

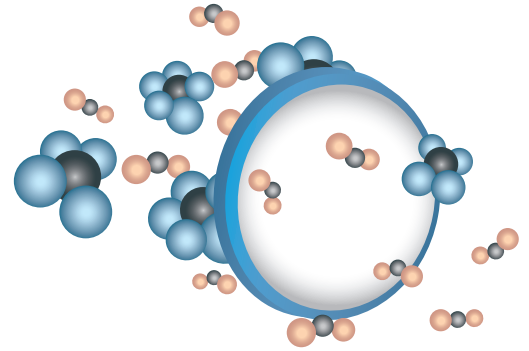
HYDROGEN MEMBRANE OVERVIEW

Advanced membrane technology for hydrogen purification and recovery



▶ PROCESS PRINCIPLE

Air Liquide Advanced Separations' (ALaS) hollow fiber membranes offer the most robust solution for hydrogen purification needs. ALaS membranes operate on the basis of selective permeation. Each membrane is composed of millions of polymeric hollow fibers similar in size to the diameter of a human hair. The “fast gases,” or gases with a higher permeation rate, permeate through the membrane into the hollow interior and are channeled into the permeate stream. Simultaneously, the “slower gases” flow around the fibers and into the residue stream. As a result, the fibers have the ability to selectively separate a fast gas like hydrogen from carbon monoxide, methane, heavier hydrocarbons and other slower gases.



GAS PERMEATION HIERARCHY



THE ALaS HYDROGEN MEMBRANE SYSTEM CAN PROCESS FEED STREAMS WITH HYDROGEN CONCENTRATIONS AS LOW AS 20Mol%.**

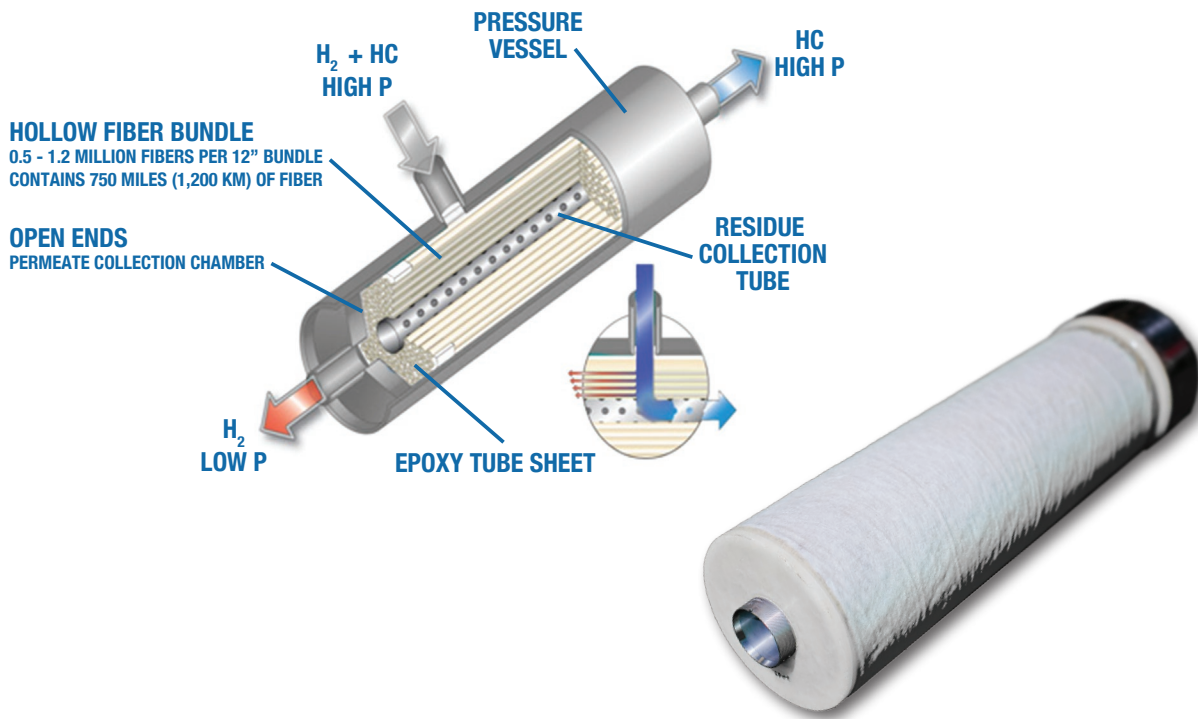
ALaS MEMBRANES HAVE THE HIGHEST CO RETENTION FOR SYNGAS APPLICATIONS

**Dependent on product requirements



▶ ALaS H₂ MODULE FEATURES

ALaS's large diameter 12" membranes pack a greater amount of surface area into less steel meaning lower system cost. Membrane modules consist of over 1 million individual hollow fibers that are formed in cross flow and counter flow designs, allowing for flexibility in meeting pressure drop and performance constraints. Bundles are designed with high performance fiber to allow operation at elevated temperatures and extreme pressures. This allows for higher membrane productivity, fewer membranes and lower system CAPEX.



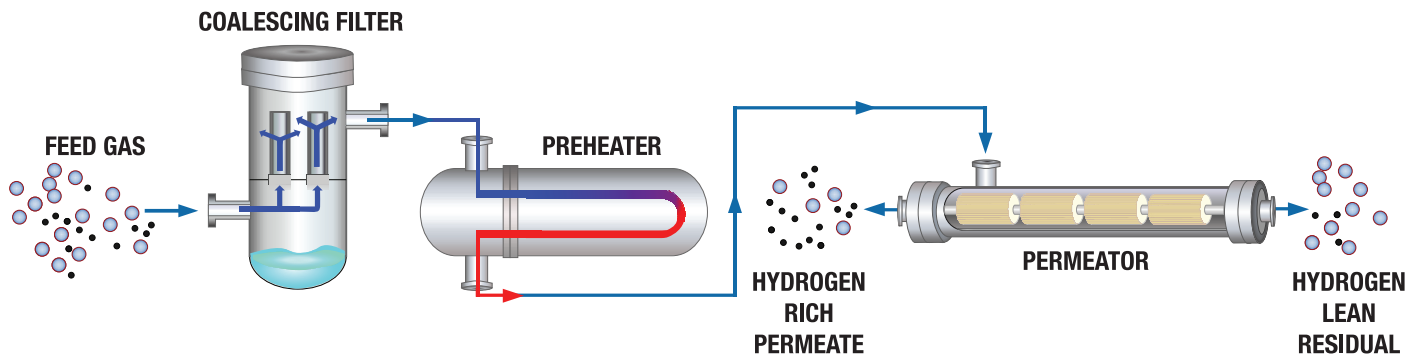
CUSTOM RESIDUE GAS COLLECTION TUBES ARE DRILLED FOR EACH APPLICATION TO ENSURE EVEN GAS DISTRIBUTION AND CONSISTENT PERFORMANCE FROM EACH ALaS BUNDLE.

STANDARD SYSTEM DESIGNS INCLUDE THE FOLLOWING KEY SAFETY FEATURES:

- ▶ Remote and local shutdown capabilities
- ▶ Stringent Air Liquide specifications for H₂ service
- ▶ Host of other membrane protections including high temperature and low temperature shutdowns

▶ PROCESS DESCRIPTION

The process begins when pressurized feed gas is sent to the coalescing filter to **remove** contaminants and protect the membrane fiber from liquid aerosols and particulates. Feed gas is then **preheated** before entering the membranes. These membranes produce the hydrogen-rich permeate and hydrogen-lean residue. The **separation** of permeate and residual gas is driven by the hydrogen partial pressure difference between the feed gas and permeate gas, as well as our advanced polymer material. The non-porous hollow fiber membranes **selectively allow** faster molecules to permeate the membrane wall while slower, bulkier molecules remain on the high pressure side.



CUSTOMER BENEFITS:

ALaS system bypass designs allow for higher flow rates in ratio adjustments.

ALaS offers the most selective membranes in the industry, meaning the highest CO retention rate for our clients.

- ▶ No moving parts
- ▶ Skid mounted systems cartridge design for simple installation
- ▶ Estimated payback period of less than a year
- ▶ High permeability membranes for compact, low capital system design
- ▶ Unrestrained turndown capabilities
- ▶ Automated turndown system for ease of operation and safety
- ▶ Linear scale up for all size systems
- ▶ Hollow fiber membranes offer higher area to volume efficiency resulting in better packing efficiency, smaller footprint and reduced weight and module count

▶ CUSTOMIZED SOLUTIONS

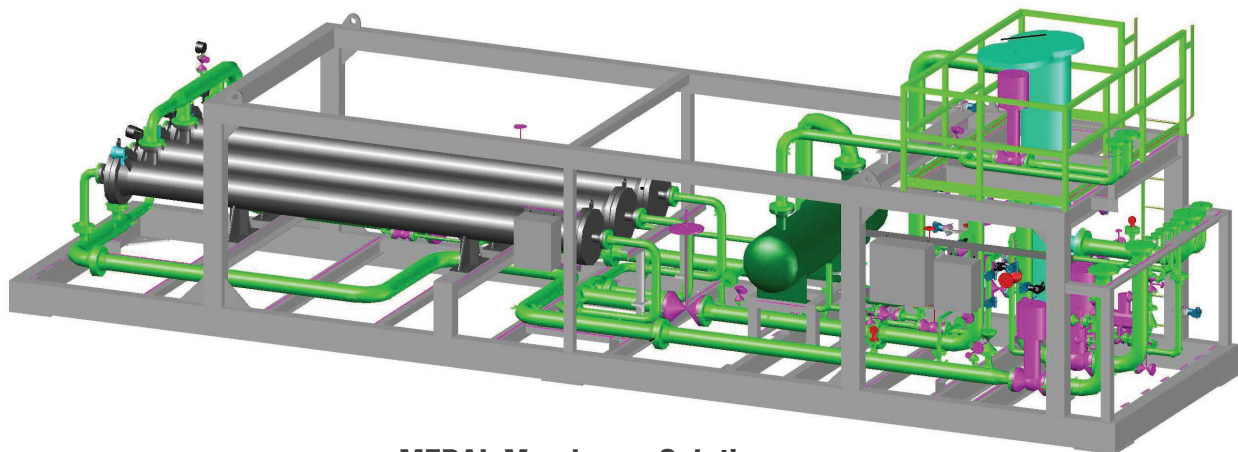
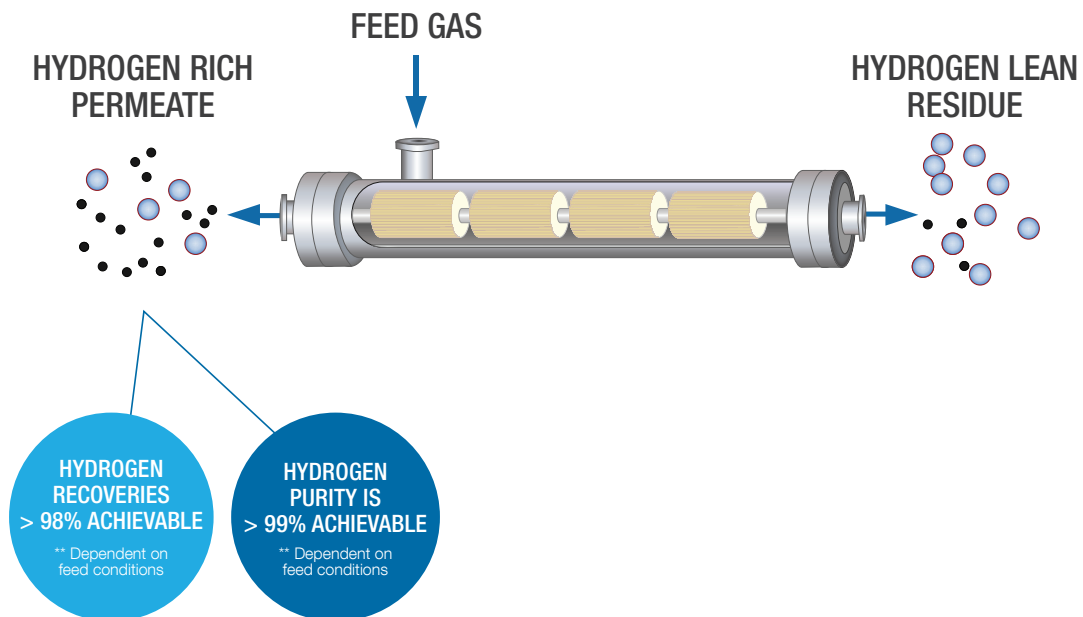
Membrane configuration and module count are tailored to each application to achieve the optimum tradeoff between purity and recovery. There are no moving parts required, offering a nearly maintenance free solution.

THE OUTCOME:

The outcome is a H₂ system that can achieve purities up to 99.9% and hydrogen recoveries up to 98%, all at the lowest cost of ownership for each molecule of H₂ recovered.

All membrane modules operate in parallel

Multiple system configurations available to optimize clients CAPEX and OPEX tradeoff



MEDAL Membrane Solution

▶ APPLICATIONS

The ALaS membranes for hydrogen recovery are a key component in refinery and petrochemical operations. Hydrogen is recovered from refinery and petrochemical streams so it can be used in hydro-treating operations to produce low sulfur fuels. ALaS membranes are also used for efficient recovery and recycling of hydrogen contained in purge gas in order to adjust H₂ / CO ratio. Our membranes prove to be useful for various industries with end users needing to be compliant with increasing regulatory requirements.

APPLICATIONS OF OUR MEMBRANES INCLUDE, BUT ARE NOT LIMITED TO:

REFINING:

- ▶ Catalytic reformer off gases
- ▶ HDT off gases
- ▶ HCU off gases
- ▶ FCC off gases
- ▶ Refinery fuel gases
- ▶ PSA off gases
- ▶ H₂ plant feed
- ▶ Platformer off gases
- ▶ Custom Applications

PETROCHEMICAL:

- ▶ Ammonia purge gases
- ▶ H₂ / CO synthesis gases
- ▶ Methanol purge gases
- ▶ H₂ purge from polypropylene
- ▶ H₂ purge from ethylene
- ▶ Ethylene off gases
- ▶ Custom Applications
- ▶ IGCC
- ▶ Gas to Liquids

▶ INSTALL AND USE - THE ALaS ADVANTAGE

ALaS membrane systems are delivered as skid mounted packages, allowing for a quick, simple, and low-cost installation, making them easily equipped for small and crowded areas. The site preparation is minimal, requiring only a concrete support pad, connections to the process, and utility lines. The ALaS modular cartridge and parallel flow design allows for linear scale up, making future expansion as easy as inserting additional cartridges.

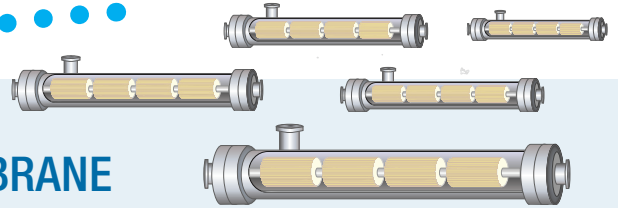
WITH VERY LITTLE OPERATOR ATTENTION OR MAINTENANCE NECESSARY, ALaS MEMBRANES HAVE BEEN PROVEN USEFUL FOR OVER 10 YEARS.

ALaS'S CARTRIDGE 'ROLLER' DESIGN ALLOWS FOR SAFE, QUICK, AND EASY INSTALLATION AND REPLACEMENT. BOTH INSTALLATIONS AND REPLACEMENTS REQUIRE MINIMAL EQUIPMENT AND MAN POWER, ENABLING SHORT AND FLEXIBLE TURNDOWNS.

A long life expectancy can also be attributed to ALaS's robust polymeric fibers. They are very resistant to contaminants such as aromatics, ammonia, HCl, H₂S, COS, methanol and ethanol. ALaS membranes accommodate variations in feed gas flowrate and composition and can easily increase capacity by adding permeators.



OVER **175** HYDROGEN MEMBRANE SYSTEM REFERENCES WORLDWIDE

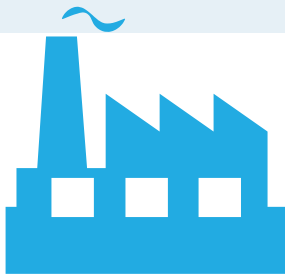
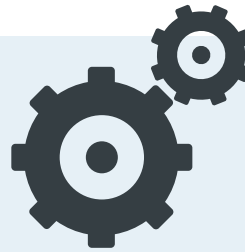


OVER **2900** ALaS HYDROGEN MEMBRANE MODULES IN OPERATION WORLDWIDE



ALL MEMBRANE MODULES MANUFACTURED WITHIN THE **USA**

WORLDWIDE SYSTEM FABRICATION CAPABILITIES



HYDROGEN SYSTEMS IN OPERATION UP TO 65MMSCFD
(SYSTEMS CAN BE DESIGNED TO HANDLE ANY FEED FLOW SINCE MEMBRANES ARE MODULAR)



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BB-022616

PRODUCT PRESSURE REQUESTED:

PRODUCT PURITY REQUESTED:

PRODUCT RECOVERY REQUESTED:

OTHER PRODUCT REQUIREMENTS:



Air Liquide is the world leader in gases for industry, health and the environment, and is present in over 75 countries with 42,300 employees. Oxygen, nitrogen, hydrogen and rare gases have been at the core of Air Liquide's activities since its creation in 1902.

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PLACE
STAMP
HERE

EVALUATION REQUEST FORM

CONTACT INFORMATION

NAME:

TITLE:

COMPANY NAME:

ADDRESS:

COUNTRY:

PHONE:

ADDRESS:

FEED GAS INFORMATION

GAS SOURCE:

GAS PRESSURE:

GAS FLOWRATE:

GAS TEMPERATURE:

COMPONENT:

Mol%

More 