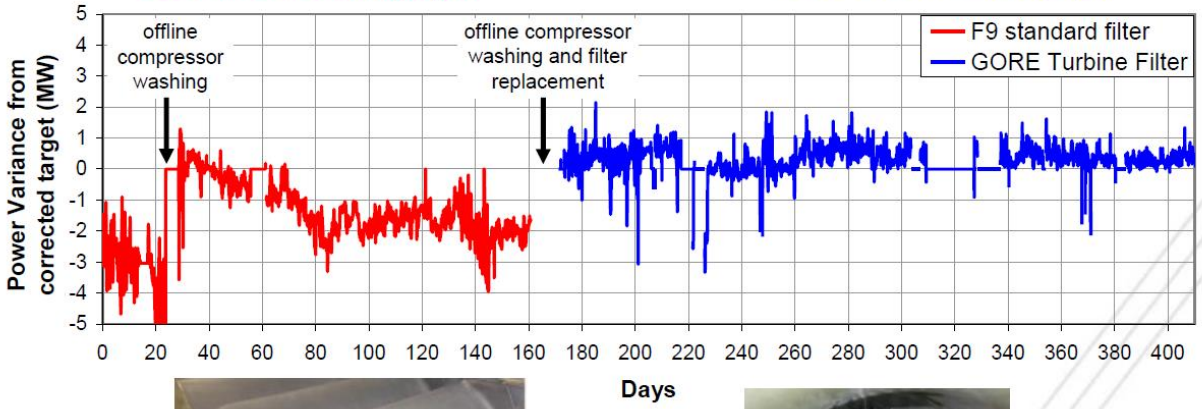
Constant Power Output with Gore Filters
Coastal Power Plant (RB211-30MW) - UK

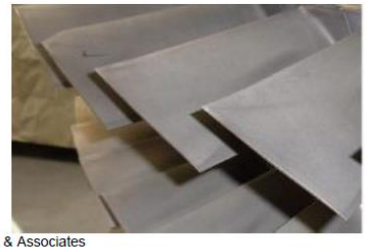
Current Filters

3 off-line washings/yr.

Gore Filters

0 off-line washings/yr.





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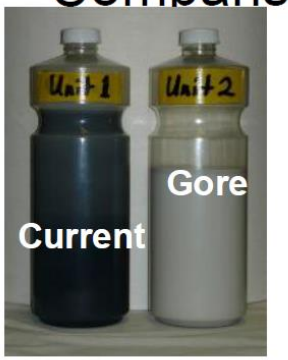
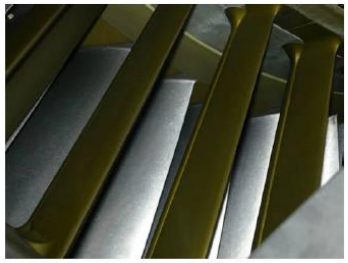
Pulsing Eliminates Off-line Washes (Gore)

Eliminating Off-Line Washes - Confirmed via Boroscope and Wash Water Comparison



End User	Off-line washes/yr with F–Class (MERV) filters	Off-line washes/yr after installing GORE® H12 Turbine Filters
Plastics Mfg. (coastal)	20	0
Brewery (coastal)	17	0
Food	26	0
University	7	0
Ceramics	52	0
Power (coastal)	3	0
Power - Refinery (coastal)	9	0



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Decision Route – Filter Choices

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May 15, 2014	**Gas Intake Filters: HEPA or Medium Efficiency** 101 minutes

InterWebViews™ (Free)

Date	Topic

Intelligence System Key Words

Search Category	Key Words
By Product	Air Intake Filter Bag Filter Cartridge HEPA Filter Panel Filter Pulsing Filter Static Filter
By Company	AAF, Clarcor, Donaldson, GEA, Midwesco, Nederman

Decision Route – filters

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Intelligence system key words

category	keywords
Product descriptor	Bag, HEPA, cartridge, static, panel
Filter suppliers	AAF, Clarcor, Donaldson, Midwesco, Nederman, xxxx
xxxx	xxx
xxx	xxxx