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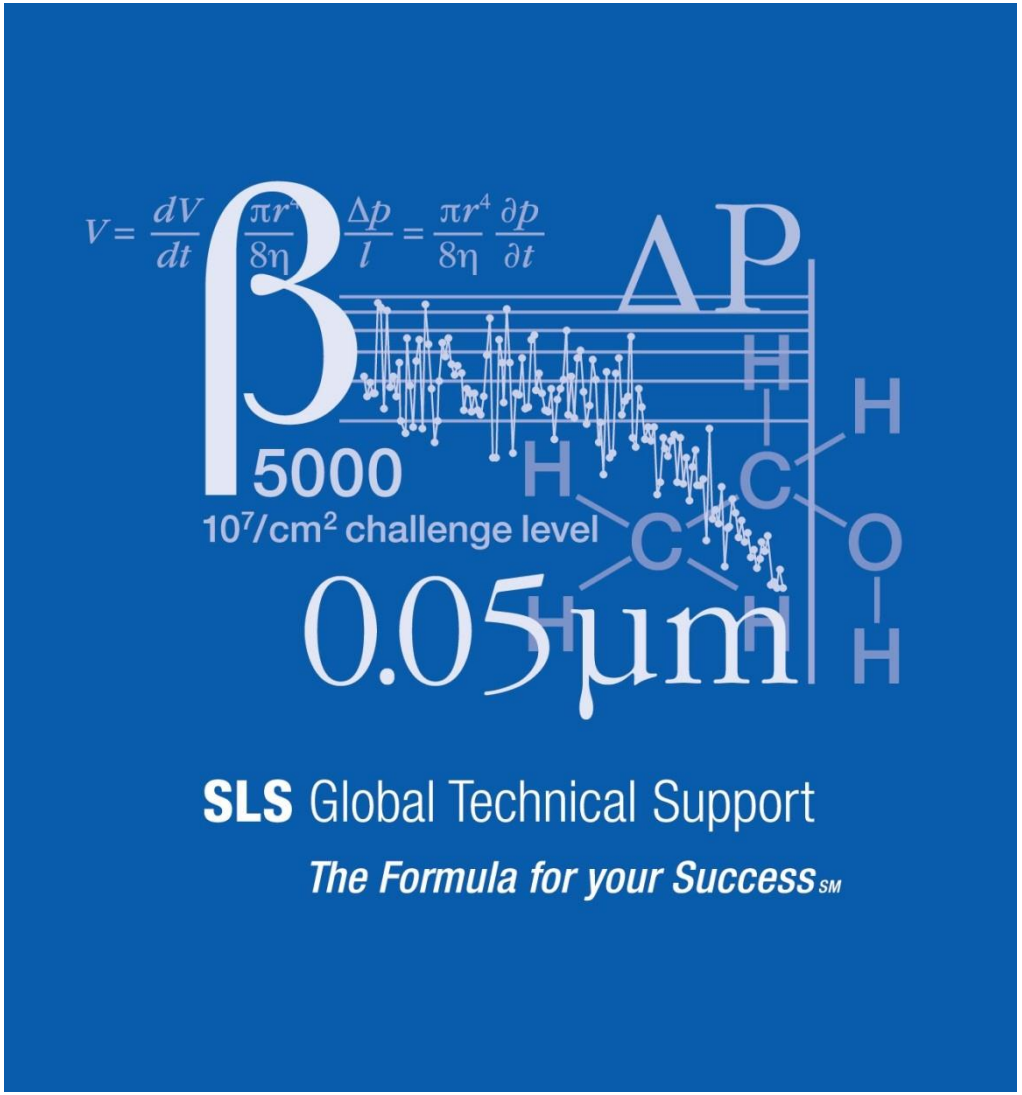

Best Practices in Fuel Supply Chain Cleanliness Management

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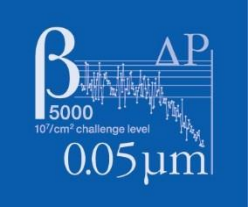
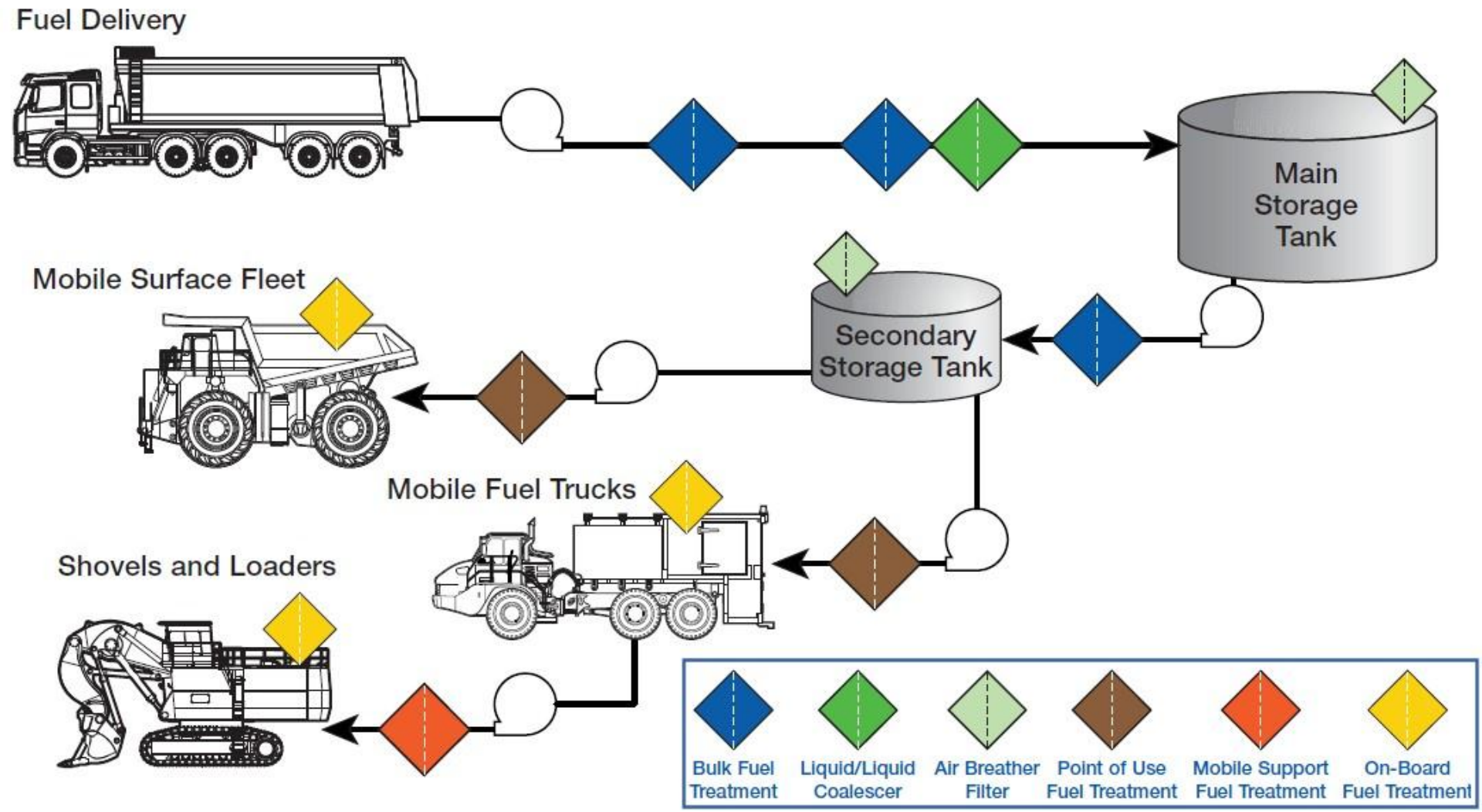


Application Description

Typical Diesel Fuel Supply Chain in Surface Mines



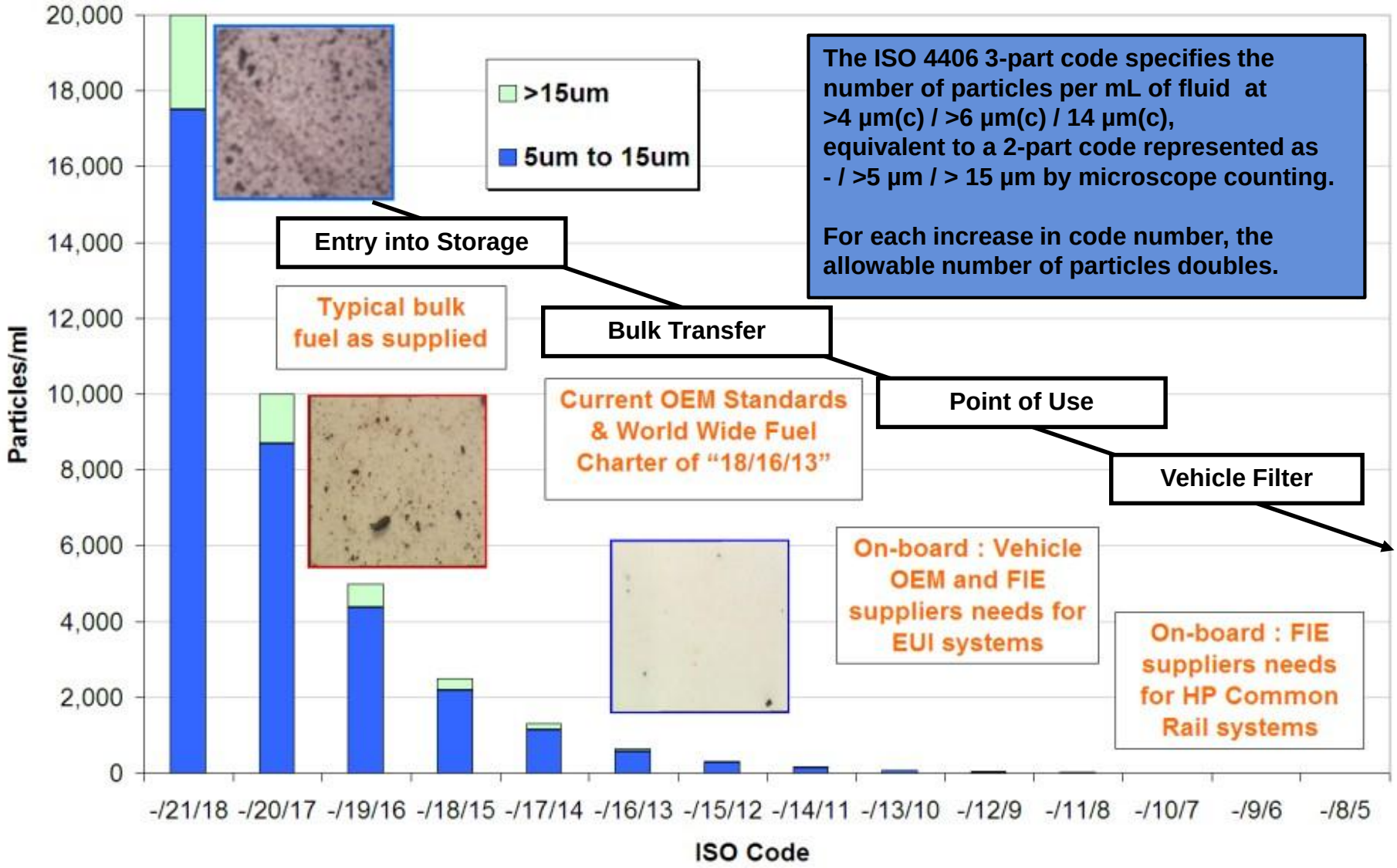
Primary Contamination Challenge

- Fuel cleanliness levels can vary significantly
  - ISO 4406 cleanliness level for incoming fuel up to 22/20/17
    - Roughly equivalent to a gravimetric level of 20 mg/L
  - Depending on geographic location and mode of transportation, incoming fuel can also contain free water
- Over the course of a year, the quantities are significant*:

ISO 4406 Cleanliness Code	22/20/17	20/18/15	18/16/13	12/9/6
Kilograms of particulate contaminant pumped per year	800	200	50	0.4
Water Content (ppm)	**5000**	**1000**	**500**	**100**
Liters of water equivalent pumped per year	250,000	50,000	25,000	5,000

* at 134,000 L/day

Fuel Cleanliness Requirements



Critical Component – Fuel Injectors (High Pressure Common Rail / HPCR)

- On-board fuel injectors are by far the most critical component in the entire fuel supply / delivery chain
  - Modern HPCR fuel injectors require far superior fuel cleanliness levels than older mechanical or hydraulic injection systems
    - Up to 30 times cleaner
  - Reasons
    - Injection pressures as high as 40,000 psi
    - Injector clearances as small as 2 µm
    - Injector solenoid valves operating up to 70 times per second with movements as small as 30 µm

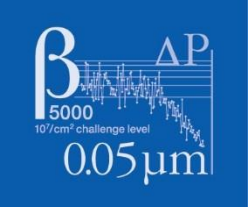
Impact of Inadequate Fuel Cleanliness Levels

- Mobile Equipment Fuel Systems
  - Premature plugging of on-board fuel filter
    - Not meeting scheduled maintenance change-out interval
  - Loss of engine power
  - Injector failure or not meeting OEM life expectation
  - Increase of emissions
    - Soot formation
    - Incomplete combustion
- Lost production

Fuel Injection Equipment OEM Cleanliness Specification

- "Severe" = off-highway vehicles
- Contamination level not to exceed ISO 4406 16/13/8
- Contamination level not to exceed ISO 4406 12/9/7 for <35% of service hours
- No restriction on service hours if fuel cleanliness at point of injection is ISO 4406 11/8/7

Advanced, supplementary filtration technology at bulk and point-of-use locations necessary to ensure these cleanliness levels.



Cleanliness Management Strategies

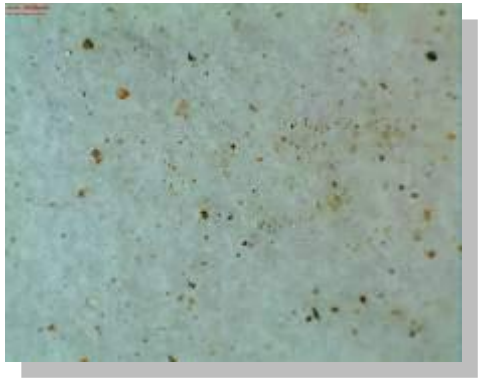
Main Components

- Fuel supply chain audit
  - Assess and document the status quo
- Determine required target fuel cleanliness levels
  - Based on critical points in process
- Select and size the required filtration
- Continuous monitoring and data acquisition
  - Fuel cleanliness
    - Particulate contamination
  - Productivity
  - Maintenance costs

Fuel Supply Chain Evaluation

- The process starts with an audit to understand the current conditions
  - Understand the overall system and how fuel is stored and moved around the site
  - What cleanliness levels are being achieved at various locations around the site?
    - What filtration, if any, is currently used?
  - Assess optimum locations of possible contamination control systems should they be required after the audit

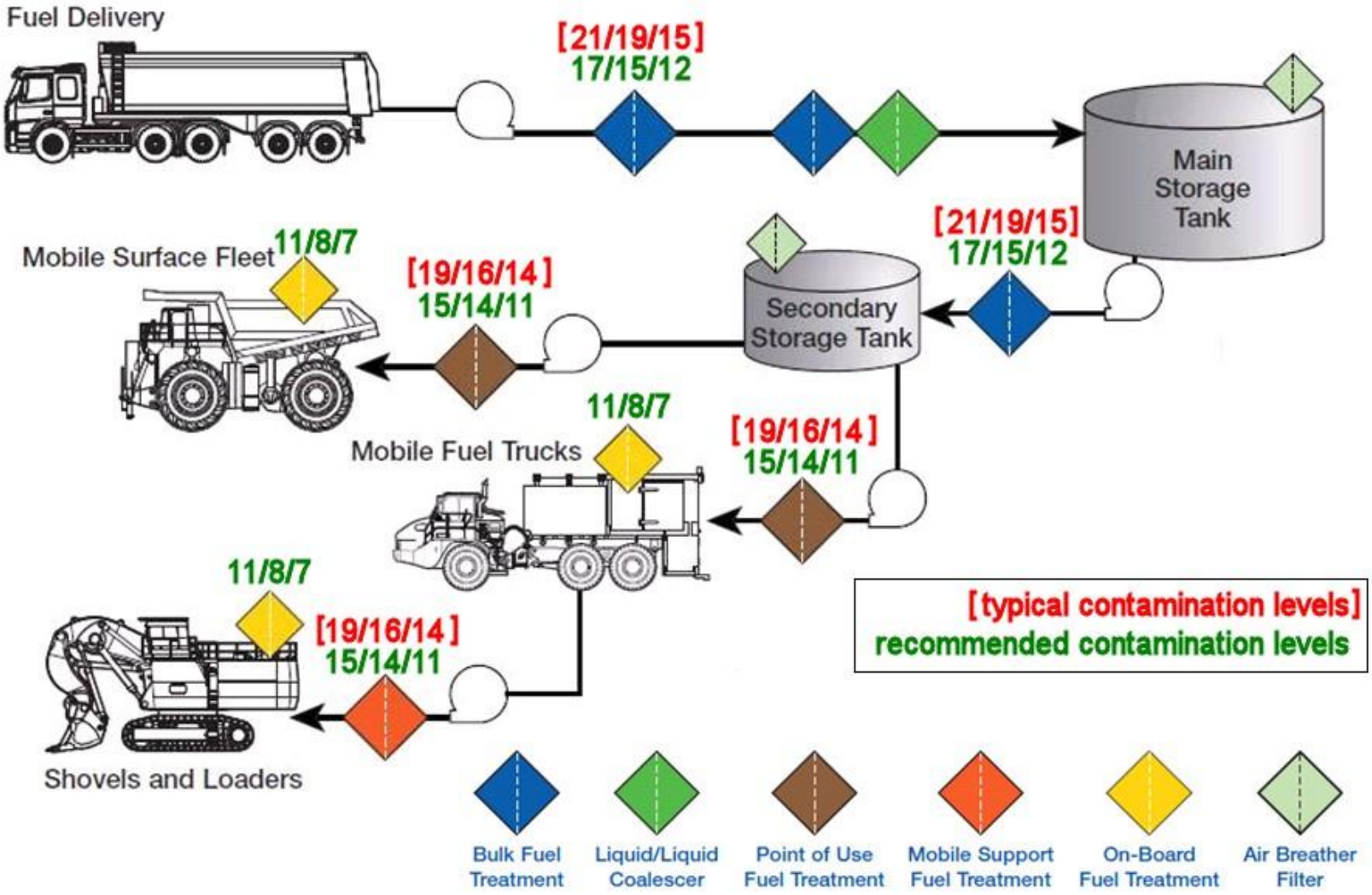
Dirty fuel nozzle



Diesel ISO 20/19/17

Bulk Fuel Filtration

Typical and Recommended Fuel Cleanliness Levels



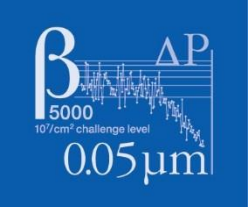
Selecting a Suitable Filtration System

- Filtration systems are key to overall success of maintaining diesel fuel cleanliness
- Proper sizing is critical
  - Single pass application
    - Only one chance to remove contamination
    - Must consider volumetric flow rate and total annual volume processed

Figure 1: Annual Fuel Contamination Mass, kg (lb)*

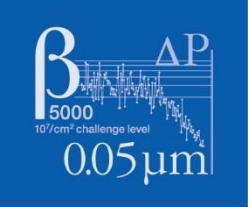
Annual Fuel Consumption, Million Liters (Million US gal)	Delivered Fuel ISO Cleanliness Level			
	23/21/18	21/19/16	19/17/14	16/14/11
25 (6.6)	160 (352.7)	40 (88.2)	10 (22)	1 (2.2)
75 (19.8)	480 (1,058.2)	120 (264.6)	30 (66.1)	4 (8.8)
100 (26.4)	832 (1,834.2)	208 (458.6)	52 (114.6)	6 (13.2)
200 (52.8)	1,664 (3,668.5)	416 (917.1)	104 (229.3)	13 (28.7)
300 (79.3)	2,560 (5,643.8)	640 (1,411)	160 (352.7)	20 (44.1)

* Contamination masses calculated based on mass of ISO FTD.



Conventional Filtration Technology

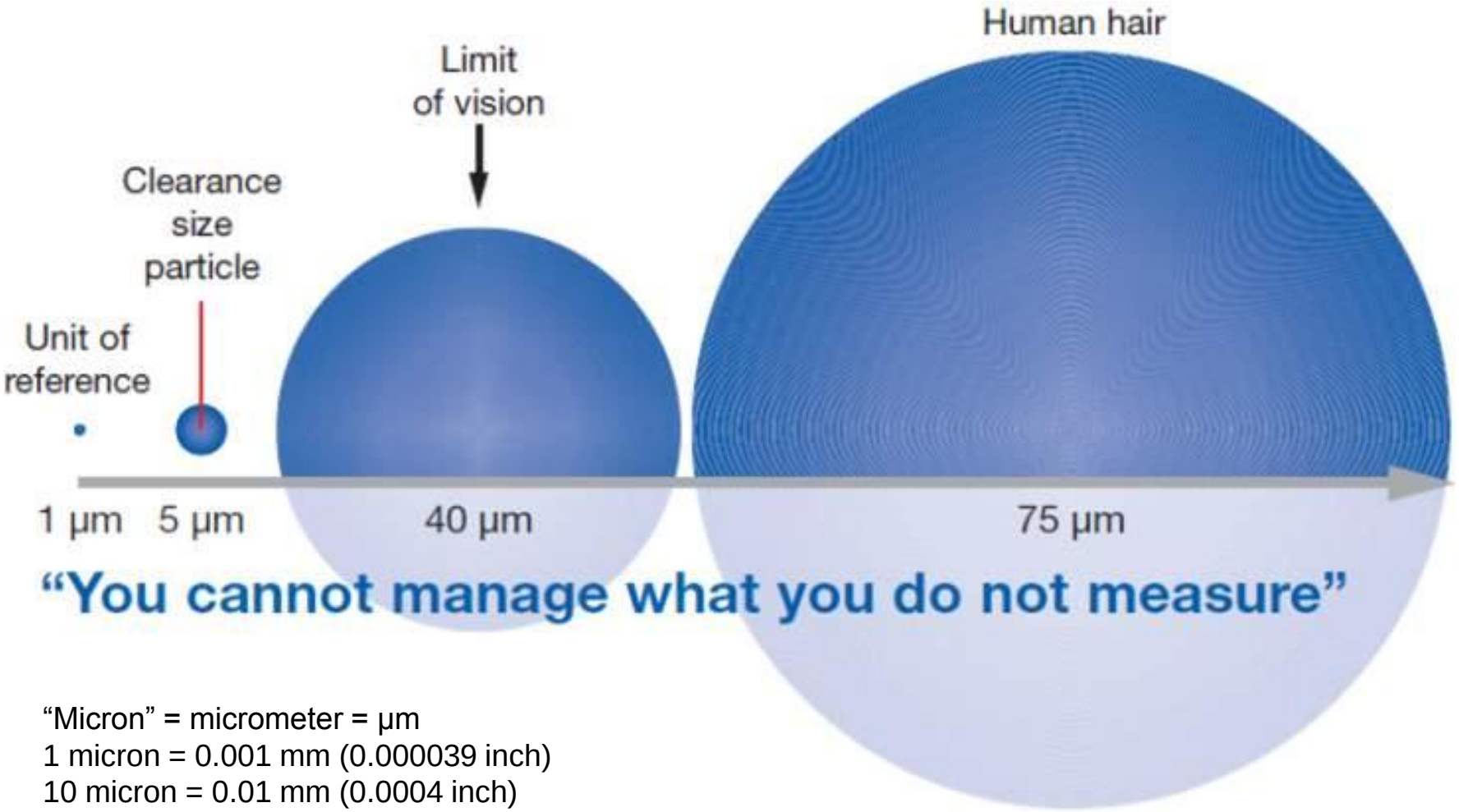
- Conventional bulk fuel filtration installations
  - Filter elements usually constructed with cellulose filtration media
  - Typical filtration ratios:
    - β = 50 (98% efficient) or β = 75 (98.7% efficient) at various micron ratings, ranging from 6 to 40 µm
- Diesel fuel supply chain filtration applications are single-pass, i.e. the fuel only gets filtered once, without recirculation
  - Fuel filtered with conventional filters can still contain significant quantities of particulate contamination
    - Transported down the fuel supply chain



Characteristics of Advanced Filtration Technology

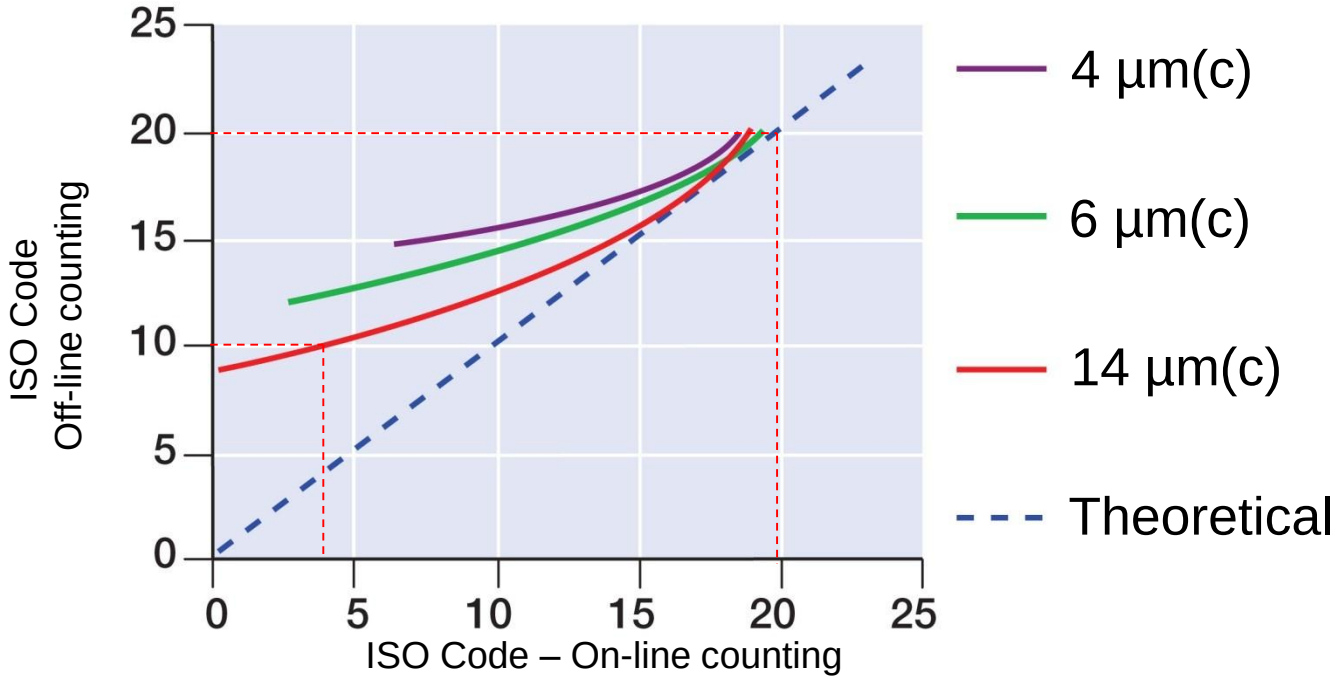
- Superior filtration ratio of β = 1000 (99.9% efficient) at stated micron rating
- Long service life due to
  - Maximized filtration medium surface area
    - Laid-over-pleat construction
  - Synthetic (glass fiber) fiber filtration media

Contamination Measurement



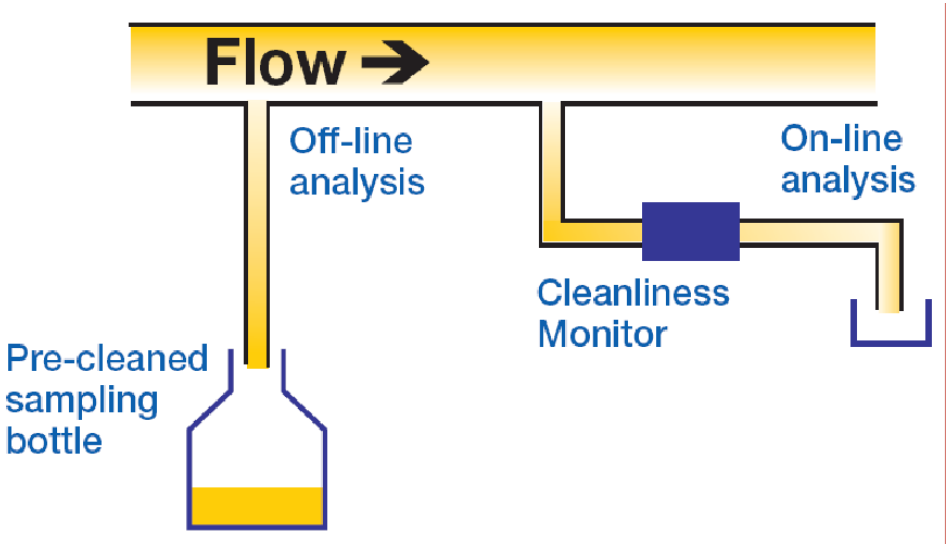
"Micron" = micrometer = µm
1 micron = 0.001 mm (0.000039 inch)
10 micron = 0.01 mm (0.0004 inch)

Comparison of on-line counting and off-line counting



- At higher contamination levels (higher ISO codes) there is little difference between the two methods
- With cleaner oil/fuel, the difference between the two methods increases dramatically

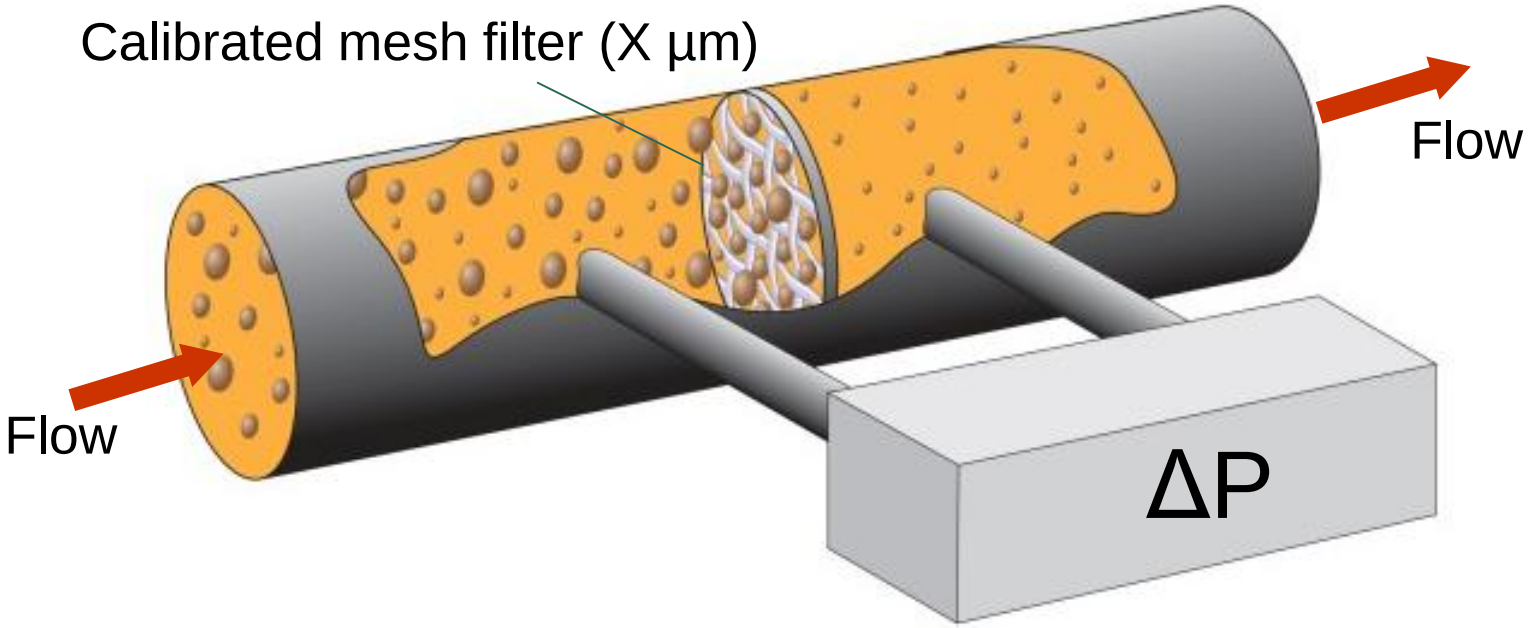
Proper Fluid Sampling



Factors influencing the accuracy of off-line analysis:

- Introduction of environmental dirt into sample bottle
- Incorrect cleaning of sample bottle
- Inadequate flushing of sampling valve
- Effectiveness of sampling process

Mesh Blockage Devices



Method	Units	Operation	Benefits	Limitations
Mesh Blockage	Cleanliness Code	Off-line, On-line	Not affected by fluid opacity, free water or air in fluid sample	Only two particle size ranges

Examples

Example 1 - Coal Mine Point-of-Use Stations

- 10 x 5 µm nominally rated pleated paper filter elements
- Flow rate 100 gpm
- Diesel fuel
- Filled into 200,000 gallon (US) storage tanks
- Typical operating temperature 80 °F
- Change-out at 15 psid differential pressure

- Upgraded original filter elements with high-performance, synthetic filter elements, rated at 7 µm(c)
  - Change-out differential pressure 30 psid
  - More filtration area
  - <u>But:</u> Over 6X the price (per filter element)

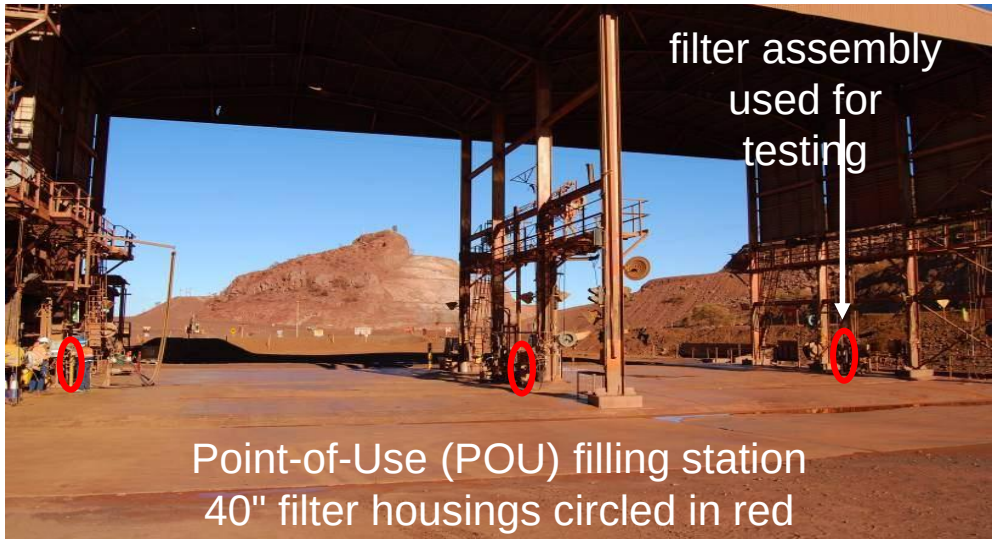
Example 1 – Results

- Upgrade filter elements lasted three times longer
- Annual cost benefit to operator: > $7,000
  - Increased procurement costs by $23,000
  - Reduced operational costs by $27,500
    - Due to higher change-out differential pressure (fewer change-outs)
  - Reduced disposal costs by $2,500
  - Cost savings for fewer maintenance man hours not included
- Improved fuel ISO code from 17/15/11 to 14/12/9

Sampling location	ISO 4406 Cleanliness Code*
Truck off-load	20/18/11
Upstream POU filter assembly	17/15/12
Downstream POU filter assembly	14/12/9

Example 2 – Iron Ore Mine – Application Description

- Surface mine Diesel fuel "point-of-use" filling station
  - Incoming fuel cleanliness typically ISO 4406: 19/17/11
  - Target fuel cleanliness at dispensing nozzle ISO 4406: 16/14/11



Point-of-Use (POU) filling station
40" filter housings circled in red

Example 2 – Results

- 40" pleated filter elements with glass fiber filtration media
  - Filtration grade 5 *µm(c)*
  - Single-pass filtration
  - Flow rate up to 300 *L/min* (80 *gpm*)
  - Field service life: 1 month

Sampling location	ISO 4406 Cleanliness Code
Upstream POU filter assembly	19/17/11
Downstream POU filter assembly	13/7/1

Target cleanliness level: 16/14/11

Example 3 – Gold Mine Diesel Fuel Supply Chain

- Off-load flow rate 400 gpm
  - Incoming ISO cleanliness codes as high as 22/20/13
- Filled into two 200,000 gallon (US) storage tanks
- No Point-of-use (POU) filtration
  - Typical fuel cleanliness codes 20/16/11
    - Indicative of some settling in storage tanks
  - Target fuel cleanliness code 15/13/10

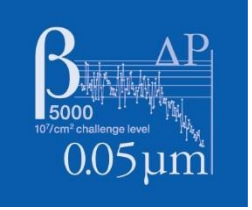
- Installed high-performance, synthetic filter elements
  - Bulk off-load: rated at 12 µm(c)
  - Bulk transfer: rated at 6 µm(c)
  - Point-of-use: rated at 5 µm(c)

Example 3 - Results

- Point-of-use is cleanliness code 14/13/11
- In the first three months of operation
  - ZERO injector failures were experienced
  - Improved service life of on-board fuel filters
    - trucks now meet scheduled service intervals for filter element replacement
  - Improved vehicle reliability
  - Increased production potential from existing fleet

Summary

- Modern Diesel fuel injection systems are very sensitive to particulate contamination and water
  - On-board fuel filters are installed on all Diesel-powered mining vehicles
- Without bulk or point-of-use filtration, service life of the on-board filter elements can vary greatly as a function of the contamination concentration in the incoming fuel
  - Service life of on-board filter elements must coincide with vehicle maintenance/service intervals
- High-performance, point-of-use and/or bulk filtration is recommended to ensure a consistently high fuel cleanliness going into the vehicle's fuel tank



Questions