PALL CORPORATION

The path to net zero carbon with filtration and separation

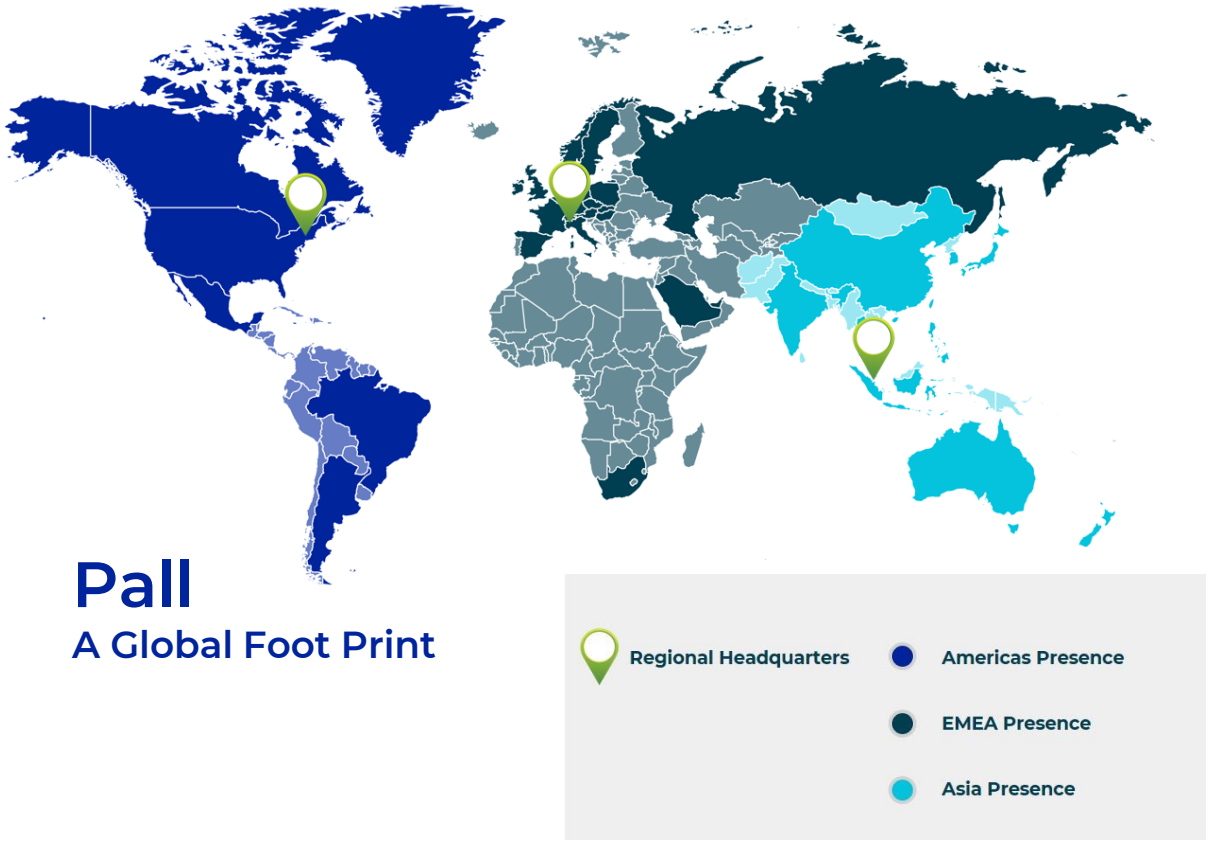
Pall Filtration & Separation Technologies
December 2022

Technical Lead, Carbon Capture: Lara Heberle, Ph.D.
Business Lead, Energy Transition: Paula Flowers

Agenda

- Introduction to Pall
- Intro to CO_2 Capture
- Filtration for Key Processes
- Pall Capabilities
- Summary
- Q&A

Introduction to Pall Corporation



Pall
A Global Foot Print

Pall is a leading global provider in high-tech filtration, separation and purification products

- 10,000 employees
- 35 countries, 90 offices globally
- Subsidiary of Danaher
  - Proven Partners
  - Focused Expertise
  - Holistic Approach

Pall: Delivering high performance filtration and separation solutions

Increase asset life ◆ Improve asset reliability and productivity ◆ Achieve high quality products

PALL CORPORATION

Pall
A Legacy of Innovation

1946
Dr. David Pall starts his own business based on a product he invented – porous stainless steel.

1959 – 1960s
Pall begins to develop filters for the airline industry and military aircraft.

1960 – 1970s
Pall successfully supports the U.S. manned space program. In 1969 a Pall product regulated the temperature inside astronaut Neil Armstrong's spacesuit.

1979
Pall developed a new filter to clean up radioactive water for the Three Mile Island disaster.

1980s
Leukocyte reduction filters developed for safer blood transfusions

1990
Dr. Pall awarded National Medal of Technology by President George Bush.

2015
In 2015 Pall joined the Danaher family. We learned about DBS and began our ability to focus increasingly on growth and innovation.

2020
Pall plays a critical role helping organizations scale-up and make large-scale manufacturing of a COVID-19 vaccine a reality.

Activities in the Energy Sector

Traditional Markets

Upstream
- O&G production
- Shale gas

Midstream
- Pipeline
- Compression station
- Gas processing & treatment
- LNG / FLG

Downstream
- Refinery
- Petrochemical (Ethylene)
- Fine Chemical

Plastic & Polymer
- PVC / PVDF
- Final Products

Energy Transition Markets

Carbon Capture
- **Capture**
- **Transportation**
- **Storage**
- **Utilization**

Hydrogen
- Blue Hydrogen
- Green Hydrogen
- Gray Hydrogen

Biofuels
- Bio-refineries
- Bio-sourced chemicals
- Biogas

And more!
- **Plastic Recycling**
- **Energy Storage**

Why CO_2 Capture, Utilization, Storage (CCUS)?

From the mid-20th century to present day, CO2 emissions per year have grown from 6 billion tons to over **35 billion tons, causing global climate shifts.**

To mitigate the worst effects of climate change and limit temperature increases to <1.5℃ as specified in the Paris Agreement, **CO_2 capture, utilization, and storage (CCUS) is seen as an essential strategy.**

To reach this goal, emissions must be reduced by 45% by 2030, and reach net zero by 2050.
Net zero emissions require CCUS capacity to grow by 140x compared to 2020 levels.

Source: Global CCS Institute, 2020

2020
40 Mtpa

2050
Need 5,635 Mtpa

CCUS economics are highly location-dependent

Market is primarily driven by environmental regulations linked to carbon trading and credits. Different regions take different approaches.

Location	USA	Canada	EU / UK	China	Japan	Middle East	Australia
National tax credits, trade systems	USA Inflation Reduction Act: $85/ton capture, $130/ton capture and storage, $180/ton DAC	50-60% tax credit for capture facilities in 2022	EU ETS emission caps: credits trading at $105 USD/ton in 2022, 2050 net-zero goal	ETS cap for coal plants in 2021: trading at $8/ton, projected to increase			2021 Australian Carbon Credit Units (ACCU)
National investment	$12B CO2 funds in 2022 infrastructure bill; $14M DAC FEED funding 2022	$8B net zero accelerator fund in 2022	EU $38B innovation fund, Netherlands $13B SDE++ scheme	CCS in 5-year development plan	$10B decarbonization fund in 2021	$10.4B Saudi carbon capture fund, 2021	Federal initiatives: $3.5B (e.g. Global CCS Initiative)
Regional, Private Investments and Voluntary Markets	California LCFS, Net-Zero corporate commitments e.g. Microsoft, United	Alberta $1.2B funding through 2025	UK CIF $1B project investment for 4 regional hubs			Saudi Arabia, UAE, Egypt carbon trading exchange	
EOR*/Utilization	Yes – EOR*	Yes – EOR*		Yes – EOR*		Yes – EOR*	Yes – EOR*

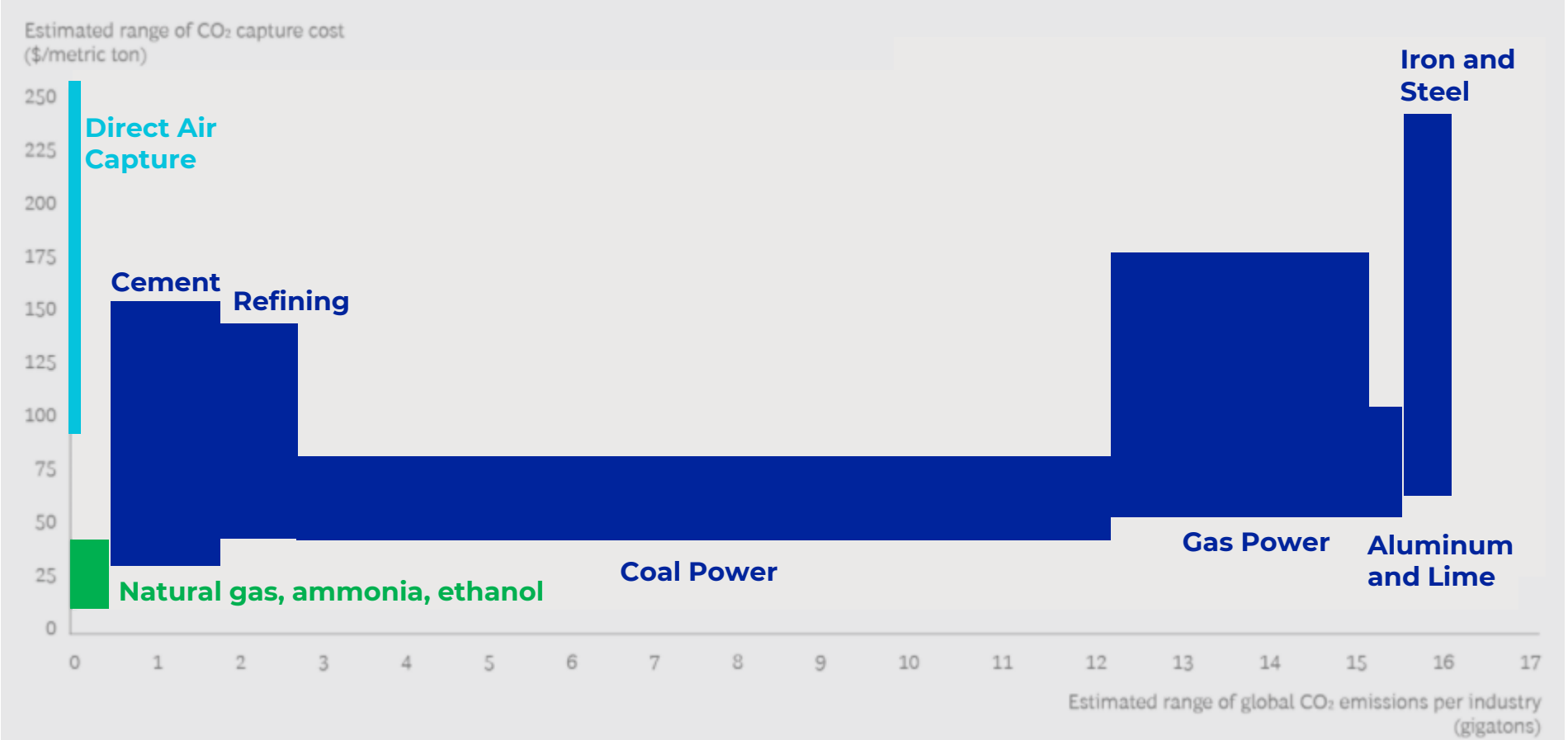
*EOR enables up to 40% more oil to be extracted

Capture costs and project viability vary by industry

Low hanging fruit
- Often high CO2 concentration
- On-spec products
- < $40/ton

Current commercial projects target high emitters
- $30-250/ton
- Costs depend on CO2 content and retrofit needs

Several commercial projects, continued R&D
- >>>$90/ton due to low CO2 in air
- Potential for negative emissions



CO_2 Value Chain

Industrial Segments

Post-Combustion

Industrial combustion (e.g. refining, iron/steel, ethylene)

Flue gas → Capture

Pre-Combustion (Connection to Blue Hydrogen)

Natural Gas

Coal

→  Gasification, SMR → Syngas → Capture

Oxy-combustion (not shown, CO2 is captured during the combustion process)

Direct Air Capture (DAC)

Atmosphere → Air → Capture

Capture Methods

- Absorption
- Membrane
- Adsorption
- Chemical Looping
- Cryogenics

Transportation, Storage, Utilization

Bulk Transport

Compression

Pipelines

Storage

Underground storage

Utilization

Fuels and chemicals production

Building materials (e.g. cement)

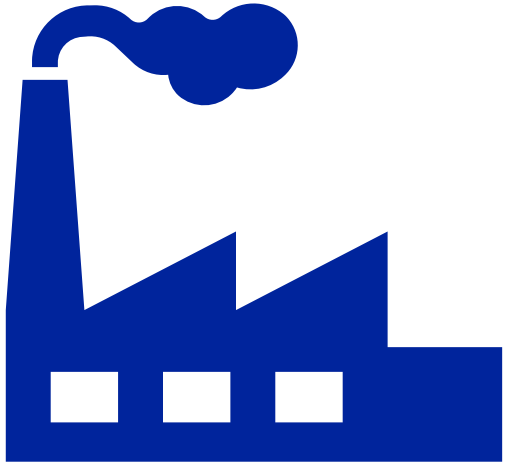
Beverage carbonation

Urea/Fertilizer production

Enhanced oil recovery (EOR)

Challenges in CO_2 capture

Where can filtration and separation help you?



Upstream

Feed can contain **particulates, mercury, heavy metals, organics**.

Such contaminants can cause absorption system foaming, blockages, and reduced efficiency.

Downstream

Outlet CO_2 stream can contain **water**, which corrodes downstream equipment.

Remnant **particulates** can hinder storage and utilization.

CO_2 Separation System

The overall capture efficiency and performance depends on how the specific system operates. We'll review filtration solutions for absorption and adsorption systems in the next few slides.

Solvent-based (absorptive) carbon capture is the current dominant technology

Industrial Segments

Post-Combustion

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Bulk Transport

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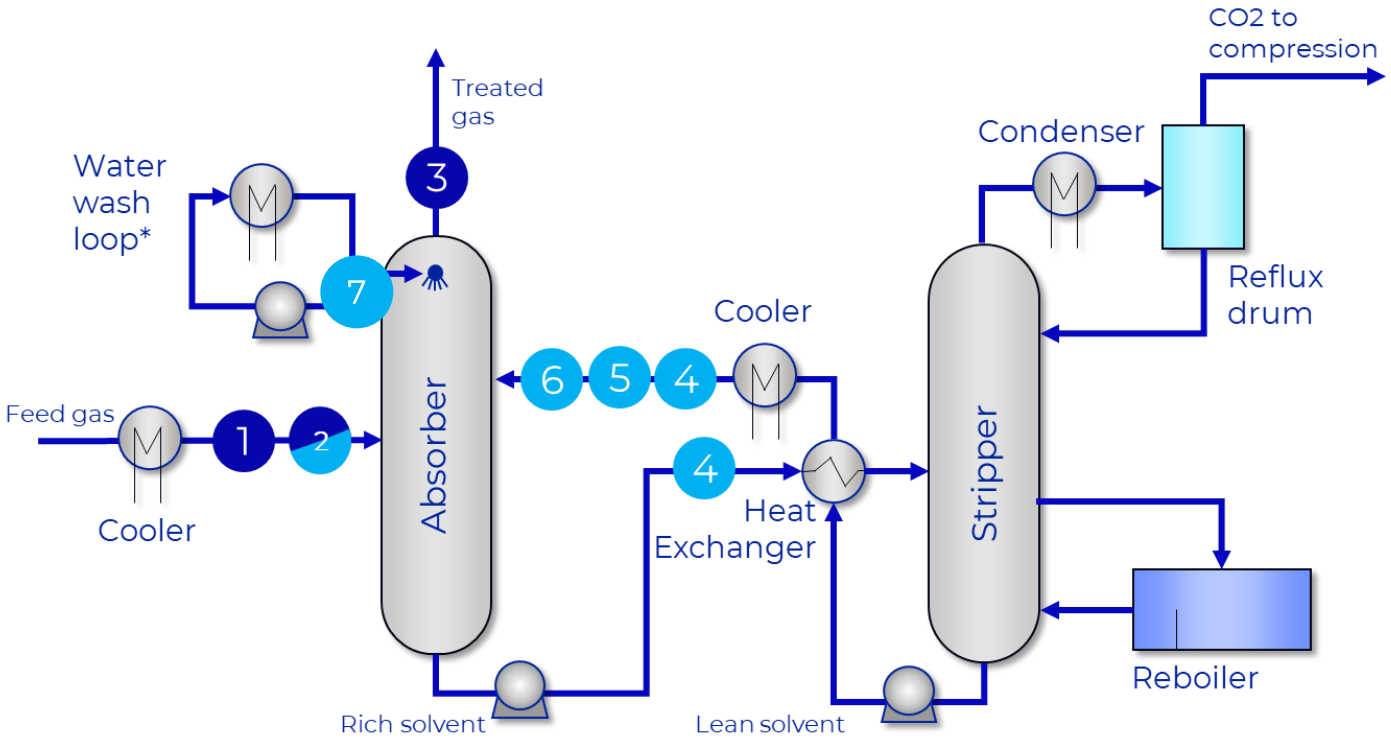
Storage

- Underground storage

Utilization

- Fuels and chemicals production
- Building materials (e.g. cement)
- Beverage carbonation
- Urea/Fertilizer production
- Enhanced oil recovery (EOR)

Pall has many opportunities in absorption processes



#	Customer Need	Pall Solution
1	Bulk particulate removal from dry gas feeds*	Regenerable gas-solid filter
2	Remove contaminants on inlet gas**	L/G coalescer
3	Prevent amine carry over on absorber outlet	L/G coalescer
4	Remove solid contaminants from solvent loop	High-efficiency particle filter
5	Remove organics, degradation products to reduce foaming	Micro-carbon filter
6	Prevent activated carbon fine carry-over in solvent loop	High-efficiency particle filter
7	Remove solids in water wash loop / sooty quench water	Hollow Fiber

Legend

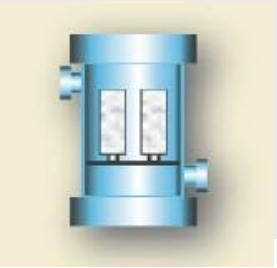
In Development **Existing Products**

* for power gen and FCC units, flue gas feeds
** for oil and gas or LNG, sour gas feeds

Recommendation for solids filtration in absorption

Pall Recommendation:

Absolute particulate filters on the feed, compressor lube oil, solvent (rich side preferred), dehydration glycol, outlet gas



Particle Filter

= removal of solids

Goals:

1. On feed, remove corrosion products, flue gas fines, salts, ammonium nitrates from upstream NOx removal
   - Prevent operation issues, improve CO2 separation efficiency, prevent foaming in contactor tower
2. Prevent fouling and corrosion of heat exchanger, recirculation pumps reboiler
   - Reduce energy consumption, avoid maintenance issues
3. Clean up outlet gas
   - Improve final CO2 purity, increase storage efficiency, protect downstream equipment

Recommendation for aerosol removal in absorption

Pall Recommendation:

High efficiency **Liquid/Gas coalescer** on feed inlet and outlet to remove entrained free liquid aerosols (and solids)

Liquid/Gas Coalescer

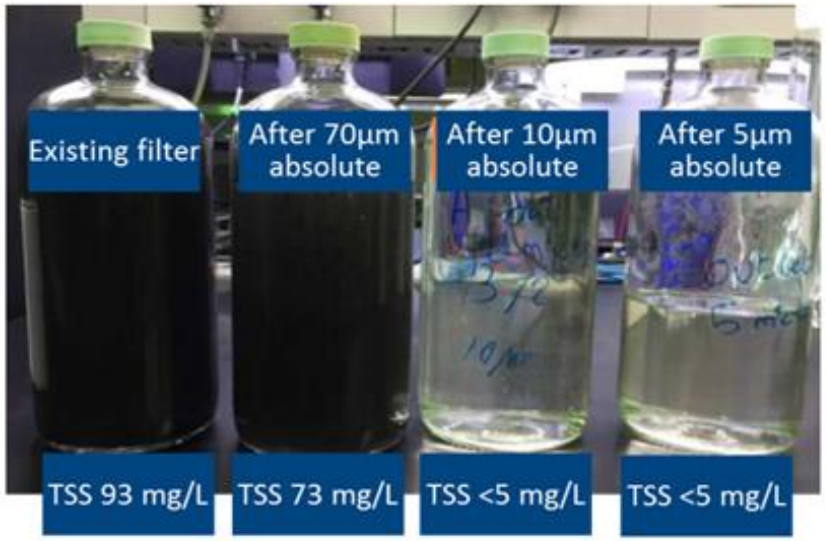
= separation of solids & liquids from a gas stream

Goals:

1. Remove contaminants (particulate matter, hydrocarbons, glycol, organic acids) in feed gas
   - Reduce Foaming,
   - Reduce Corrosion rates, reduce formation of heat stable salts
   - Prevent reduction in gas treatment rates
   - Debottleneck solvent loop
2. Reduce solvent carry-over
   - Reduce solvent losses, reduce corrosion downstream, protect downstream equipment (mole sieve drier, MRU)

Pall has a proven record in solvent filtration

Amine (solvent) filter retrofit case study



Visual comparison of filtered solvent samples

Operational Problems

- 5 micron rated cartridge filter, 10 mg/L solids spec
- Foaming experienced resulting in **15% capacity drop**

Pall Solution

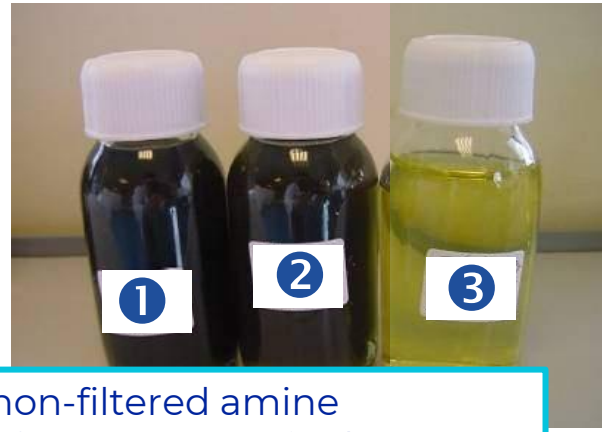
- Adaptor cages to fit **standard, absolute rated** cartridges
- Gradual solvent clean-up down to 5 ppm solids, foaming stopped

<1 month payback

20% of Capex for new housings

$47,000 lower yearly filter spend

Black Powder deposits in a heat exchanger



❶: non-filtered amine
❷: after 10µm nominal
❸: after 10µm absolute filter

Membrane-Based Carbon Capture is an emerging area

Post-Combustion

Industrial combustion (e.g. refining, iron/steel, ethylene)

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Capture Methods

- Absorption
- **Membrane**
- Adsorption
- Chemical Looping
- Cryogenics
- Electrochemical

Transportation, Storage, Utilization

Bulk Transport

Compression

Pipelines

Storage

Underground storage

Utilization

Fuels and chemicals production

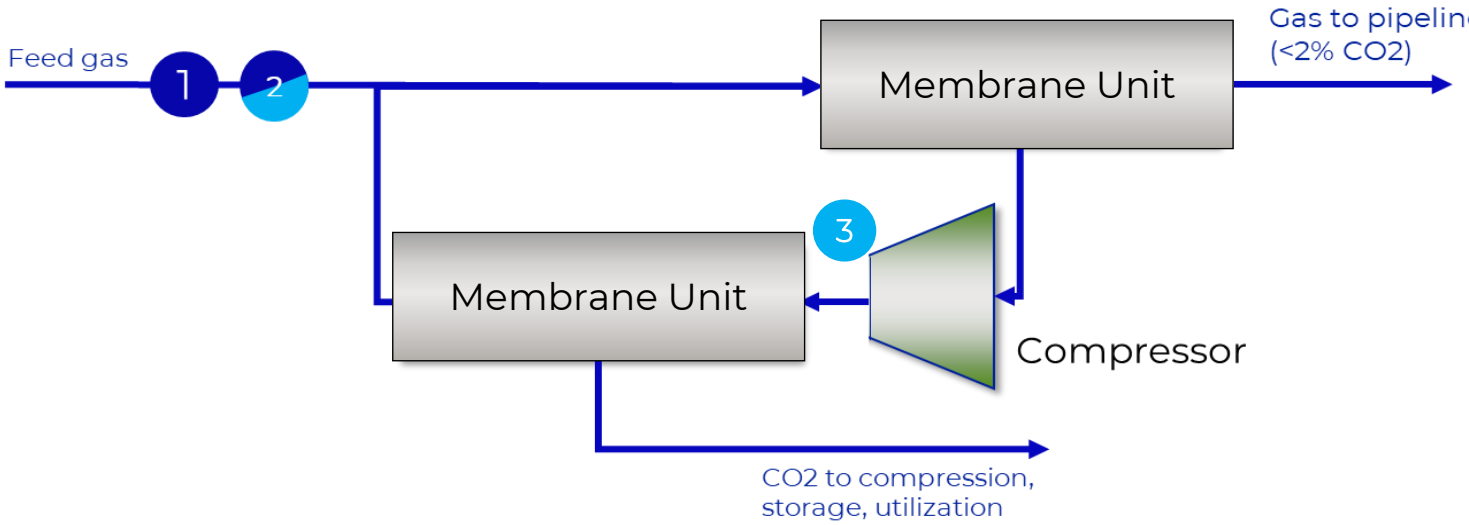
Building materials (e.g. cement)

Beverage carbonation

Urea/Fertilizer production

Enhanced oil recovery (EOR)

Pall can protect your membrane processes



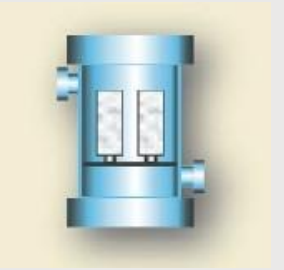
#	Customer Need	Pall Solution
1	Bulk particulate removal from dry gas feeds	Regenerable gas-solid filter
2	Remove contaminants on inlet gas	High efficiency L/G coalescer or particulate filter
3	Prevent lube oil carry-over, protect membrane	High efficiency L/G coalescer

Legend

In Development **Existing Pall Products**

Membrane protection is highly recommended

Pall Recommendation:
SepraSol™ LG Coalescer



LG Coalescer
= removal of solids & Liquids

Membrane Contactors: H2 & CO2 Membranes

- Membrane contactors very sensitive to liquid and solid contaminants even at very low levels
- Improved membrane life & throughput maintained
- New & Existing Plants
- Plant Debottlenecking
- Typical position :
  - Membrane contactor Inlet. Usually High efficiency LG, AC Bed and Dust filter is specified by licensor.

CO2 Membrane Protection
Eromanga Basin, Australia

Cryogenic Carbon Capture is another emerging area

Post-Combustion

Industrial combustion (e.g. refining, iron/steel, ethylene) → Flue gas → Capture

Pre-Combustion (Connection to Blue Hydrogen)

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- **Cryogenics**
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Transportation, Storage, Utilization

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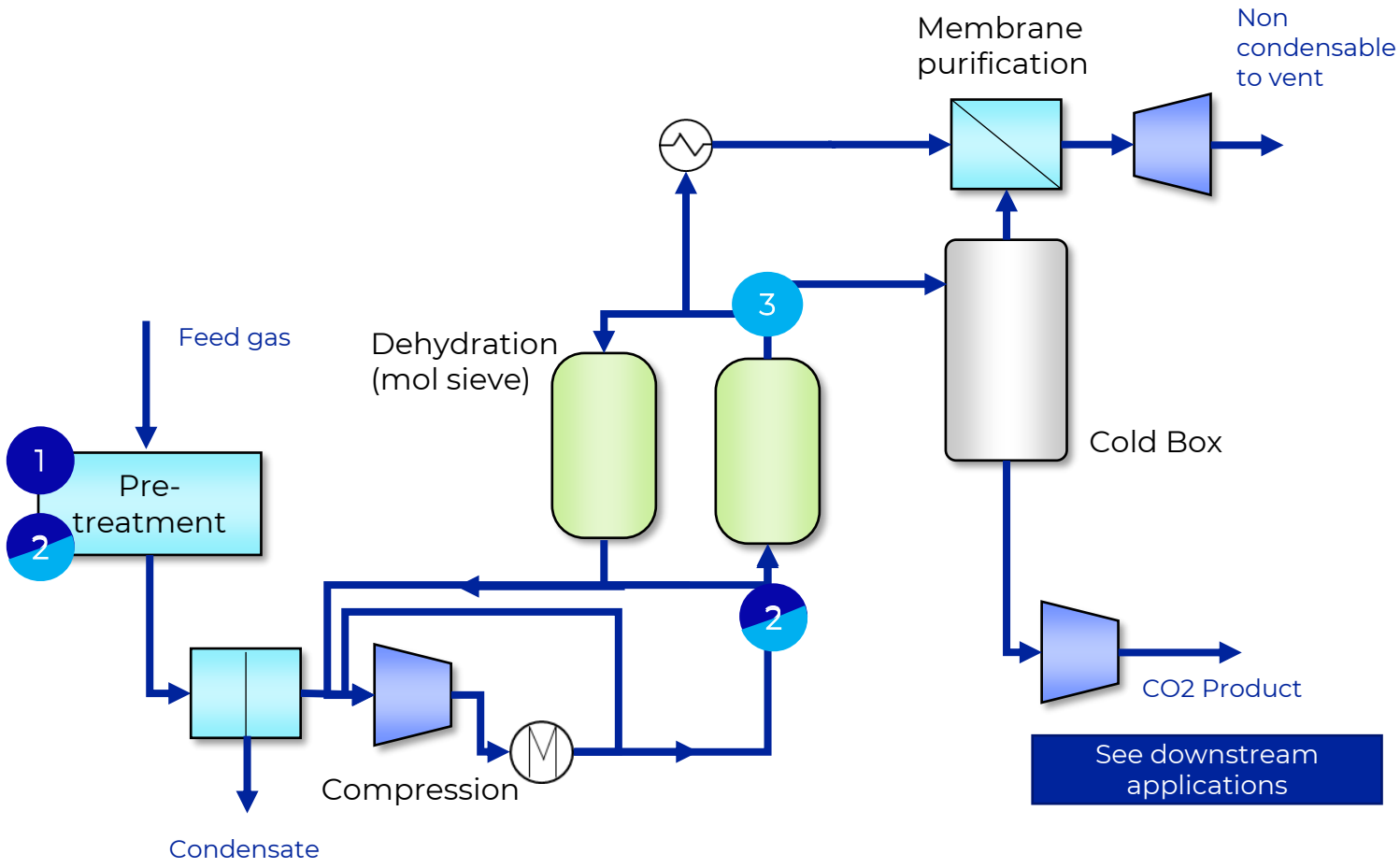
Storage

- Underground storage

Utilization

- Fuels and chemicals production
- Building materials (e.g. cement)
- Beverage carbonation
- Urea/Fertilizer production
- Enhanced oil recovery (EOR)

Filtration and separation can protect your cryogenic capture equipment



#	Customer Need	Pall Solution
1	Bulk particulate removal from dry gas feeds	Regenerable gas/solid filter
2	Remove contaminants on inlet gas	L/G coalescer
3	Cold box protection, mol sieve adsorbent fines removal	L/G coalescer or particulate filter

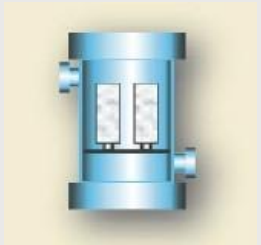
Legend

NPD **Existing Pall Products**

Coalescers and filters recommended for adsorbent beds

Pall Recommendation:

Liquid/Gas coalescer on feed and Dust Filters on outlet gas



Liquid/Gas Coalescer

= separation of liquids from a gas stream

Particle Filter

= removal of solids

Goals:

Remove free water, amine or liquid hydrocarbons

- ➢Extend adsorbent life

Remove contaminants that increase dP.

- ➢Keep process efficiency high, prevent channelling / bypass.

Keep adsorbent bed fines from passing downstream

- ➢Prevent erosion & fouling in downstream equipment and piping
- ➢Protect cold box (where installed e.g. LNG)

Degraded adsorbent beads - Photo courtesy of CECA

Case Study: Molsieve

Problem:
Presence of residual liquids upstream molsieve drier

Issues:
- Frequent bed regeneration (higher energy use)
- Gas mal-distribution (channeling)
- Premature drier bed replacement
- Fouling of downstream equipment

Solution:
1. High efficiency L/G coalescer on wet gas
2. Absolute rated dust filter on dry gas

Benefits:
- Extend life of adsorbent beds (best practice > 4 years)
- Eliminate 1 week shutdown & loss of revenues for premature absorbent replacement

Old separator removed

Post Drier Dust Filter

Replaced by Pall LG coalescer

Storage and utilization are needed for every capture technology

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Transportation, Storage, Utilization

Bulk Transport

Compression

Pipelines

Storage and Injection

Underground storage

Enhanced oil recovery (EOR)

Utilization

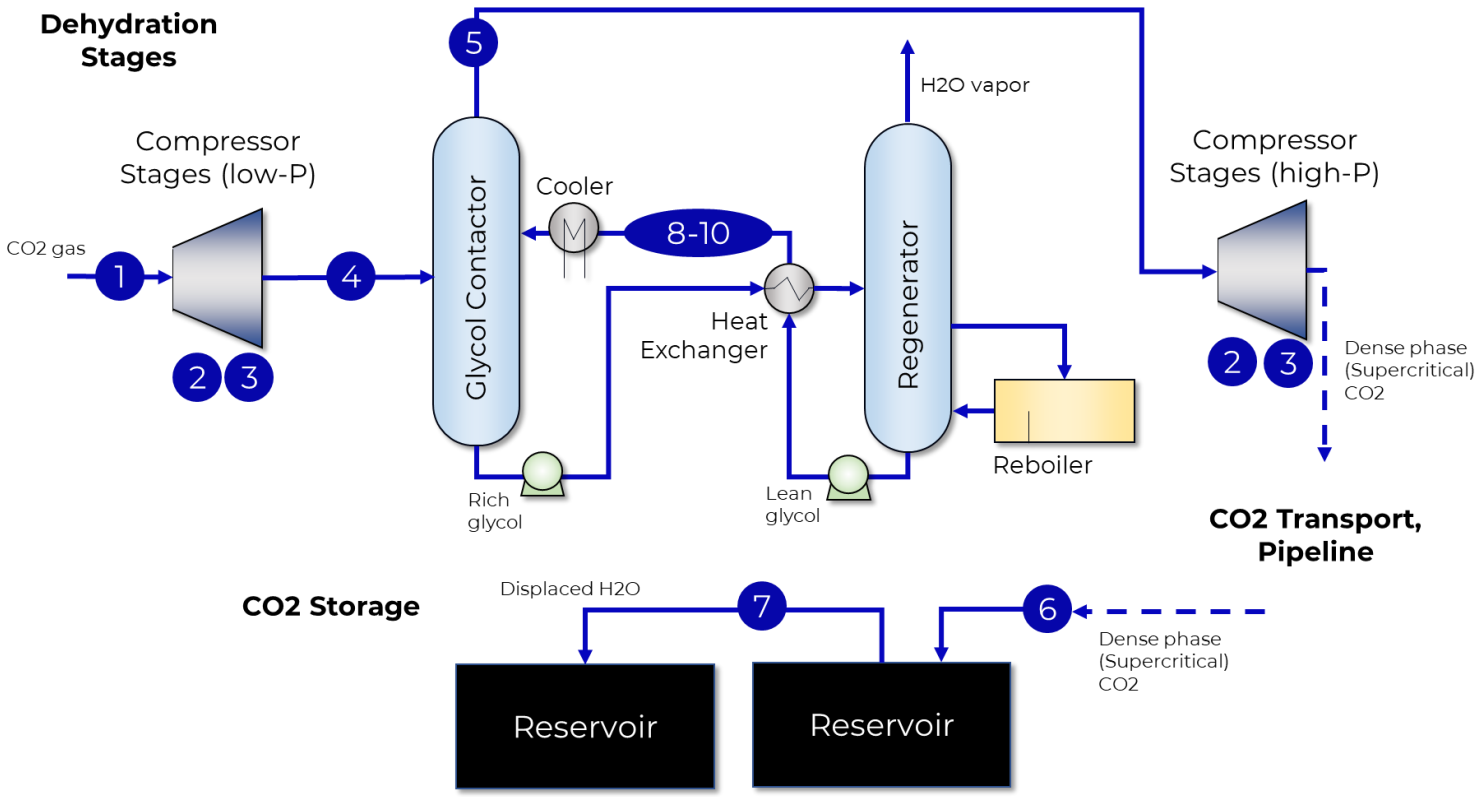
Fuels and chemicals production

Building materials (e.g. cement)

Beverage carbonation

Urea/Fertilizer production

Pall's current product slate is ready to protect your downstream processes

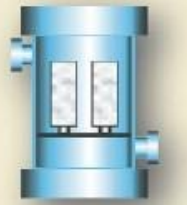


#	Customer Need	Pall Solution
1	Compressor protection	L/G coalescer
2	Remove solid contaminants from lube oil	Particulate filter
3	Prevent compressor cavitation (depends on compressor)	Vent filter
4	Prevent lube oil carry-over to TEG dehydration loop	L/G coalescer
5	Remove solvent carry-over, protect compressor	L/G coalescer
6	Prevent reservoir fouling – supercritical CO2	Particulate filter
7	Prevent reservoir fouling – displaced H2O	Particulate filter
8-10	See applications 4-6 on solvent absorption diagram	

Liquid is compressed for easy transportation and storage. Compression and storage needs are across all CO2 industries.

Compressor protection is a crucial element of downstream CO_2 processing

Pall Recommendation:
SepraSol ™ Plus LG Coalescer



LG Coalescer
= removal of solids & Liquids

Problem: 500kg salt built up in 6 months resulting in compressor trip

SLS test revealed 1,860 ppmw water & salts measured in inlet gas.

Solution: New LG Coalescer installed with 110 SepraSol™ Plus Coalescer elements and pre-separation

45 barg operating pressure

363,000 kg/hr flow

Offshore North Sea

Particulate filters protect pipelines and ensure on-spec CO_2

Pall Recommendation:
Coreless or MCC1401 Dust Filter

Particulate filter

= removal of solids

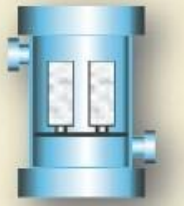
Gas Transmission Pipeline

Goals:
Remove particulate matter such as pipe scale and corrosion products to protect metering, control valves compression stations, and ensure product quality to customers.

#600 Coreless Filter, UAE
36” NB Pipeline, 700 mmscfd, 60 bar g

Pall has experience with dense phase CO_2 filtration

Pall Recommendation:
Ultipleat® High Flow Particle Filter



Particulate filter
= removal of solids

CO_2 Injection for underground storage

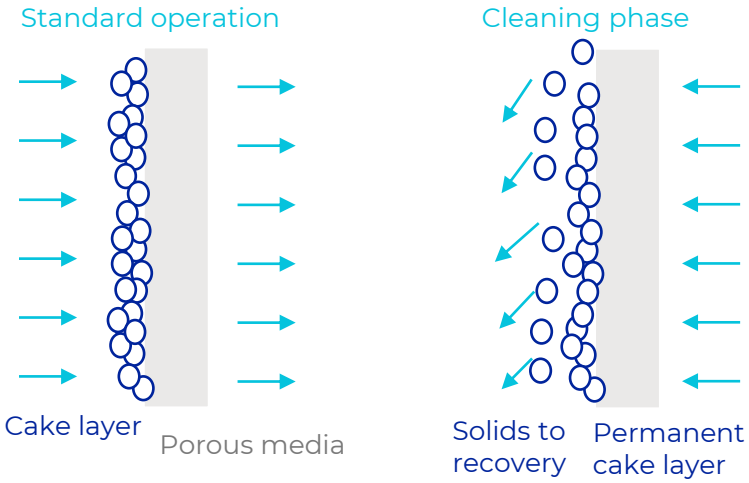
Goals:
Remove particulate matter such as pipe scale and corrosion products from pipeline to protect reservoir from fouling.

Note:
High pressure / dense phase CO_2 behaves differently – between gas and liquid.

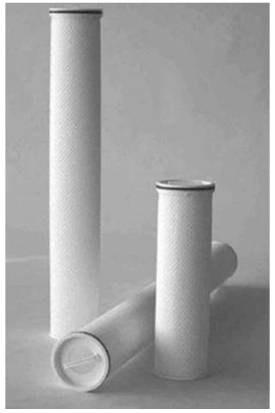
Ultipleat® HighFlow filters

Overview: Pall's filtration technologies

Particle filters




Range of layouts

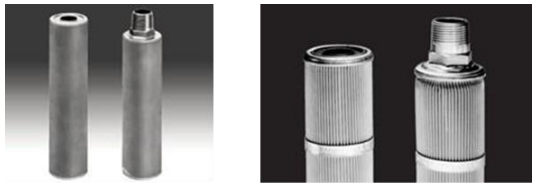

High Flow formats


Coreless formats


Ceramic filters


Hollow Fiber filters


Polymer and Fluoropolymer filters

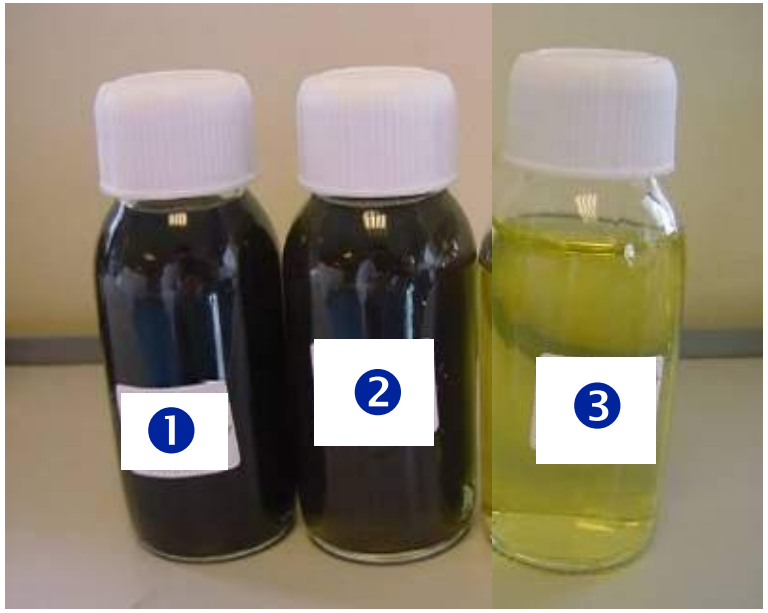

Metallic filters

Robust, self-cleaning systems for high contaminant loading and long life

Available in absolute removal ratings of 0.1 to 100 microns and for a wide range of compatibility with corrosive fluids and varying temperatures

Pall Absolute vs Nominal Filter Ratings

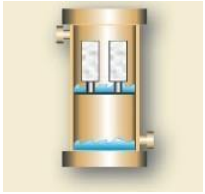
The Pall Standard – quality, quality, quality



❶: non filtered amine
❷: after 10µm **nominal** filter
❸: after 10µm **absolute** filter

- **Absolute** = **tested** efficiency, according to industry standards (e.g ISO 4572)
- **Nominal** (non-absolute) = filter not tested, **arbitrary** removal rating given by manufacturer, based upon weight percent removal, not reproducible
- Typical problem with nominal filters: particles larger than the claimed removal rating **pass through**

Overview: Pall's liquid/gas coalescers



Liquid / Gas Coalescers

Not all technologies can separate the finest liquid droplets (aerosols) to **avoid liquid carry-over**

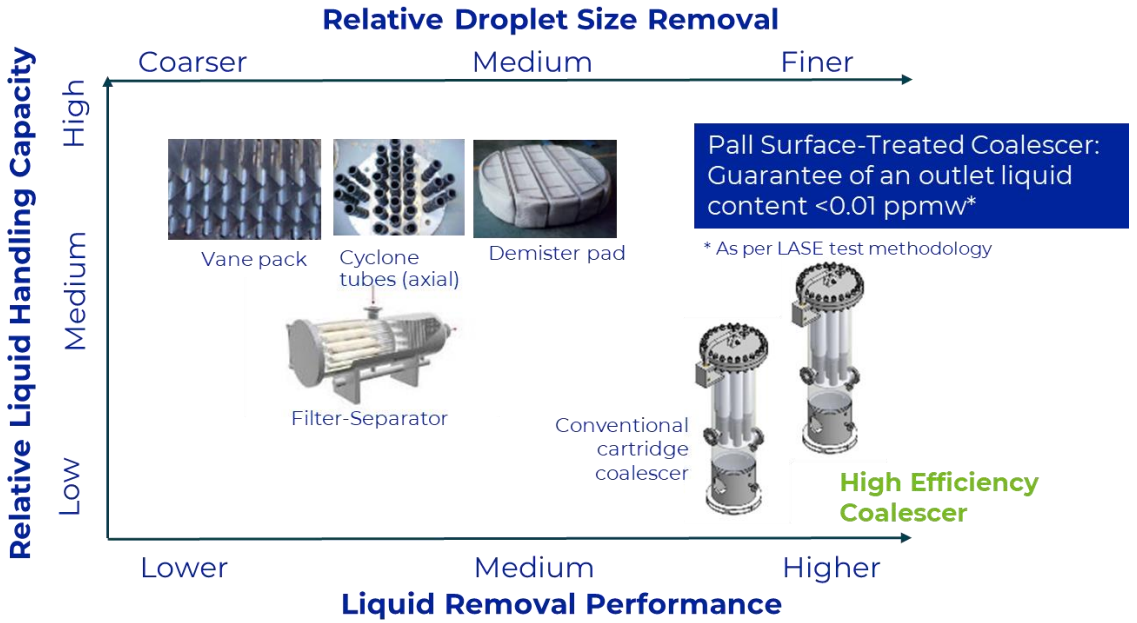
SepraSol™ and SepraSol™ Plus

Solid removal rating (gas) 0.3 µm (99.99%)
Temperature rating 82°C (65°C water)
Liquid removal level (LASE) 0.003-0.01 ppmw

Medallion™ and Coreless

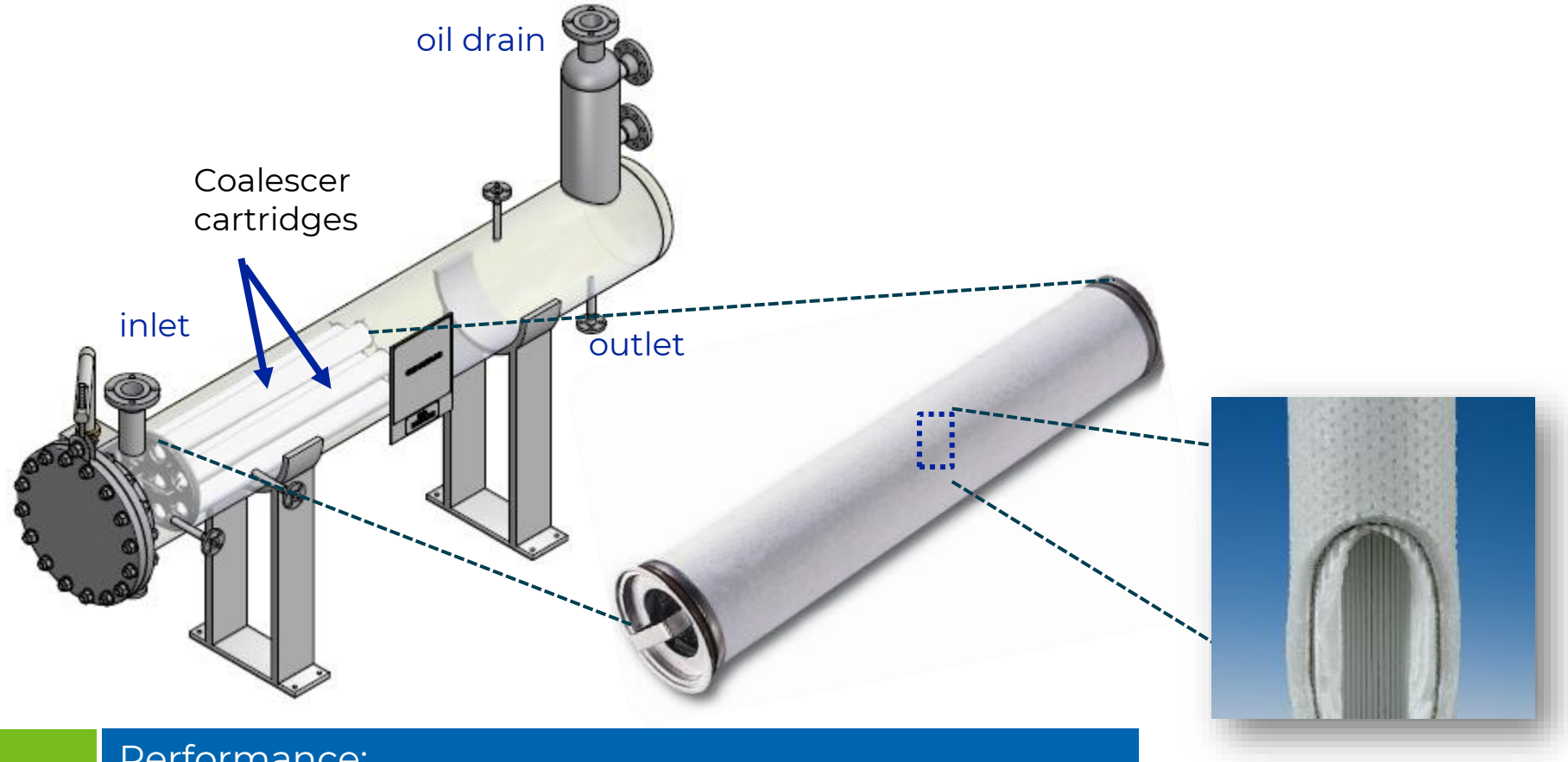
(PP, Nylon, PPS)

Solid removal rating (gas) 0.3 µm (99.99%)
Temperature rating 62°C - 204°C
Liquid removal level Various



Overview: Pall's liquid/liquid coalescers

Liquid / Liquid Coalescers



PhaseSep® Polymeric Liquid/Liquid coalescer cartridge

Performance:
<20 ppmw hydrocarbons downstream oil from water
<15 ppmv free water from hydrocarbon

Pall Mobile Systems and Monitoring Devices

Mobile filter services

Fluid cleanliness monitoring devices

Filter and coalescer skids

Fluid conditioning purifiers

Component cleanliness cabinets

Mobile Water treatment units (MF & RO)

Modular solutions (Hollow Fibers)

PALL CORPORATION

SLS
Global Technical Support

Over 400 qualified engineers

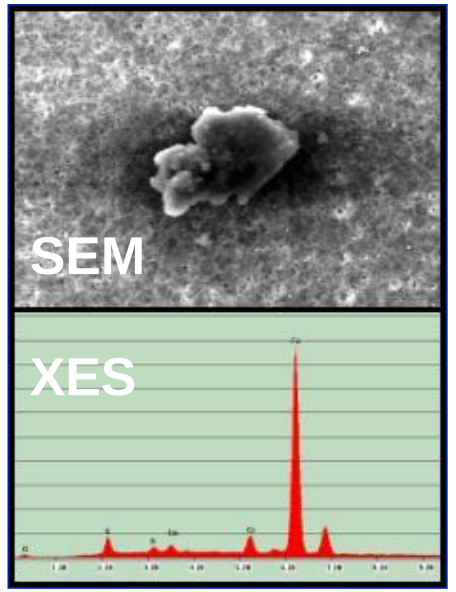
Our customer-focused technical support organization ensures product is working in the application as intended:

- Product testing during prototype phase
- Assisting customers with process integration by on-site work, best practice training, process optimization
- Troubleshooting of product applications issues
- Validation services
- Presentation of Pall technology (e.g., in scientific forums or on congresses through papers or technical bulletins)

Pall Lab and Pilot Capabilities

Liquid and Gas Particulate Contamination

- In-line sampling membrane
- Total Suspended Solids (TSS)
- Particle Size Distribution (PSD)
- Elemental Analysis (XES)
- Scanning Electron Microscope (SEM)
- Organic residue analysis (FTIR)



PALL CORPORATION

Your Needs

- Operation reliability
- Sustainability
- Longer Life
- Applic

Your Solution

- Novel media housed within novel filter formats (“media packaging”)
- Right Media + Right Filter = Optimized Application Performance
- Functional considerations – housings, sealing, integrity testing

Extensive Pall Media Library

Formats

- Membranes
- Micro/Nano Fibers

es

tnesses,

, Nylon, PVDF, PES, Cellulose, Polypropylene

- Inorganic – Metals, Ceramics, Borosilicate glass
- Chemistry – Surface modification leverages into thousands of options

We welcome you to speak to our sales representatives for existing products or to partner with us in developing new carbon capture solutions!

Pall In-house Technology

- Depth, membrane filtration
- Liquid/gas coalescing
- Liquid/liquid coalescing

Internal Infrastructure coupled with external collaboration

Pall Corporation: a proven record of Innovation and Technology Development – Let us partner with you to optimize your process

Thank you for your attention.

ANY QUESTIONS?

Please write to

Geetha_Sanjeev@pall.com
toshi_sato@pall.com