

MEMBRANE SOLUTIONS FOR NATURAL GAS TREATMENT

Advanced technology for purification of natural gas and associated gas



OUR SOLUTIONS

THE AIR LIQUIDE ADVANTAGE

Air Liquide Advanced Separations (ALaS) manufactures a comprehensive line of membrane products for natural gas and associated petroleum gas treatment. Our product portfolio includes the most robust and efficient hollow fiber membranes in the industry. Whether you need to simply dehydrate your natural gas stream for re-injection, adjust the BTU value for fuel use, recover NGLs, or meet export pipeline specifications, Air Liquide has a membrane solution for you. Our Solutions Development team will work with you to design the most efficient process that meets the gas treatment requirements.

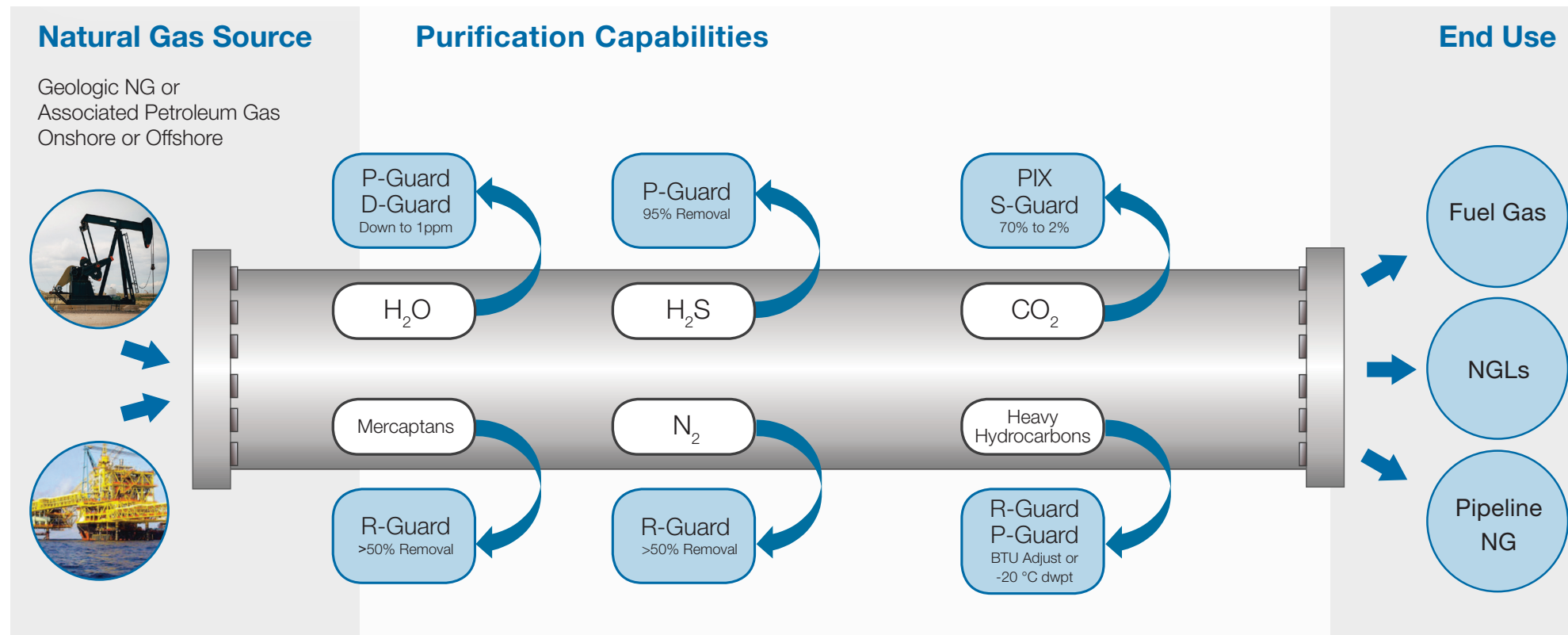
The end result may either be an All-Membrane Solution™ or hybrid offering, combining our membrane technology with absorption, adsorption, or cryogenic-based unit operations, to provide the lowest CAPEX and OPEX solution compared to conventional purification methods.

APPLICATIONS

Air Liquide's MEDAL and PoroGen PEEK-Sep product portfolio provides for natural gas conditioning solutions from the wellhead to the pipeline. Our All-Membrane Solution™ greatly simplifies the gas purification process by removing multiple contaminants in fewer steps than conventional processes.

NATURAL GAS MEMBRANE SOLUTIONS-WELLHEAD TO PIPELINE

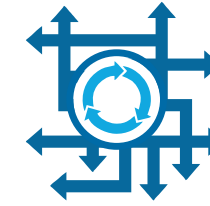
All-Membrane Solution™



ADVANTAGES OF ALL-MEMBRANE SOLUTION™



> 50% REDUCTION IN BOTH FOOTPRINT AND WEIGHT



OPERATIONAL SIMPLICITY WHILE MEETING ALL PROCESS GAS SPECIFICATIONS



REDUCED SPARE PARTS INVENTORY



REDUCTION IN CAPEX AND OPEX



ALL-MEMBRANE SOLUTION™ VS CONVENTIONAL PROCESS

ALL-MEMBRANE SOLUTION™



TYPICAL CONVENTIONAL PROCESS



PoroGen PEEK-Sep membranes can operate in condensing mode with minimal pre-treatment.

ONSHORE OR OFFSHORE

Air Liquide offers the most robust, reliable and cost effective gas treatment solutions for your onshore or offshore applications through a global network of engineering and system fabrication partners.

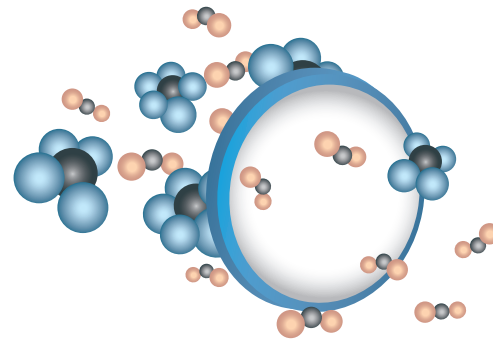
Our All-Membrane Solution™ offers distinct advantages over conventional multi-step unit operations and spiral-wound cellulose acetate membrane alternatives. The benefits are magnified for offshore platform and FPSO applications where multiple contaminants must be removed from the gas stream.

OUR TECHNOLOGY

HOW GAS SEPARATION OCCURS

Air Liquide membranes exploit the pressure difference between the feed gas and waste (permeate) gas, where impurities are concentrated, as the driving force for the separation. The hollow fiber membrane materials allow certain selective removal of impurities that permeate membrane walls as fast molecules while the product is collected at high pressure as the non-permeate stream. Membrane material and configuration are tailored to each application to achieve the optimum trade-off between purity and recovery.

Target product purity and recovery is economically achieved utilizing our high selectivity and high productivity membranes. Unique module designs enable meeting of these targets even at low trans-membrane pressures.

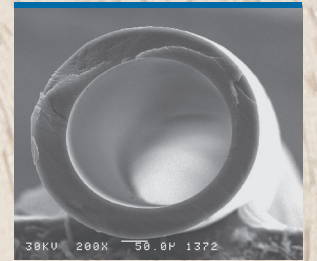


INSIDE THE MEMBRANE MODULE

MEDAL TECHNOLOGY

The MEDAL membranes are asymmetric polyimide-based hollow fibers comprised of a core which is optimized for mechanical strength and a sheath optimized for gas separation.

*A 12-inch module contains 0.5-1.0 million fibers.
Laid end-to-end, the fibers would stretch for 750 miles (1200 km).*

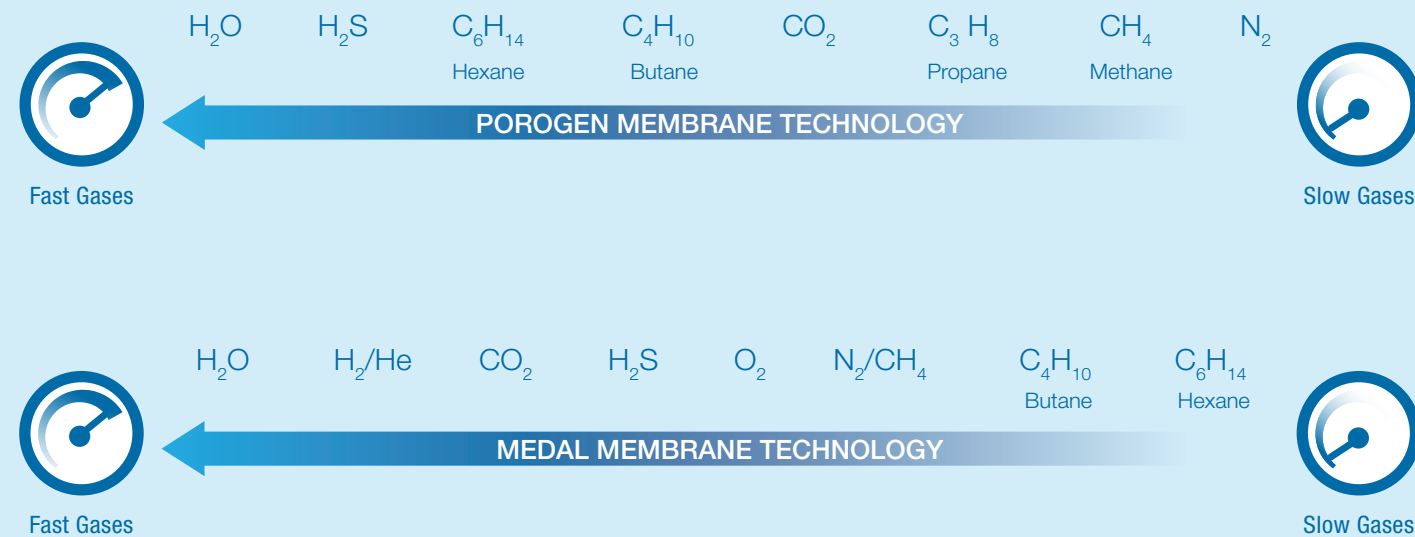


As compared to other membrane technologies, MEDAL large diameter 12" membranes fit more surface area into a given volume, which requires less steel, thereby lowering system cost. Membrane modules may contain over 1 million individual hollow fibers. Fiber bundles are formed in cross flow and counter flow designs allowing for flexibility in meeting all pressure drop and performance constraints.

Hollow fiber membranes are formed using high performance materials to allow operation at elevated temperatures and extreme pressures. Residue gas collection tubes, with orifices custom drilled for each application, ensure even gas distribution and consistent performance from each MEDAL bundle.

GAS PERMEATION HIERARCHY

Our MEDAL and PoroGen PEEK-Sep product lines are highly complementary. Natural gas product purity targets can be achieved and process economics optimized using either conventional or non-conventional gas permeation hierarchy, or a combination of both.



POROGEN PEEK-SEP TECHNOLOGY

PEEK exhibits "best in class" thermo-mechanical properties and chemical resistance. PEEK membranes are not affected by solvents and chemicals present in the natural gas and can operate without extensive pretreatment. Membranes from PEEK are extremely robust with exceptional properties:

- Superior combination of strength and flexibility
- High temperature operating limits with almost constant mechanical properties over a wide temperature range
- High chemical resistance in all kind of aggressive media
- High wear resistance

The hollow fiber dimensions and pore size are tailored towards the target gas purification. The hollow fiber surface chemistry is optimized to enhance target separation by chemical modification or coating.

PEEK-Sep hollow fiber membrane modules use proprietary computer controlled winding technology that enables construction of membrane cartridges with uniform predetermined packing density, which in turn provides superior flow dynamics, minimizes pressure drop and improves separation efficiency. Hollow fiber devices operate in counter-current mode for enhanced separation efficiency.

UNIQUE MEMBRANE FEATURES

- Minimal pretreatment required for membrane protection
- Exceptional chemical and thermal resistance
- Resistant to all gas phase components – including acid gases H₂S, CO₂
- Broad range of operating temperatures
- Resistant to aromatics and aliphatic hydrocarbons, NGLs
- Resistant to process fluids - water, methanol, amines, glycol
- Efficient heat and mass transfer in the same device
- Structured hollow fiber configuration for optimal thermodynamic separation efficiency
- Low pressure drop and low hydrocarbon losses
- In case of liquids flooding, membrane performance is restored after liquids are drained and membrane returned to gas phase operation

MEMBRANE CONFIGURATION

HIGHLY EFFICIENT MEMBRANE PACKAGING

MEDAL and PoroGen PEEK-Sep membranes are manufactured in hollow fiber configuration, small diameter porous tubes made of polyimide and PEEK polymers. The small contained volume of the hollow fiber membrane is advantageous for offshore separation applications where space is limited and the natural gas product is of high value. ALaS hollow fiber module designs are configured for counter-current flow for most efficient hydrocarbon recovery.

HOLLOW FIBER CONFIGURATION PROVIDES THE MOST OPTIMAL PACKAGING CONFIGURATION

Counter-current flow characteristics achieve high purity and recovery

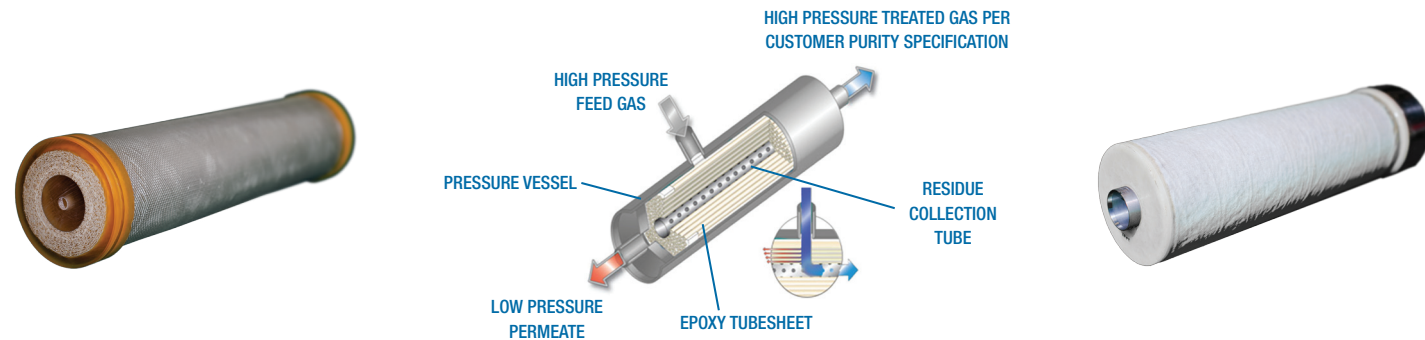
High membrane area in given module volume

Compact system footprint

SUPERIOR GAS SEPARATION EFFICIENCY

The membrane cartridge is installed into a pressure housing and sealed with o-rings. The cartridge can be installed and removed easily. Multiple membrane modules are packaged into a separation system tailored towards a customer separation application. The high pressure feed gas is introduced on the shell side of the hollow fibers and impurities are removed as a low pressure permeate gas on the bore side of hollow fibers. Membranes are tailored towards target gas purification and multiple impurities can be removed simultaneously in a single process step.

The MEDAL PIX membrane is highly efficient for CO₂ removal applications where high methane recovery is required. The high selectivity of this polyimide-based membrane maximizes recovery of CH₄ in the high pressure product stream, meaning more sales gas in the pipeline. Selectively permeable PoroGen PEEK-Sep membranes with ultra-thin separation layers are tailored towards removal of heavy hydrocarbons (C3+), H₂S, and water vapor from raw natural gas to improve gas quality.



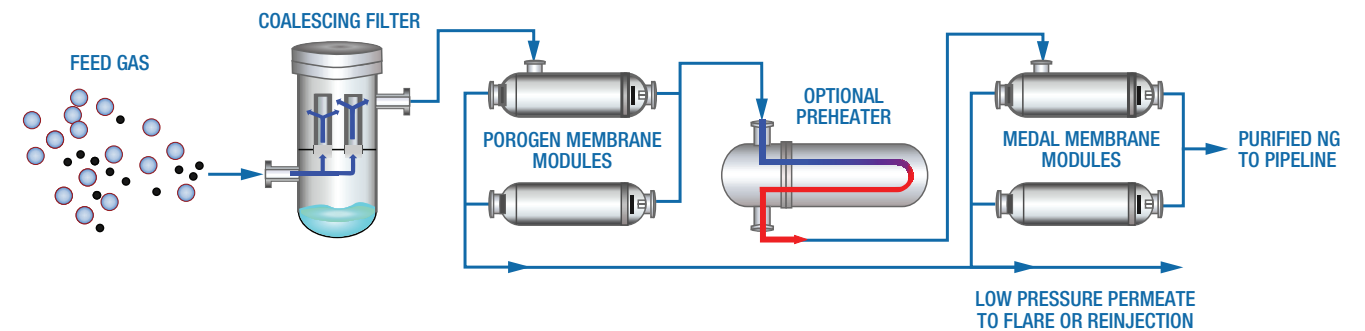
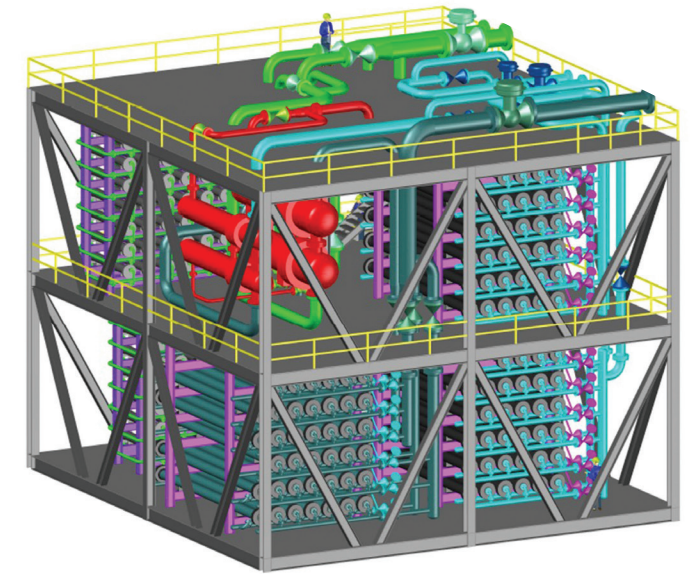
FLEXIBLE MEMBRANE MODULE DESIGN

- Simple, flexible and cost effective membrane module design
- Compact packaging with small footprint
- Adjustable purge used to enhance separation efficiency by purging membrane permeate conduit with fractional volume product gas
- High pressure operating capability, 1000-1500 psig ΔP differential pressure

COMPLETE MEMBRANE SOLUTIONS

From individual hollow fibers to complete separation systems, Air Liquide membrane modules are incorporated into packaged systems to provide a complete natural gas purification solution.

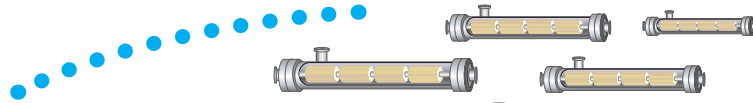
The feed gas to be purified is pretreated to remove bulk liquids and particulates using a coalescing filter. The feed gas is processed in our PoroGen and MEDAL membranes with interstage heat applied to achieve optimal membrane performance and desired natural gas purity and recovery.



Typically each membrane module operates in parallel; however, multiple membrane configurations (parallel or series) and stages are available to optimize client's CAPEX and OPEX requirements.



OVER **40** NATURAL GAS MEMBRANE SYSTEM REFERENCES WORLDWIDE

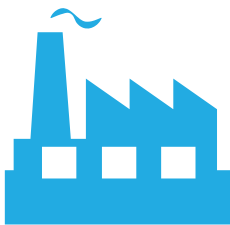


OVER **1000** ALaS NATURAL GAS MEMBRANE MODULES IN OPERATION WORLDWIDE



ALL MEMBRANE MODULES MANUFACTURED WITHIN THE **USA**

WORLDWIDE SYSTEM FABRICATION CAPABILITIES



NATURAL GAS SYSTEMS IN OPERATION UP TO 530MMSCFD
(SYSTEMS CAN BE DESIGNED TO HANDLE ANY FEED FLOW SINCE MEMBRANES ARE MODULAR)

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