

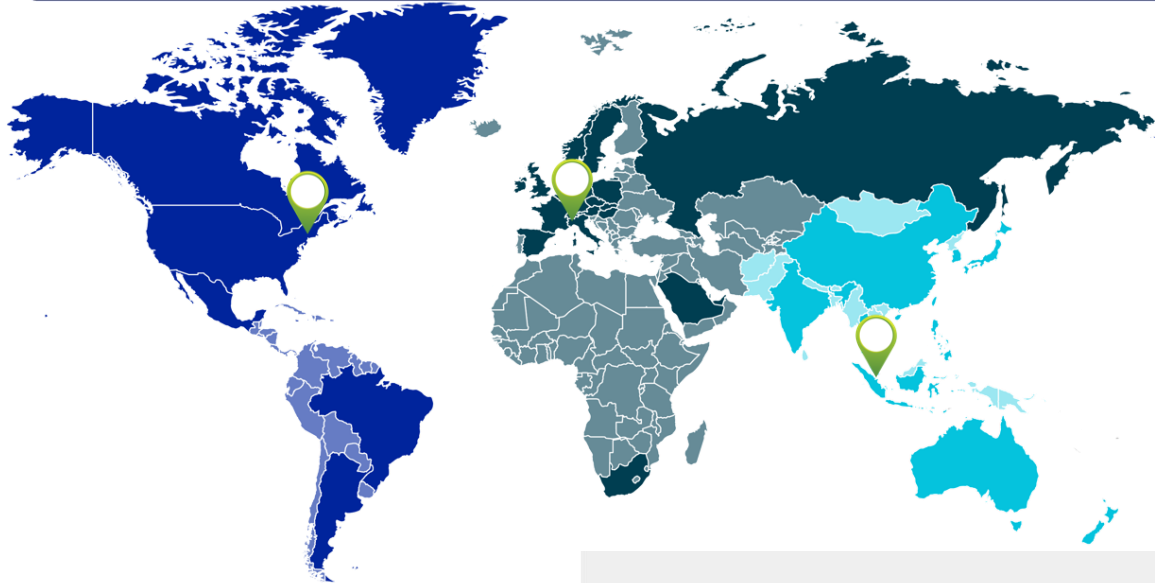
Green Hydrogen: Add cleanliness to your production value chain!

Filtration & Separation Technologies

Agenda Content

- An introduction to Pall
- Why Hydrogen?
- Green Hydrogen Production
- Liquid/Gas Separations
- Particle Removal
- Summary
- Q&A

An Introduction to Pall Corporation



Pall
A Global Foot Print



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

- Two operating divisions
 - **Pall** Industrial
 - **Pall** Life Sciences
- 10,000 employees
- 35 countries, 90 offices globally
- \$80M annual investment in R&D
- A subsidiary of Danaher
 - Proven Partners
 - Focused Expertise
 - Holistic Approach



Deliver higher performance liquid and gas separation solutions

Increase Asset Life ♦ Improve Asset Reliability and productivity ♦ Achieve high quality products

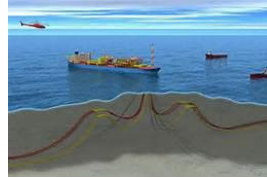
Activities in the Energy sector



EPCs



Adjacent / Complementary Markets



FPSO & FLNG



OEMs & Packagers



Licensors

Target Markets



Upstream

- O&G production
- Gas processing & treatment
- LNG / FLG
- Shale gas



Midstream

- Pipeline
- Compression station
- Metering station
- Terminals



Downstream

- Refinery
- Petrochemical (Ethylene)
- Fine Chemical



Plastic & Polymer

- PVC / PVDF
- Final Products



Green Energy

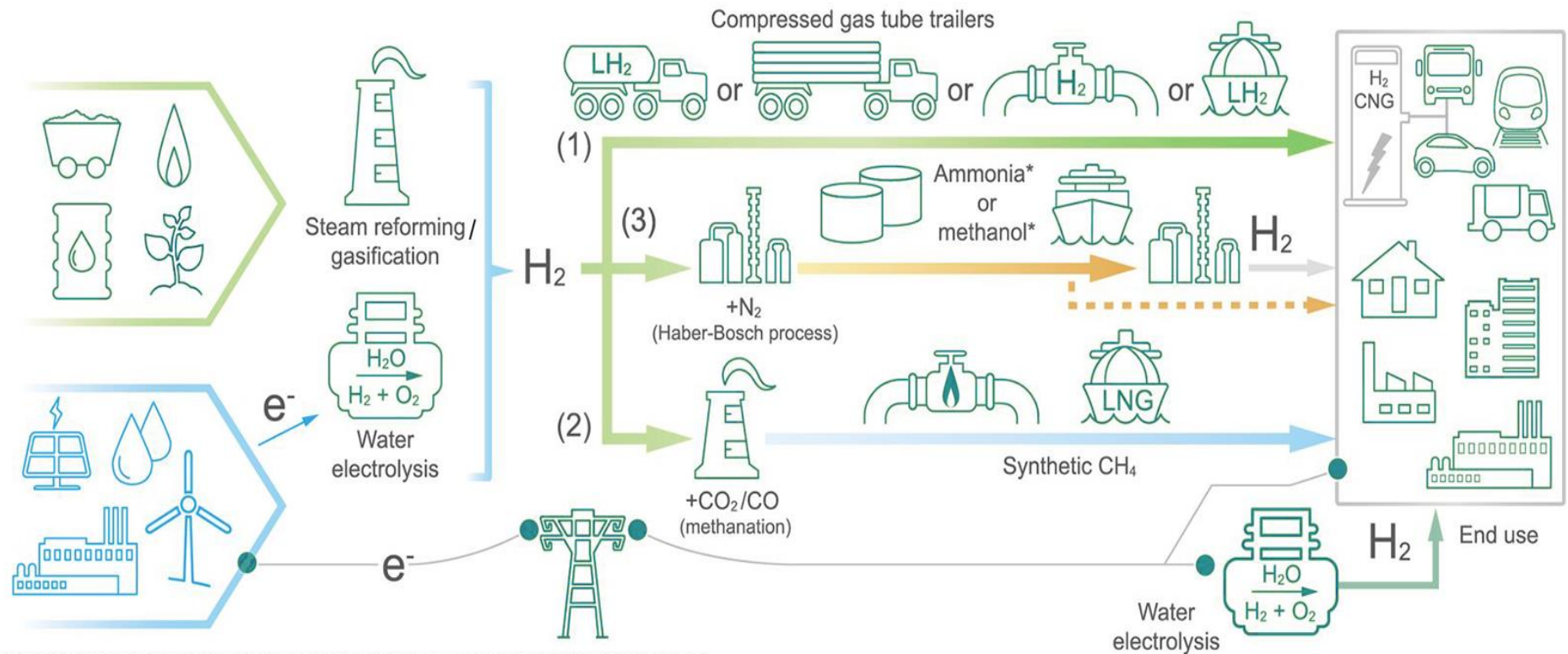
- Bio-refineries
- Bio-sourced chemicals / polymers
- Biogas
- Hydrogen
- Batteries

Why Hydrogen?



- No toxic emissions – water vapor
- Energy source
- Energy Storage

- Decarbonizes Industries
 - Transportation
 - Feedstock to refineries
 - Building heat and power



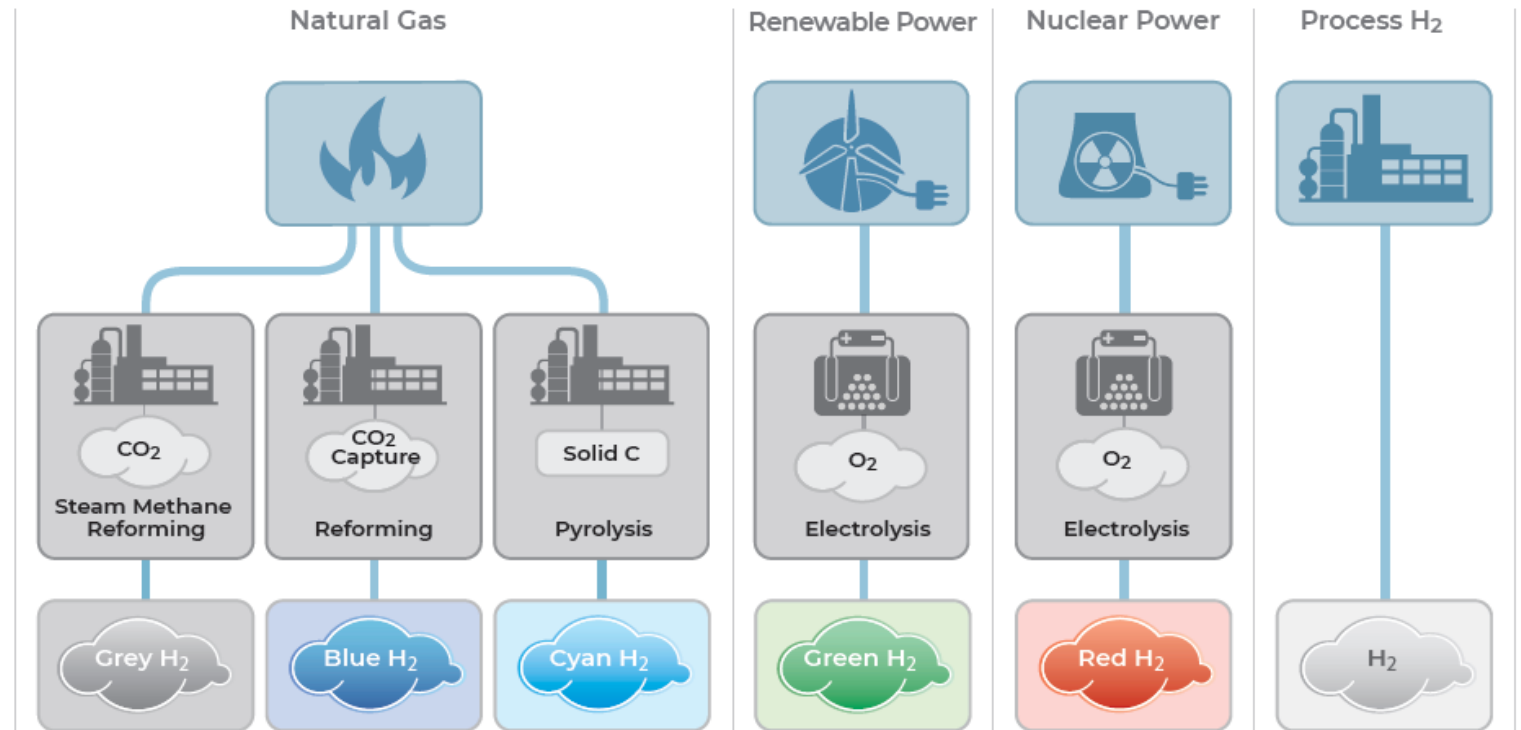
*Alternative transport methods like ammonia and methanol will be assessed at IHS Markit fall 2019 workshops.
Source: IHS Markit

© 2019 IHS Markit/1736808

Hydrogen Production Processes



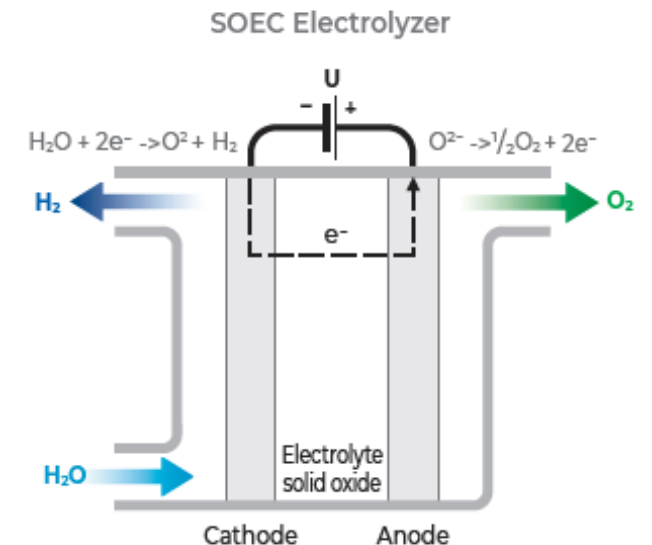
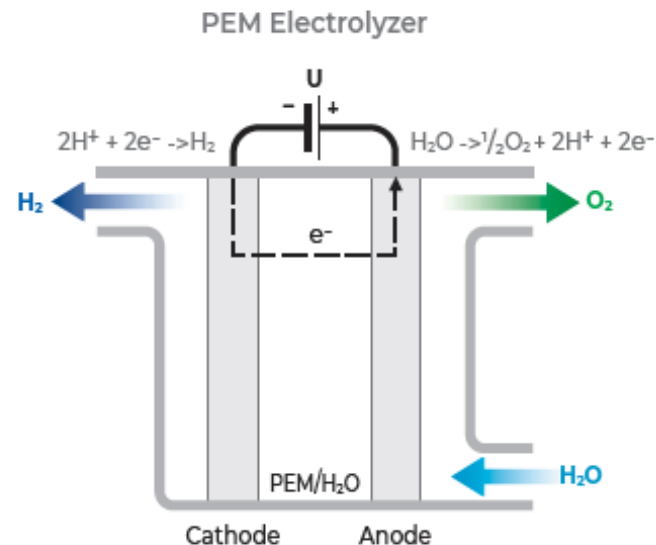
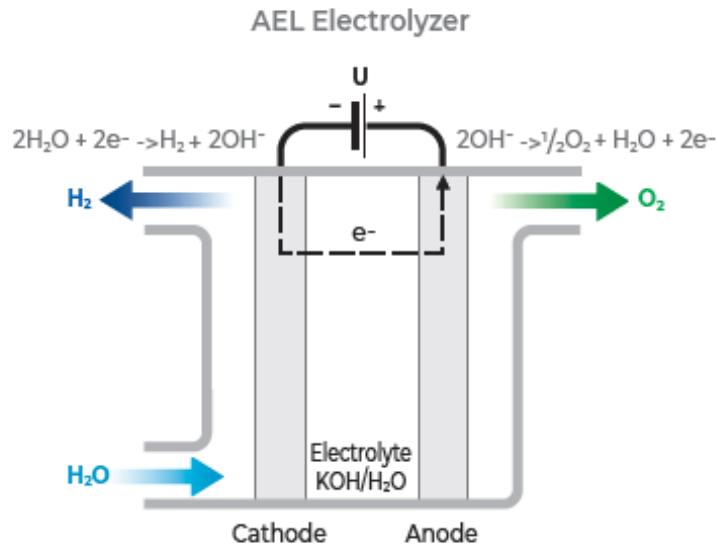
- Grey Hydrogen
 - Reforming
 - \$1.25 - \$3.5/kg (Cheapest)
- Blue Hydrogen
 - Reforming plus carbon capture
- Green Hydrogen
 - Electrolysis powered by renewables
 - \$2.5-\$7.25/kg (Most Expensive)



Green Hydrogen Production



- Electrolysis of water powered by renewable electricity – solar, wind, hydropower
- Hydrogen produced at the Cathode
- Oxygen Produced at the Anode
- 3 Types of Electrolyzers



Types of Electrolysers



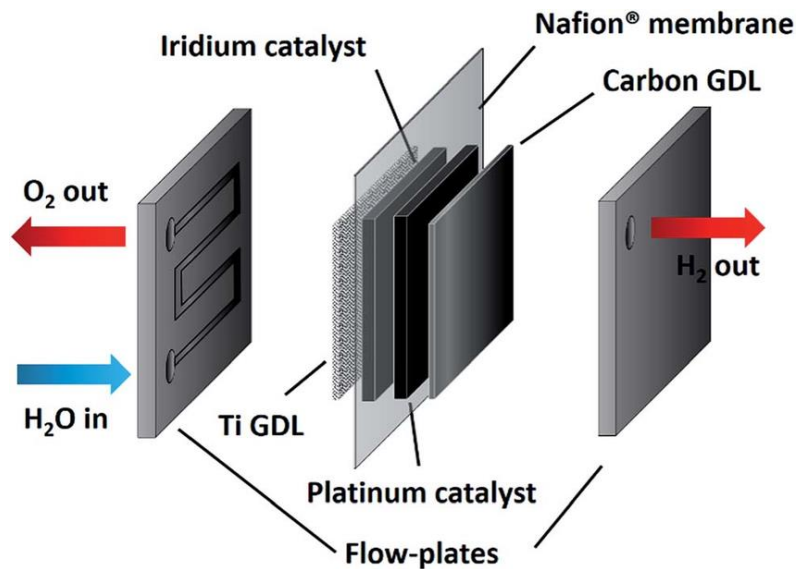
Alkaline Electrolyser	PEM Electrolyser
Low system pressure	High system pressure
Moderate temperature	Moderate temperature
Liquid electrolyte	Solid electrolyte
Low feed purity (KOH/water)	High feed purity (water)
Diaphragm	Membrane
H ₂ purity: 99.9 %	H ₂ purity: 99.99 %
Energy efficiency: 70-80 %	Energy efficiency: 80-90 %
Low current density	High current density
Low cost components	High cost components
Slow response system	Quick response system

Green Hydrogen Production - Challenges

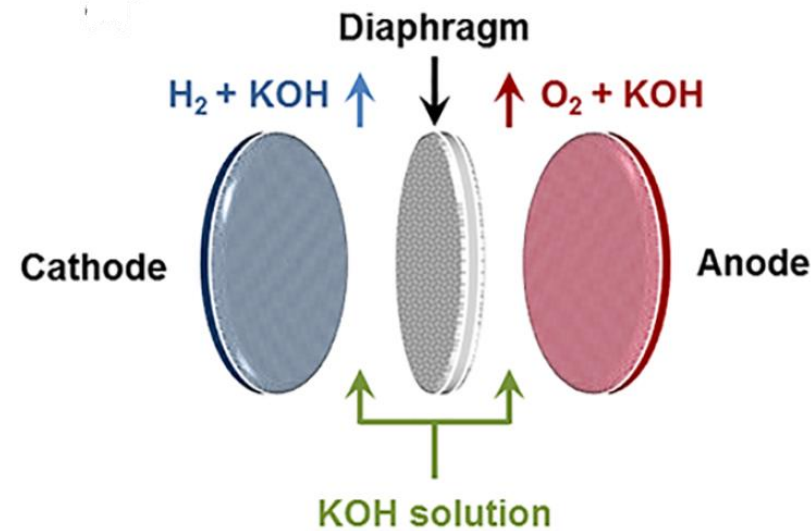


- High Cost of Electrolyzers
- Stringent Gas Purity Specifications

- Example: For fuel cells
 - Water 2000ppm to <5 ppm
 - Oxygen 4000 ppm to < 5 ppm



Typical PEM Electrolyzer

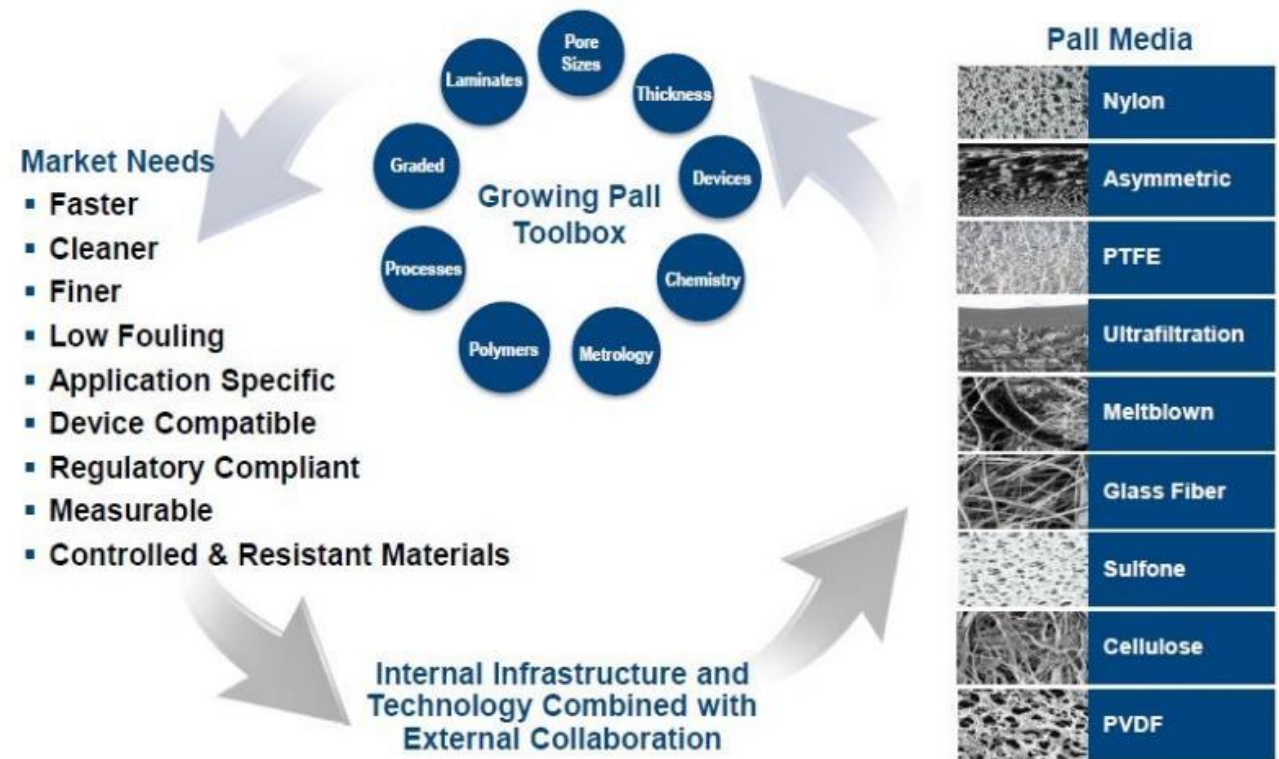


Typical AEL Electrolyzer

Green Hydrogen Production - Separations

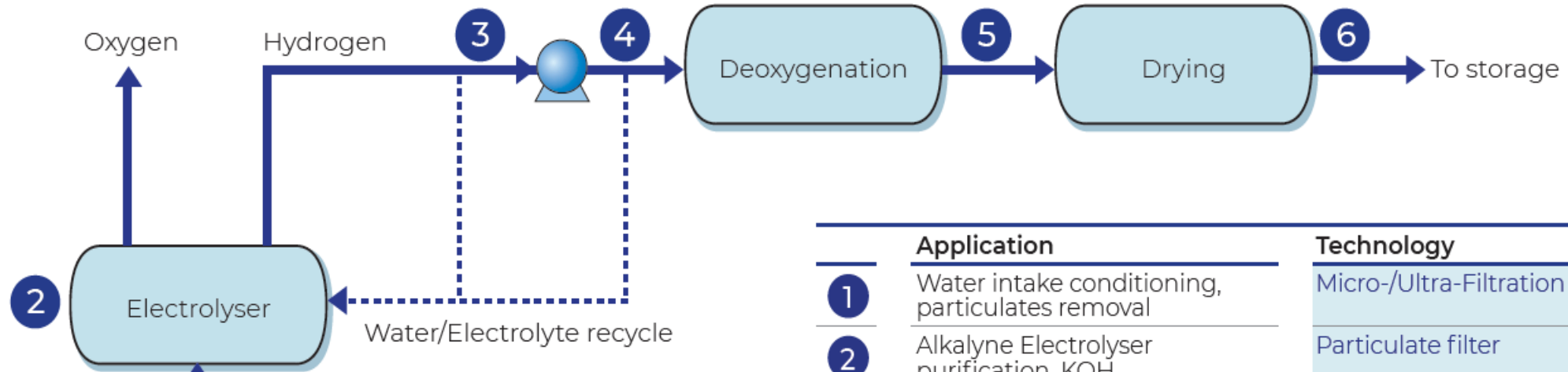


- Liquid/Gas Separations and Particle Removal
- Separation Equipment Choice
 - Quality Required
 - Flow Rate
 - Type and Amount of Contaminants
 - Economics
 - Capital and Operating Costs
 - Waste Disposal
 - Maintenance



Pall's Broad Technology Portfolio Ensures the Correct Separations Solution for the Customer's Process

Green Hydrogen Production - Separations

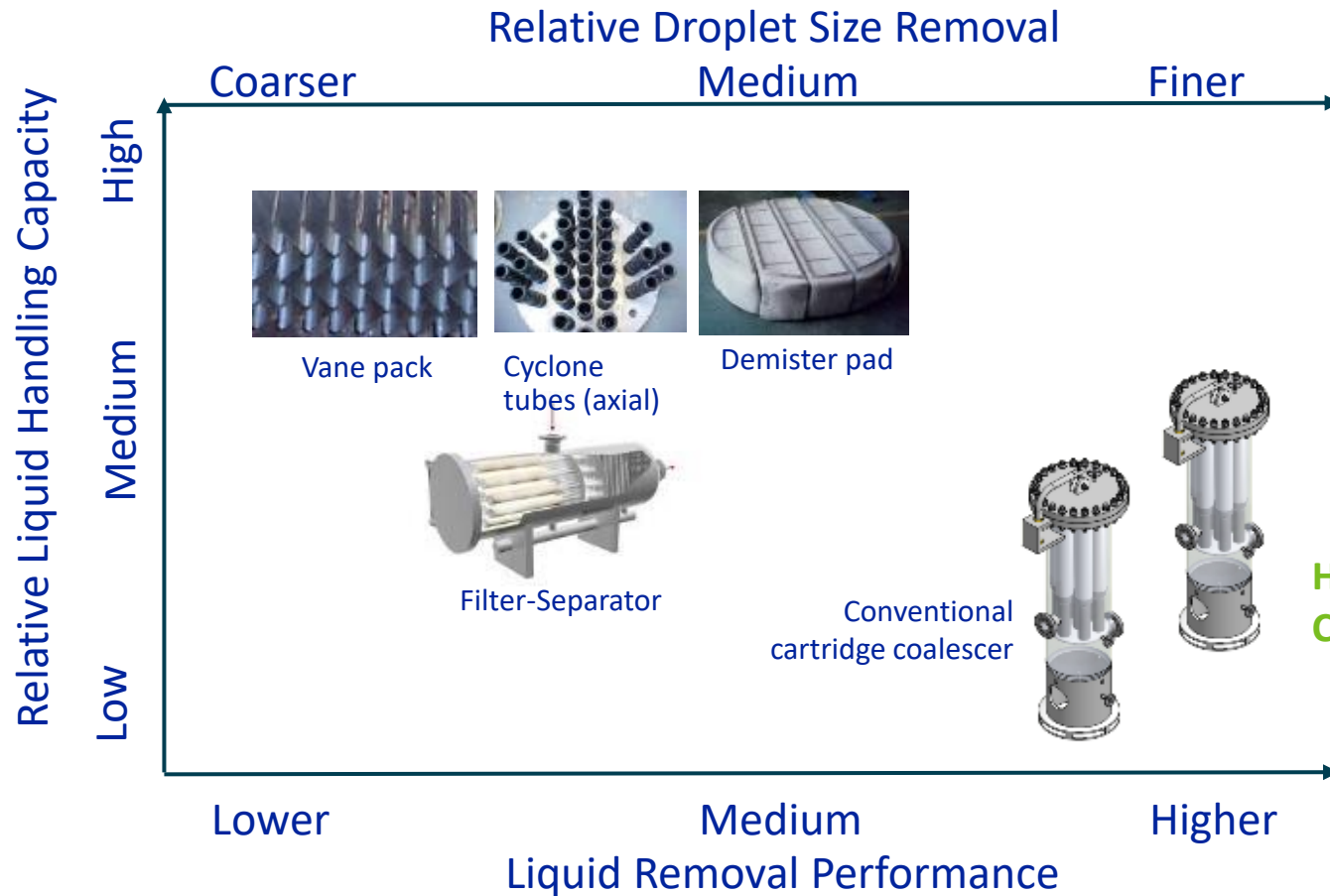


	Application	Technology
1	Water intake conditioning, particulates removal	Micro-/Ultra-Filtration
2	Alkaline Electrolyser purification, KOH	Particulate filter
3	Water separation, compressor protection	Liquid/Gas coalescer
4	Water separation, catalyst protection	Liquid/Gas coalescer
5	Water separation, solids removal, drier protection	Gas Filter, Liquid/Gas coalescer
6	Solids removal, product quality	Gas Filter

Liquid/Gas Separations



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



Pall Surface-Treated Coalescer:
Guarantee of an outlet liquid content <0.01 ppmw*

* As per LASE test methodology

High Efficiency Coalescer

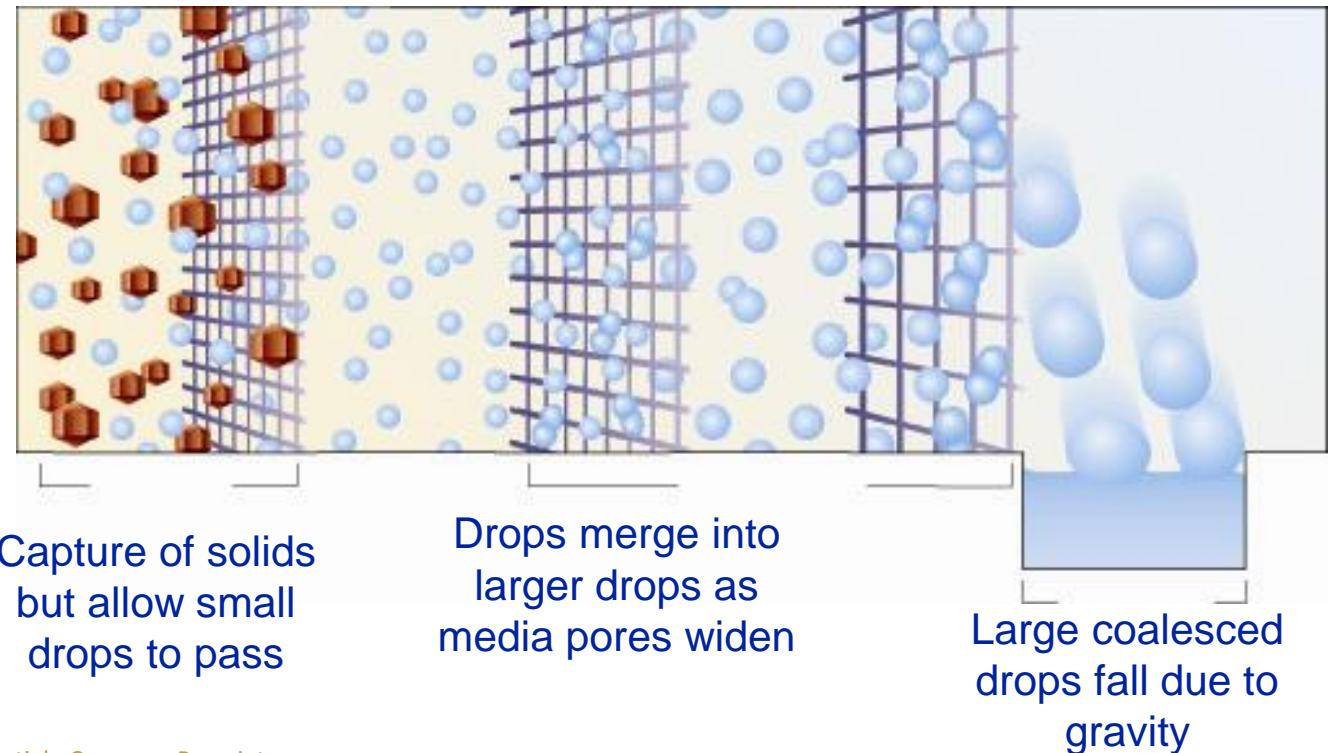
Coalescence



- **Coalescence** = Removal of a fine dispersed liquid phase from a bulk phase (liquid or gas)
 - **Liquid/Gas** coalescers = Removal of liquid **AEROSOLS** from a gas
 - **Liquid/Liquid** coalescers = Removal of liquid **DROPLETS** from a liquid

Coalescence principle MECHANICAL separation based on ability of the coalescer media to combine the droplets, and to separate them

- NO chemicals required
- NO electricity
- NO centrifugal motion



Liquid/Gas Coalescer Performance



- L/G Coalescer performance is defined as a liquid content in the outlet gas
- A specification based on a droplet size for a given removal efficiency is inappropriate for liquid/gas separation technologies
For example: '99% removal of 5 micron droplets (particles)'
- Droplet size distribution is difficult to predict by computer simulation, and hard to measure in the field
- A good spec is based on the outlet liquid content
 - Measurable in the field
 - Consistent with the inlet gas quality (inlet liquid content)

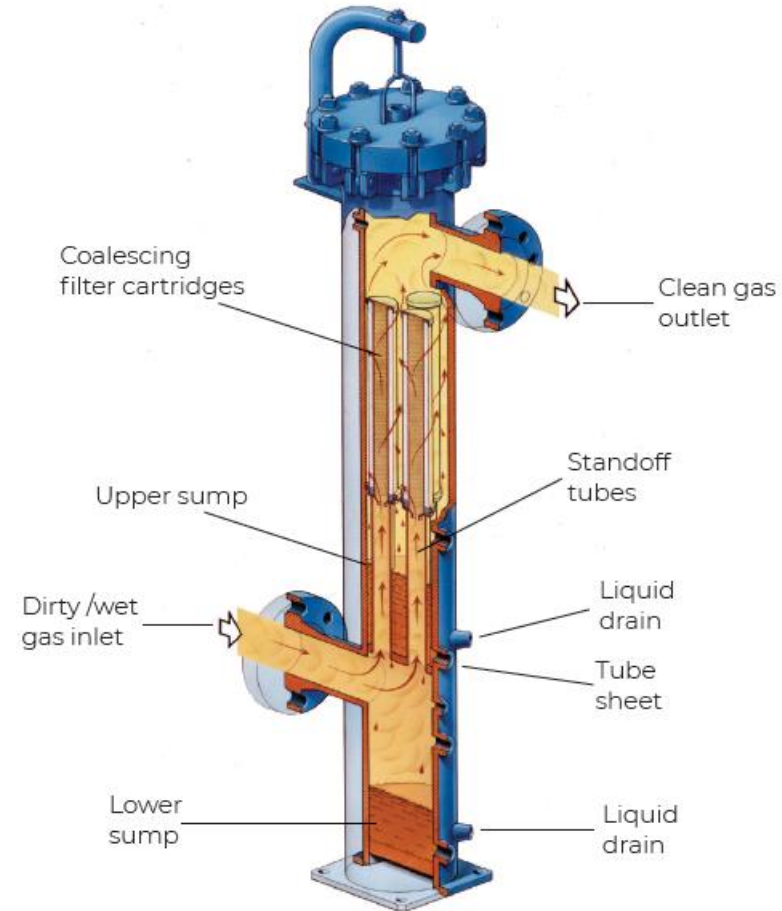
Pall's High Efficiency Coalescers



- Configuration : VERTICAL only
- Smaller footprint vs. horizontal configured coalescers or demisters
- High flow capacity & High liquid handling capacity
- Oleophobic & Hydrophobic Treatment
- **Resulting in compact vessel design**
- **Reliable high efficiency performance**

Performance:
<0.01 ppmw liquids downstream

* As per LASE test methodology



Pall's Liquid/Gas Coalescers



SeptraSol™

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



SeptraSol™ Plus

Solid removal rating (gas) 0.3 μm (99.7%)
Temperature rating 82°C (65°C water)
Liquid removal level 0.01 ppmw (LASE)



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

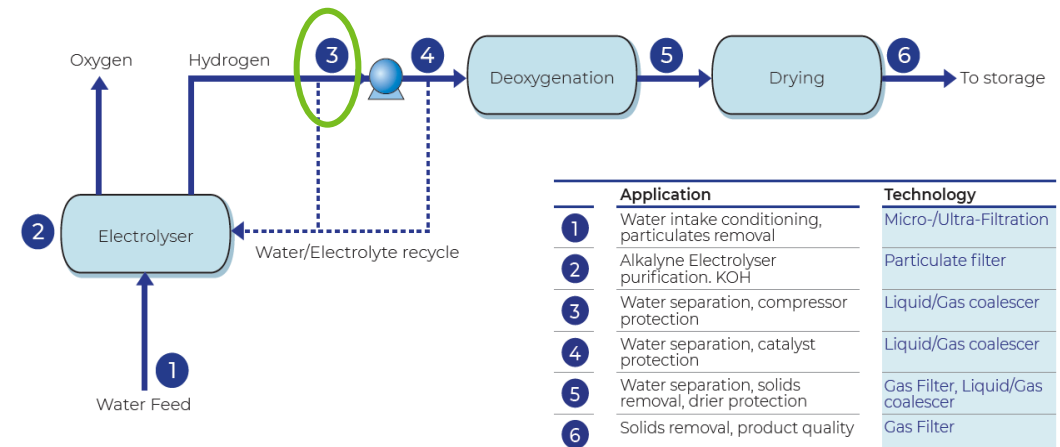
Case Study – Coalescers after Electrolysis



- Electrolyzer Manufacturer in Germany
- AEL Electrolyzer
- Removing Water/KOH from H₂ gas after electrolysis (before compression)
- Retrofit of Mist Eliminator with Pall Coreless Liquid Gas Coalescer
- Configuration : VERTICAL
- Fully compatible polypropylene MOC vs glass fiber
- Lifetime and operating costs TBD as testing continues
- Further separation optimization TBD
- Testing on Oxygen stream



Pall Coreless Liquid Gas Coalescer



Case Study – Coalescers after Compressors



After compression, additional liquids and oil droplets can be present in gas stream
Pall has hundreds of installations globally and in many industries!!

Oil from Hydrogen Separation

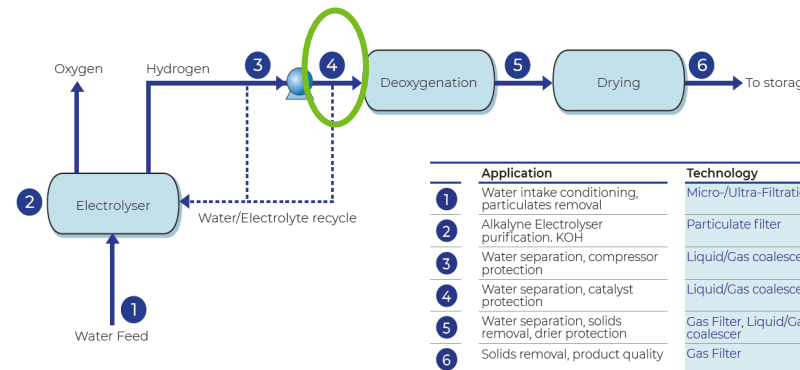
- Flow: 340 kg/h H₂
- Inlet Oil content 100 ppmw
 - Outlet Oil Content < 0.01 ppmw
- Temperature: 40 °C
- Compression to 200 – 300 bar



Reciprocating Compressor



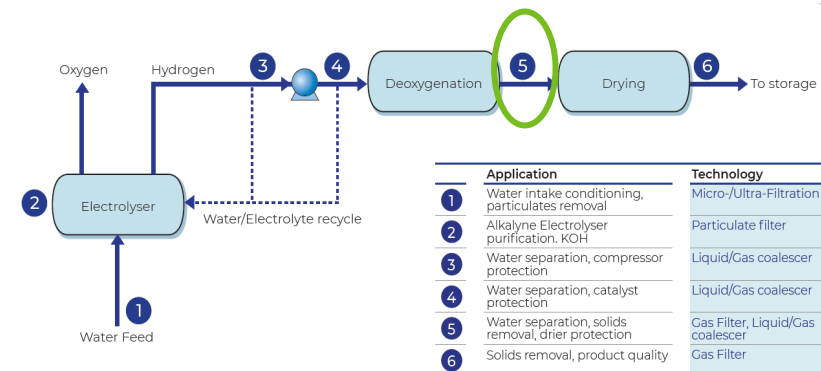
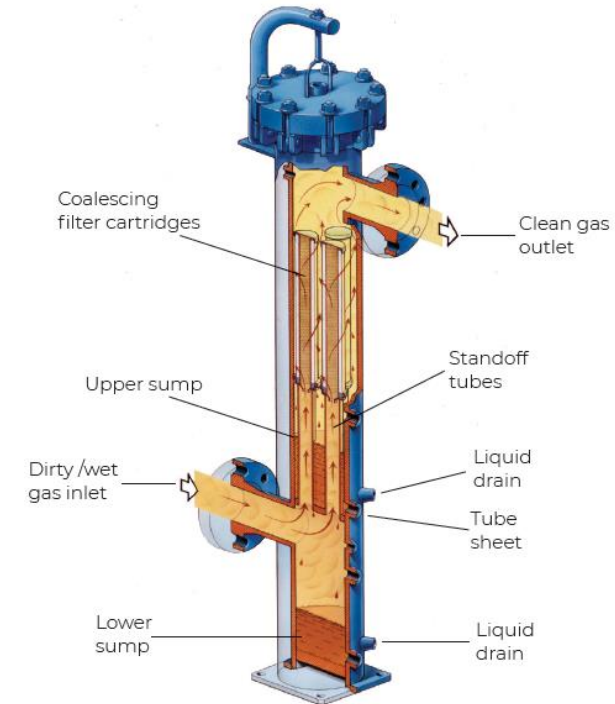
SeptraSol™ Elements



Case Study – Coalescers for PSA protection



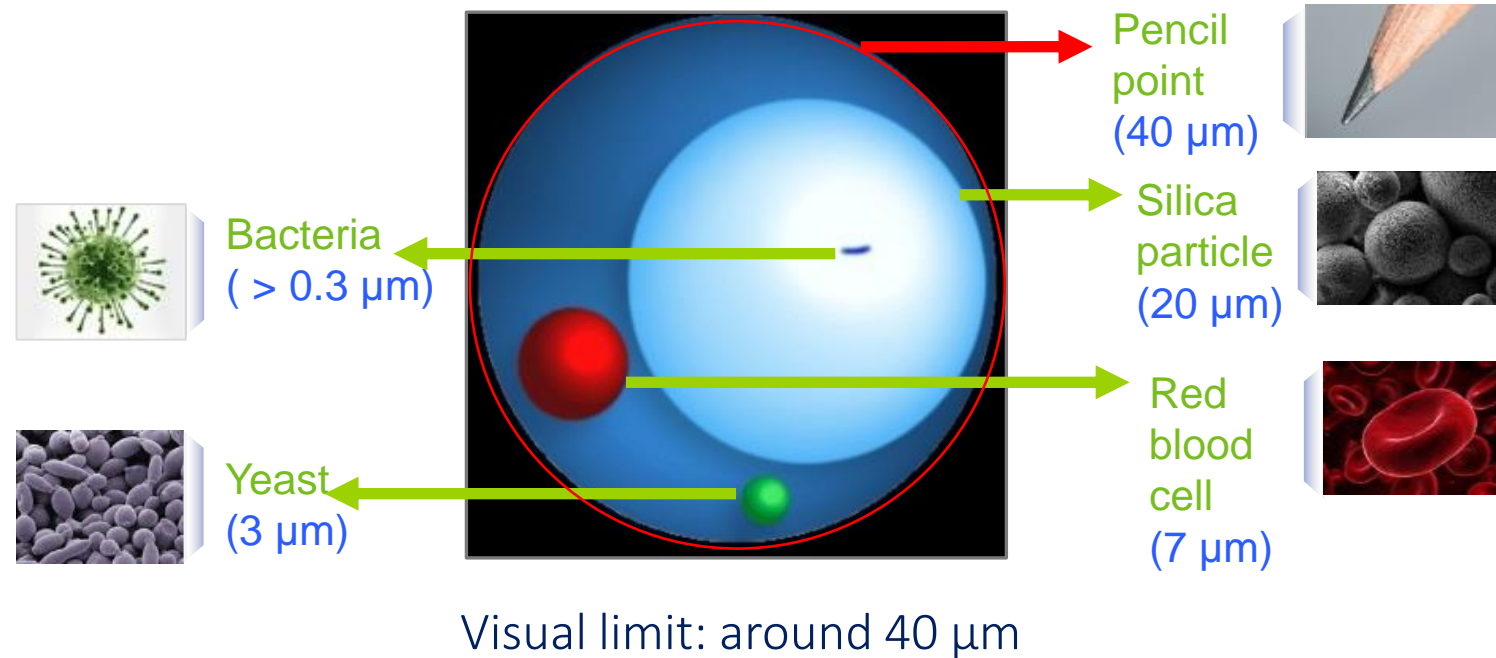
- French Ammonia Plant
- Pall LG Coalescer upstream of PSA
- Field measurements confirmed liquid carry over < or = to 2 ppb...
- A manual mistake on a valve created a high delta P back flush damaging the coalescer cartridges
 - A rapid PSA yield decrease was observed
 - New cartridges installed



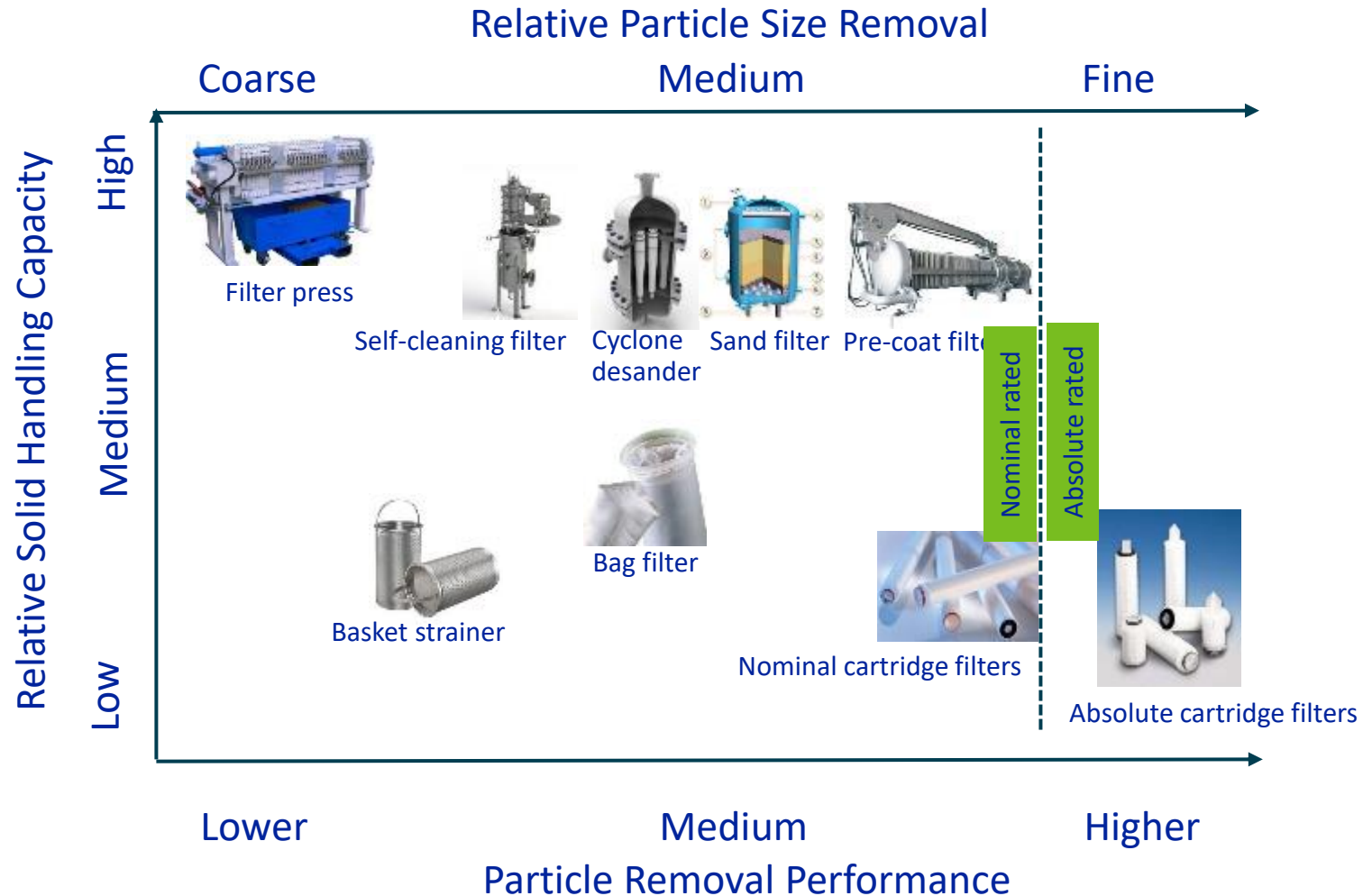
Particle Filtration



- Sources of solid contaminants
 - Incoming water feed and/or KOH feed (in AEL systems)
 - Oxidation in process piping and equipment such as pumps and compressors
 - Downstream of adsorbent driers
 - Changes in chemistry/degradation
 - During maintenance such as welding, grease, lubricants, dirt



Particle Filtration



Not all filter technologies can eliminate the most elusive particles consistently

Absolute vs Nominal Ratings



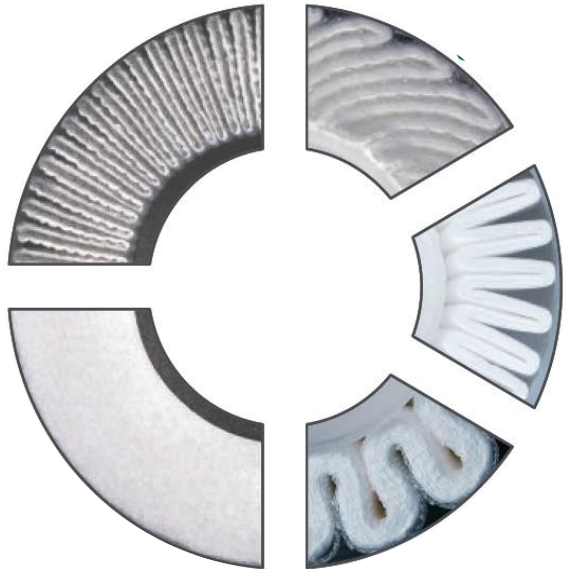
In practice, what is the difference?



- ①: non filtered amine
- ②: after 10 μ m **nominal** filter
- ③: after 10 μ m **absolute** filter

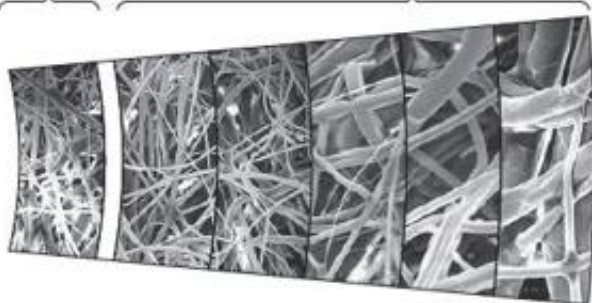
- **Absolute** = **tested** efficiency, according to industry standards (e.g ISO 4572)
- **Nominal** (non-absolute) = filter not tested, **arbitrary** removal rating given by manufacturer, based upon weight percent removal, not reproducible
- Typical problem with nominal filters: particles larger than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

Particle Filtration

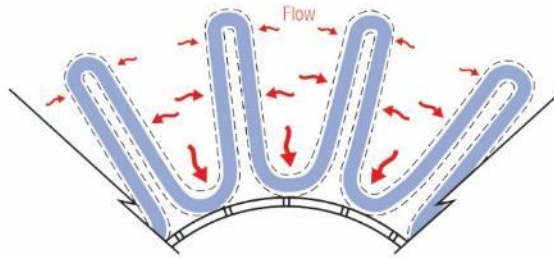


Constant pore final filter layer

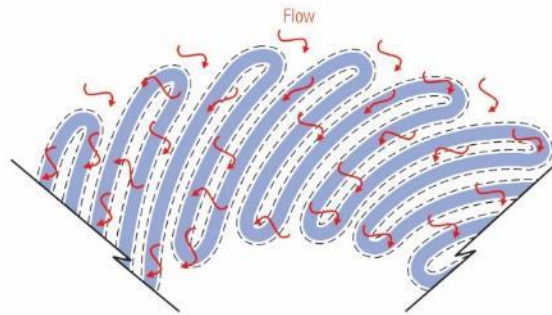
Continuously graded pore prefilter layer



Conventional Fan pleat media layout



Pall patented Ultipleat® media layout

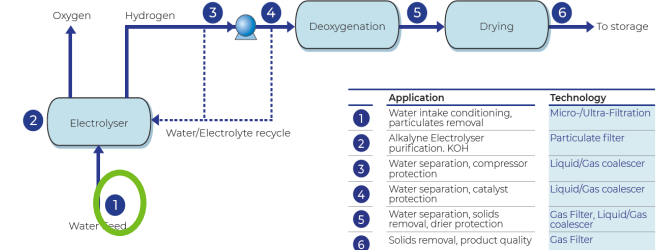
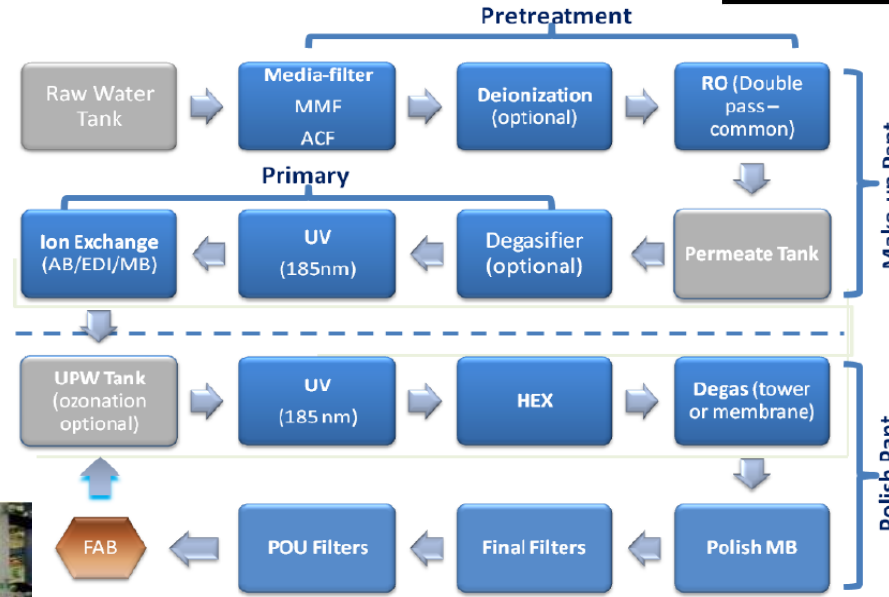
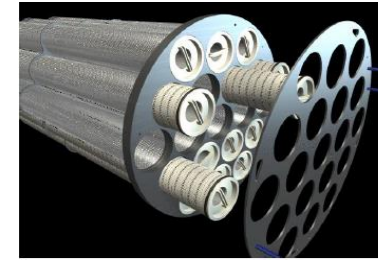


Pall: 10.85m
Competitor: 3.61m

Water Feed – PEM Electrolyzers



- RO Protection – e.g. 5 microns absolute
- Downstream of RO - e.g. 0.02 to 1 micron absolute
- Ion removal: e.g. iron and calcium



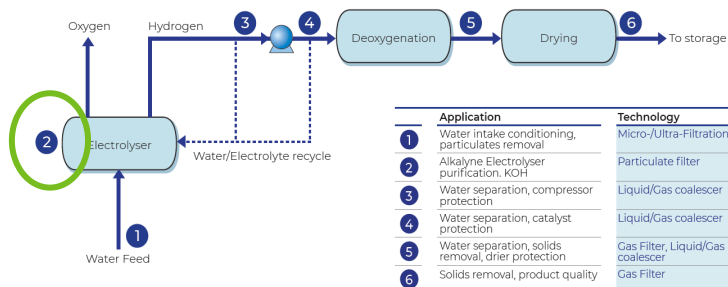
KOH Feed – AEL Electrolyzers



- Exchange intervals up to 1 year
- Absolute filtration (10 micron) for pump protection
- 30% KOH/ Water @ 80 °C
- High flow rates
- Materials available in portfolio: PP, PTFE, ECTFE



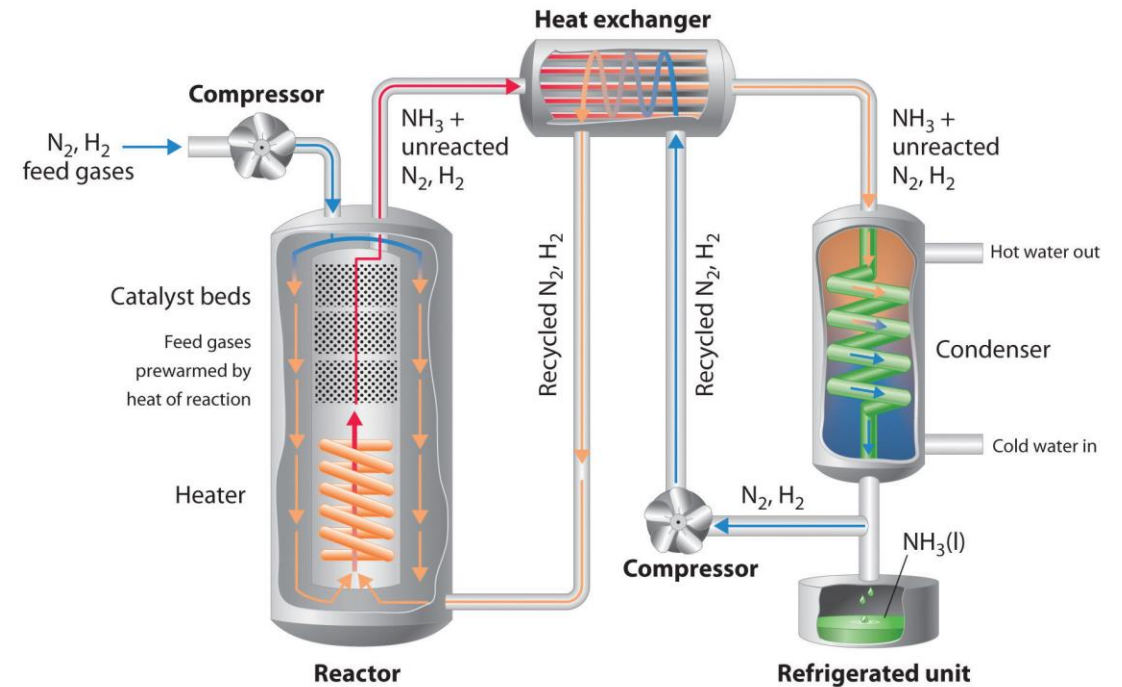
Pall Ultipleat^(R) Highflow Filter



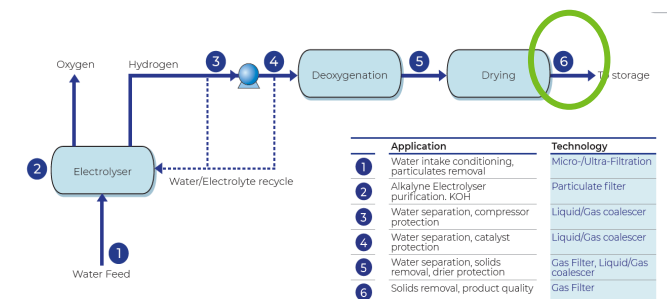
Hydrogen Storage



- Storage Possibilities
 - Tanks
 - Salt Caverns
 - Conversion to Ammonia by Haber-Bosch synthesis
 - Pall has >200 filter and coalescer installations in ammonia plants!!
- After compression, gas can be contaminated with fine solids and compressor oil
- Further contamination can occur in tanks and in salt caverns
- **Pall's gas filters and liquid/gas coalescers can be employed to reduce contaminants to reach the desired specifications for the end use**



Haber-Bosch Synthesis



Case Study - Blue Hydrogen



- Electricity provider gasifying coal to produce hydrogen and capturing/storing the CO₂ produced = BLUE H₂
- Hydrogen is then liquefied and shipped to neighboring country
- Pall's metal blow back technology was tested in pilot plant to remove char after gasification
- Iron Aluminide construction to meet extreme material and temperature resistance
- Pall's technology moving to scale-up



**Pall PSS^(R) Series Filter
Elements in Pilot Housing**

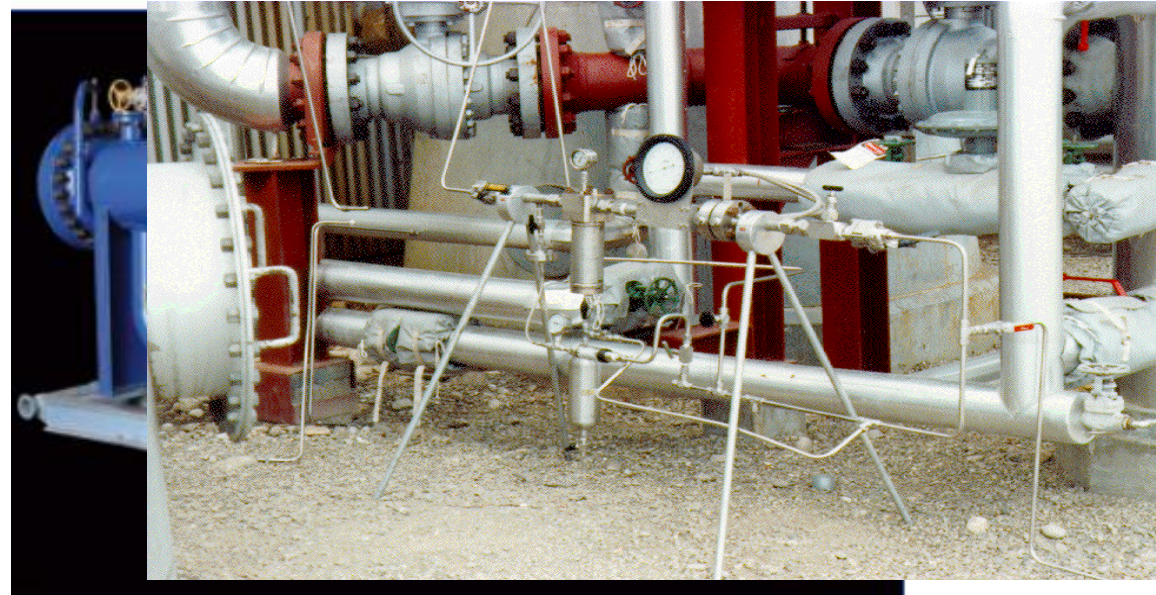
SLS

Global Technical Support

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 Rental Units – Full Scale and Pilot Scale



- Connect directly to your process
- Direct scale-up
- Short- or long-term rentals
- On-site support

Summary



- Hydrogen plays a key role as the shift to renewable energy continues
- Green hydrogen production must be increased but faces challenges in commercialization and scale –up
- High cost of electrolyzers and strict purity standards
 - Removal of liquid and solid contaminants are crucial
- **Pall Corporation is committed to help advance the production of green hydrogen by providing separation and purification solutions that can meet any specific need**



Thank you for your attention
QUESTIONS?



Contact

toshi_sato@pall.com

takemi_namba@ap.pall.com

geetha_sanjeev@pall.com

This presentation is the Confidential work product of Pall Corporation and no portion of this presentation may be copied, published, performed, or redistributed without the express written authority of a Pall corporate officer.

© 2021 Pall Corporation