Biogas and Membranes - Upgrading Essentials

ABC Sponsored Webinar
August 2, 2023

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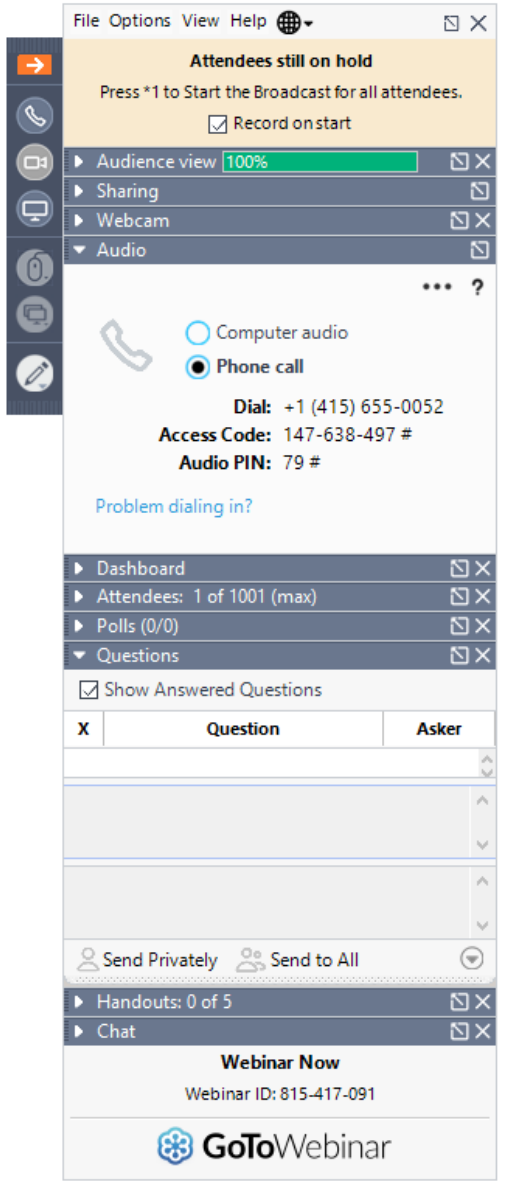


Audio

Questions

Who We Are

The only US organization representing the entire biogas industry

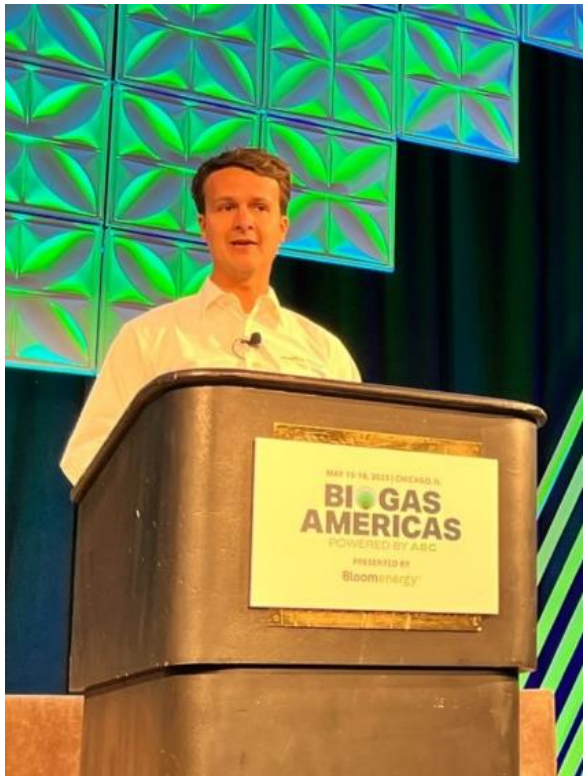
All sectors represented

- Project developers/owners
- Equipment retailers and dealers
- Waste management companies
- Waste water companies
- Farms
- Utilities
- Municipalities
- Consultants and EPCs
- Financiers, accountants, lawyers and engineers
- Non-profits, universities and government agencies

370+ organizations

5,000+ individuals

Speakers



Rory Deledda
Global Biogas Product Manager
Air Products

Paul Greene (Moderator)
Principal
GreeneTec

Moving Forward

Air Products Membrane Solutions

Biogas and Membranes - Upgrading Essentials

Agenda for today

- Membrane basics
- System designs & configurations
- Membranes vs. other technologies
- Case histories
- How membranes can benefit your system

The Membrane Solutions group is an essential integrated business of Air Products supporting internal and external customers

- Active R&D since 1970; first commercial install 1980.
- Enough membrane fiber produced per year for use in membranes to go to the moon and back more than 3 times!
- 625+ systems installed in process gas applications (petrochemical, refinery, natural gas)
- 300+ engineered to order nitrogen systems installed in petrochemical plants, offshore platforms, oil-field locations
- 1500+ nitrogen systems installed on marine vessels
- >175 global references in biogas upgrading installations through OEM channels
- Global footprint of partners who utilize and resell PRISM® membranes in their generated gases systems

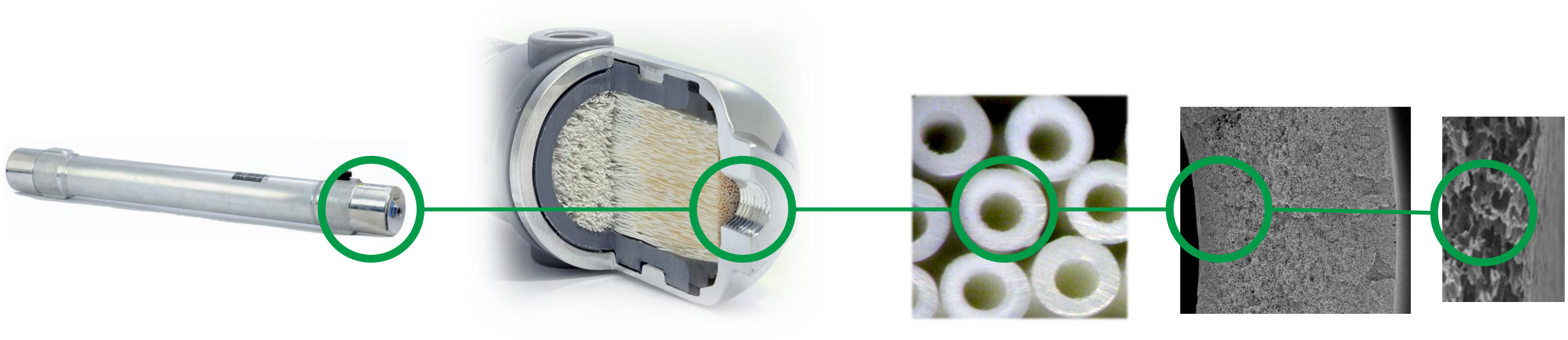
The potential of membranes as technology in biogas upgrading has been recognized early by Air Products Membrane Solutions

- Active R&D with focus on biogas upgrading since 1994
- First commercial install 1983 – test site for landfill gas upgrading
- Over >175 references in the biogas membrane upgrading space
  - References in Americas, EU and Asia
  - One of the largest biomethane system (12.000 Nm3/hr)
- References with diverse feedstocks:
  - Landfill
  - Manure
  - Agricultural Waste
  - Biowaste
  - Food Waste
  - Waste Water
- Biogas upgrading with membranes to:
  - Grid injection
  - CNG bottling & fueling
  - LNG production & fueling
  - Conversion to H2

Membrane basics

- What is a membrane?
- How does a membrane work?
- Selectivity & Permeability

A gas separation membrane is a static, mechanical/chemical and highly engineered separation mechanism for complex gas mixtures



PED certified aluminum/SS closed and ready-for use shell in different diameters & lengths

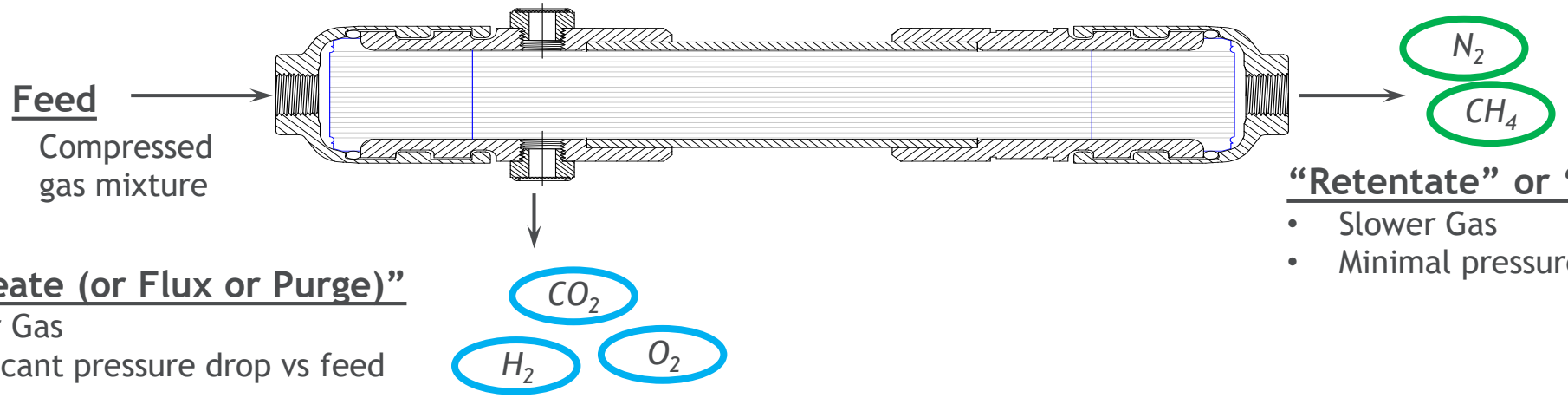
Polymeric fibers which are bore-side (fiber is pressurized) fed with gas “pushed” against the tube sheet

Thousands of fibers are bundled together and packed into the membrane shell

Polymeric fibers have an asymmetric fiber structure with thin selective skin

Increased engineering & R&D complexity

Gas separation membranes act as a permeable barrier through which different molecules “move” across at different rates

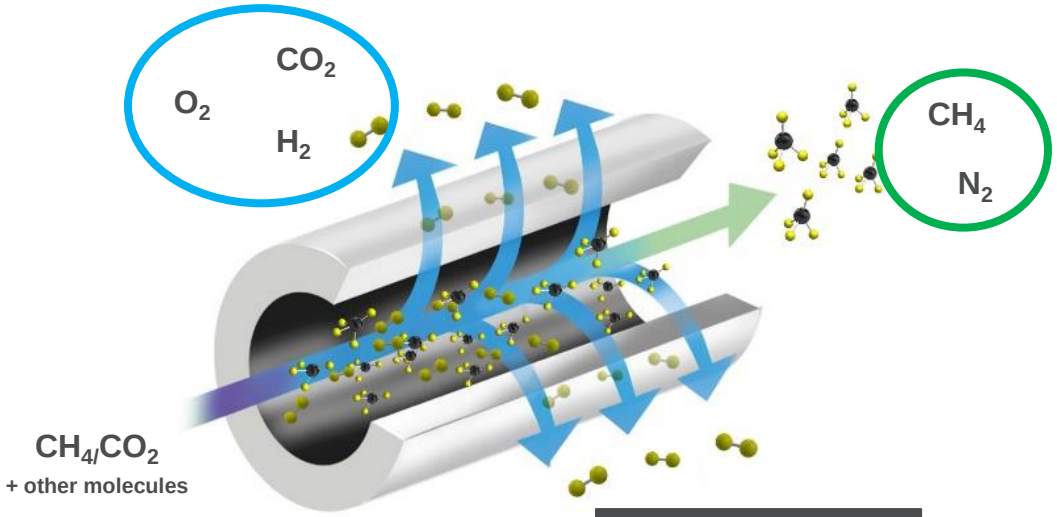


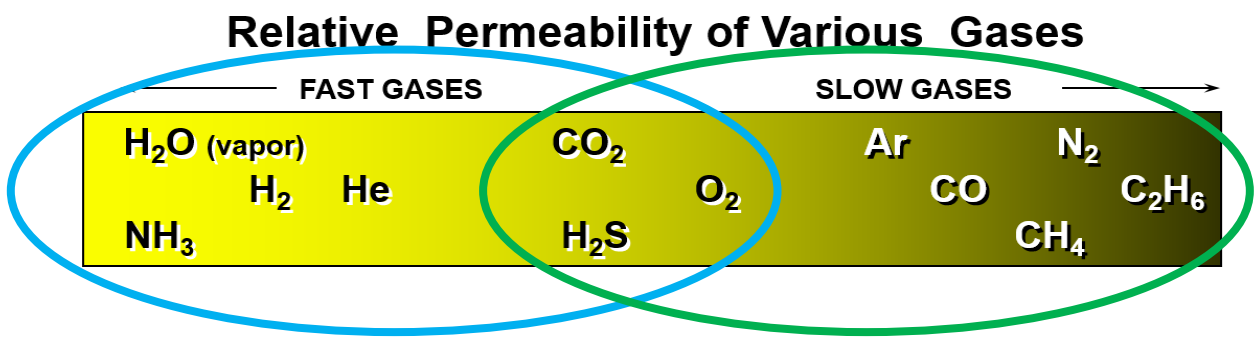
“Retentate” or “Nonpermeate”

- Slower Gas
- Minimal pressure drop vs feed

“Permeate (or Flux or Purge)”

- Faster Gas
- Significant pressure drop vs feed





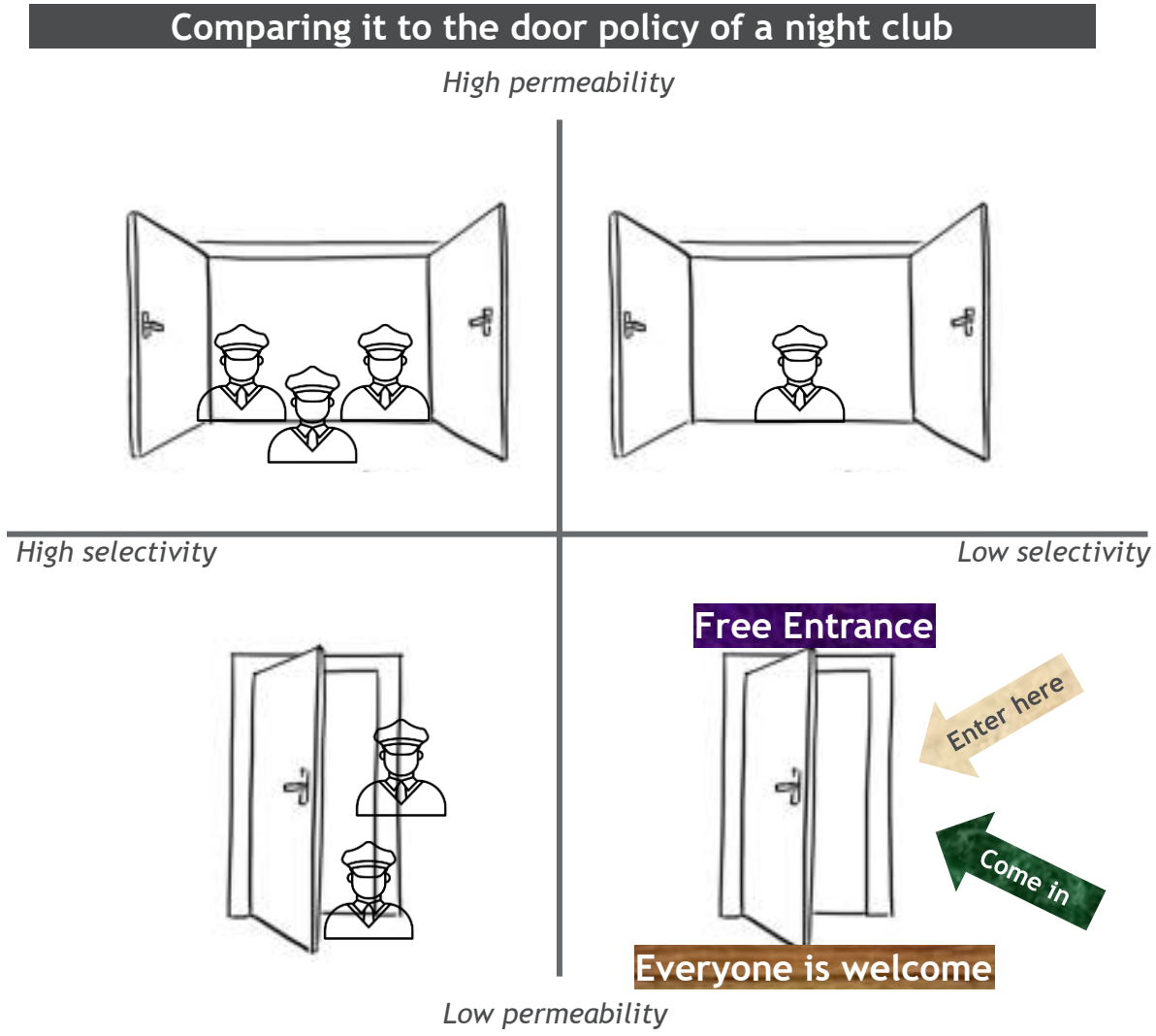
The membrane characteristics are defined as permeability & selectivity. Raw material choice for membrane production change characteristics

Permeability is the rate that gases "diffuse and dissolve" through the polymeric fiber

- Measure of membrane productivity
- Molecule size (smaller molecules permeate faster)
- Structure of fiber

Selectivity is the rate that gases are allowed to pass through the polymeric fiber

- Measure of membrane efficiency
- Defined by membrane material
- Very thin separating layer

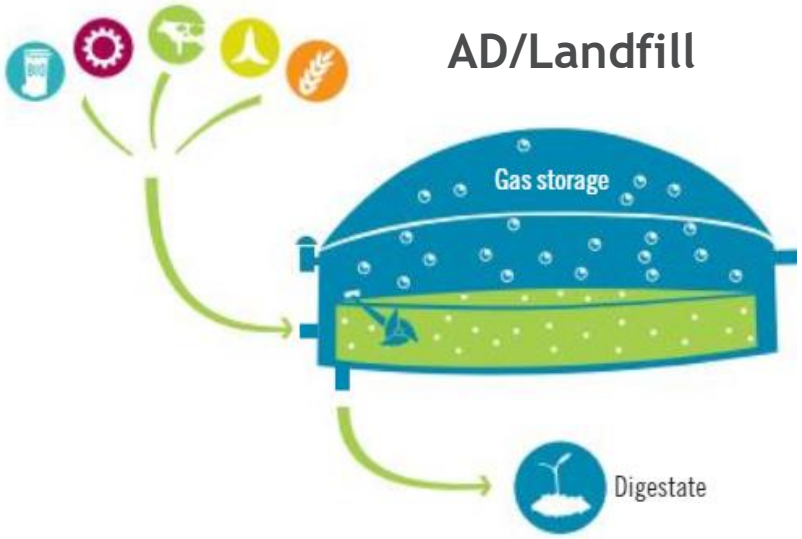


System design & configurations

- Pre-treatment
- Membrane configurations
- Operating variables

Membranes are the most reliable and maintenance free technology available if…. the pre-treatment is designed and operated correctly

Feedstocks



Raw biogas

- 45-85 vol% CH4
- 25-50 vol% CO2
- Byproducts: H_2O, H2S, NH3, O2, N2, VOC's, Siloxanes, Particles, amines, oil, etc.

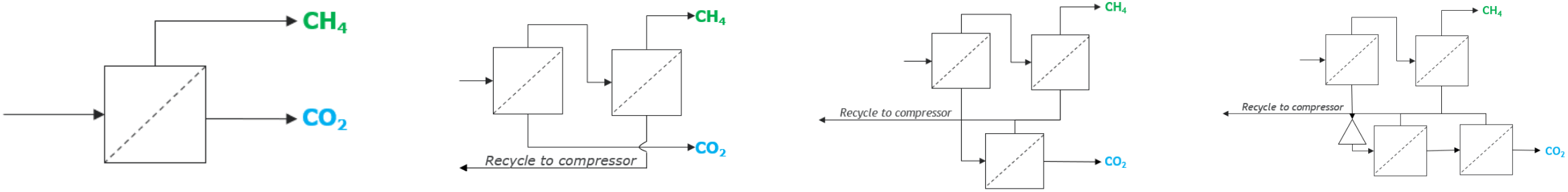
These components require removal before compressor and/or membrane feed

Typical pre-treatment including compression

Correct pretreatment gives:

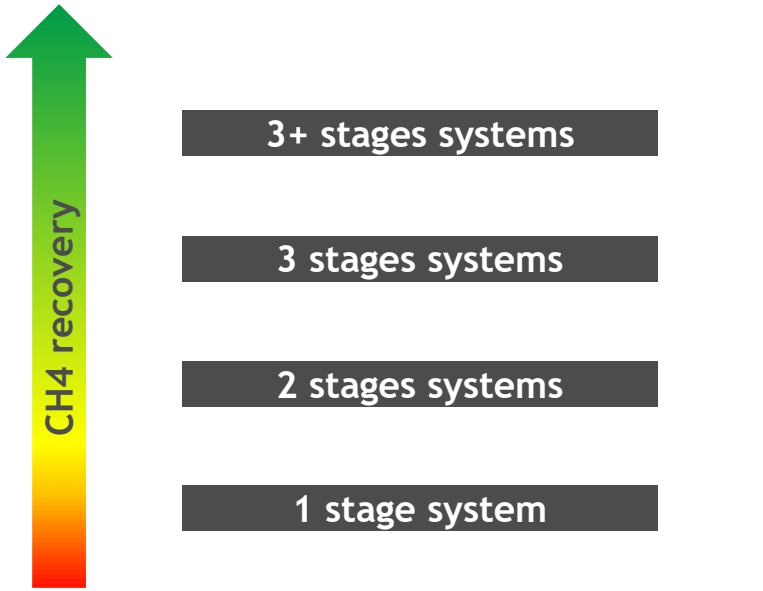
- Extended lifetime & reduced maintenance
- No unpredicted downtime
- Performance upkeep
- Corrosion & deposits prevention

The configuration of membranes (parallel and in series) defines the system performance, power consumption & OPEX/CAPEX relation



Functions of each separation stage:

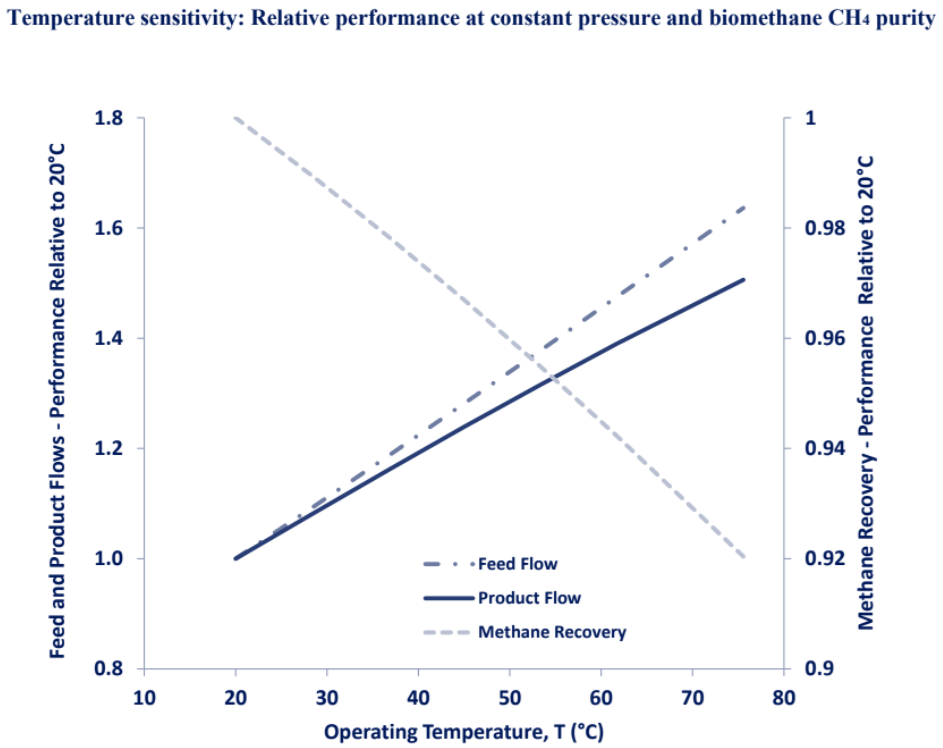
- Stage 1 (Feed Stage): Initial bulk separation – must permeate almost all the CO2 in the raw biogas
- Stage 2 (Stripping Stage): Final polishing step - determines CH4 purity
- Stage 3: (Enriching Stage): Final CO2 enriching step (also must permeate nearly all the CO2 in the raw biogas) - determines CH4 recovery
- Additional stages: increase CH4 recovery and/or CH4 purity



Two controllable parameters, temperature and pressure, determine performance efficiency of the membrane configuration.

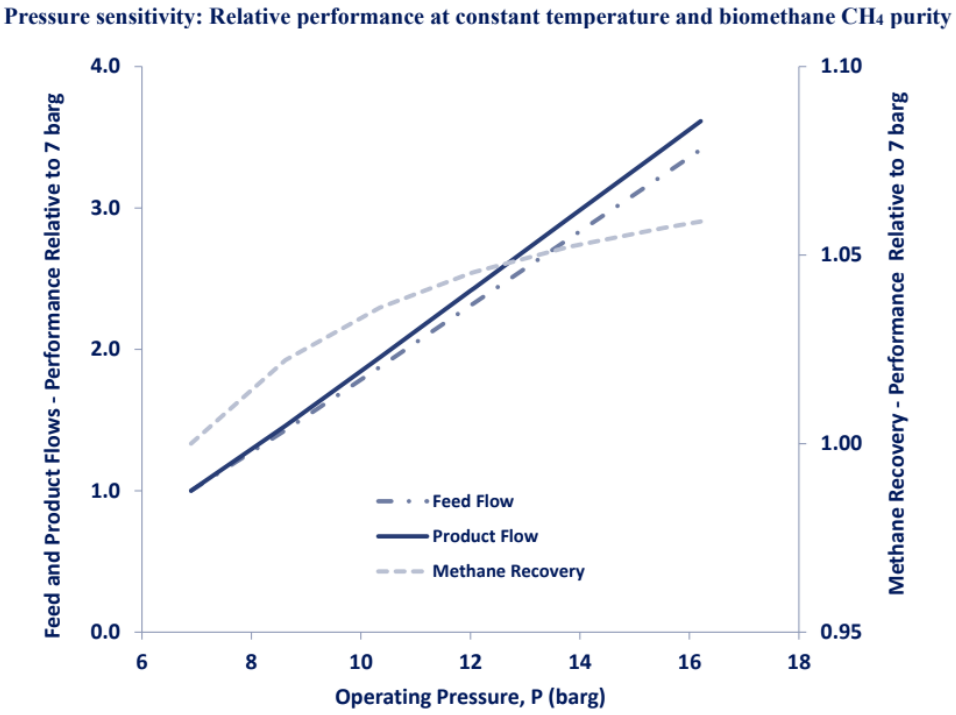
Membrane operating temperature

- Typical operating temperature is 20-50°C
- ↑ Temperature ≡ ↑ Permeability ≡ ↓ selectivity
- ↓ Temperature ≡ ↓ Permeability ≡ ↑ selectivity



Membrane operating pressure

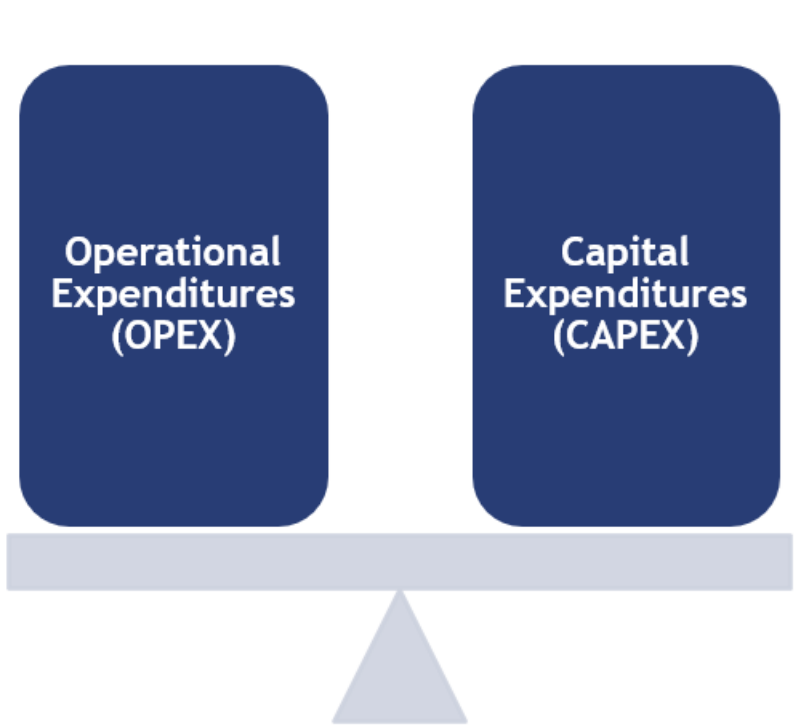
- Typical operating pressure is 10-16 barg
- ↑ Pressure ≡ ↑ Permeability ≡ ↑ selectivity
- ↓ Pressure ≡ ↓ Permeability ≡ ↓ selectivity



Choosing the most efficient configuration depends on how efficient is defined. Most improvements have a trade-off in the OPEX/CAPEX relationship

Considerations for choosing a desirable configuration

Compressor sizing	Recycle rate	Maintenance
Power consumption	CH4 slip in CO2 vent	Legislation
CH4 purity	CO2 purity	Membrane count
CH4 recovery	Physical footprint	Local benefits like IRA
CO2 recovery	Intellectual property	Plant operational flexibility



Membrane vs. other technologies

- Competing technologies
- Comparison of technologies

Membrane upgrading, due to its excellent performance and reliability is the most dominant and further growing technique in biogas upgrading to RNG.

Methane recovery

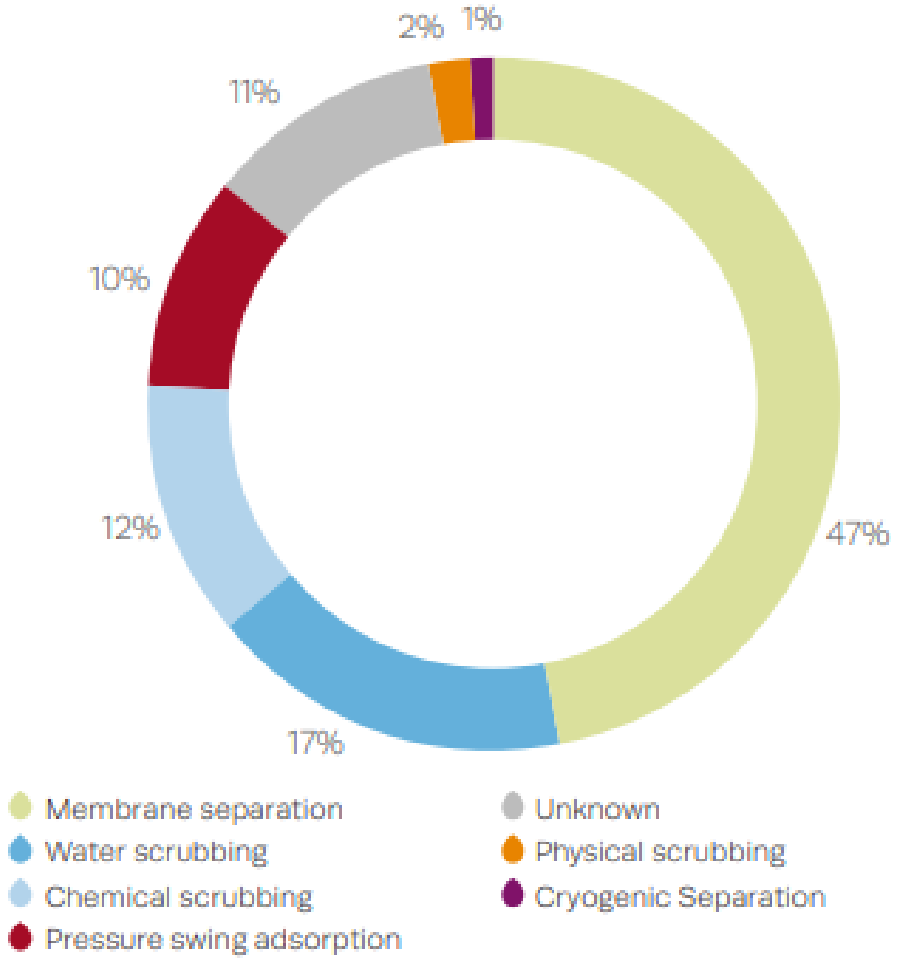
- Amine 99.9%
- Membranes 99.5%
- Water Scrub 98%
- PSA 98%

Methane Slip

- Amine 0.1%
- Membranes 0.5%
- Water Scrub 2.0%
- PSA 2.0 %

Membrane system: 3-stage high recovery configuration

Example: 250 m^3/hour -- data calculated using Bio-methane Calculator -- Vienna University of Technology



Source: EBA Statistical report 2022

Comparing upgrading techniques 1 to 1 is challenging as choice of technique will depend on the set performance parameters by the project owner

All technologies can deliver good quality and high recovery CH4, however all technologies have their pros and con's

Technology	Pro's	Con's
Chemical scrubbing	▪ Almost complete H2S removal	▪ Only one component per column ▪ Catalyst cost ▪ Requires height (tower) ▪ Heat requirement
Cryogenic separation	▪ Requires large flows ▪ Scale-up required ▪ No chemicals	▪ Heavy equipment ▪ High energy consumption
Membrane separation	▪ Compact and light equipment ▪ Low maintenance ▪ Low energy consumption	▪ Membrane size (scalability) ▪ Pre-treatment required
Pressure swing adsorption	▪ Low power consumption ▪ Low emissions ▪ N2 and O2 removal	▪ Requires H2S removal ▪ High maintenance
Water & physical scrubbing	▪ Gas and particle removal ▪ No chemicals ▪ Neutralizes corrosives	▪ Requires H2S removal ▪ Water consumption ▪ Heat requirement

Case histories

- Biogas to H2
- Biogas to bio-LNG
- High CH4 rec. for emission compliance

Case history 1 – Shikaoi, Japan – Biogas to H2

First of its kind project globally

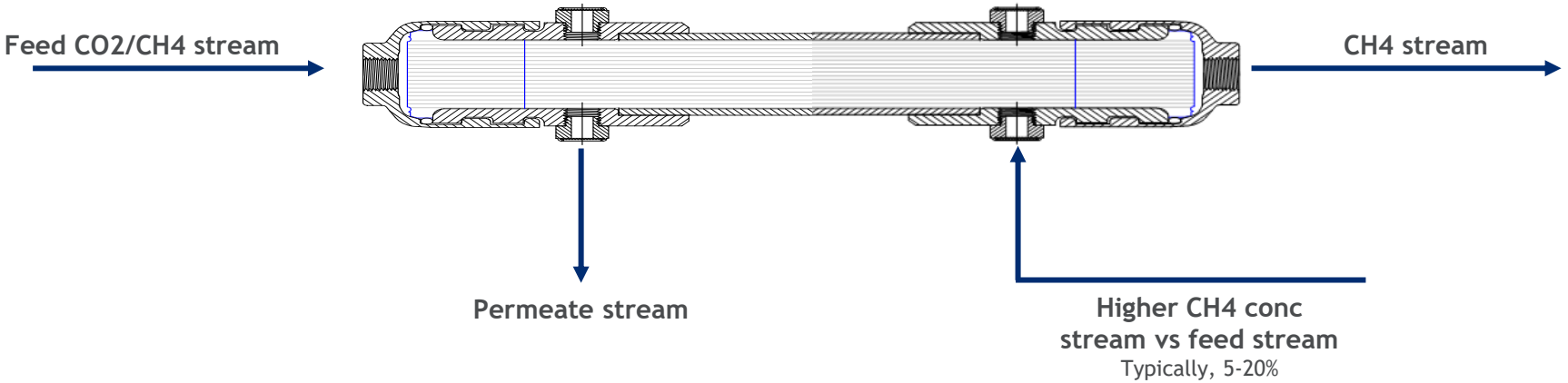
- Membrane upgrading to very pure CH4
- Steam-methane reformer to convert CH4 to H2
- H2 used as fuel grade for transportation

Source: [Air Products webpage]

Case history 2 – Biogas to bio-LNG – Hybrid system

Utilizing the full potential of membrane sweep

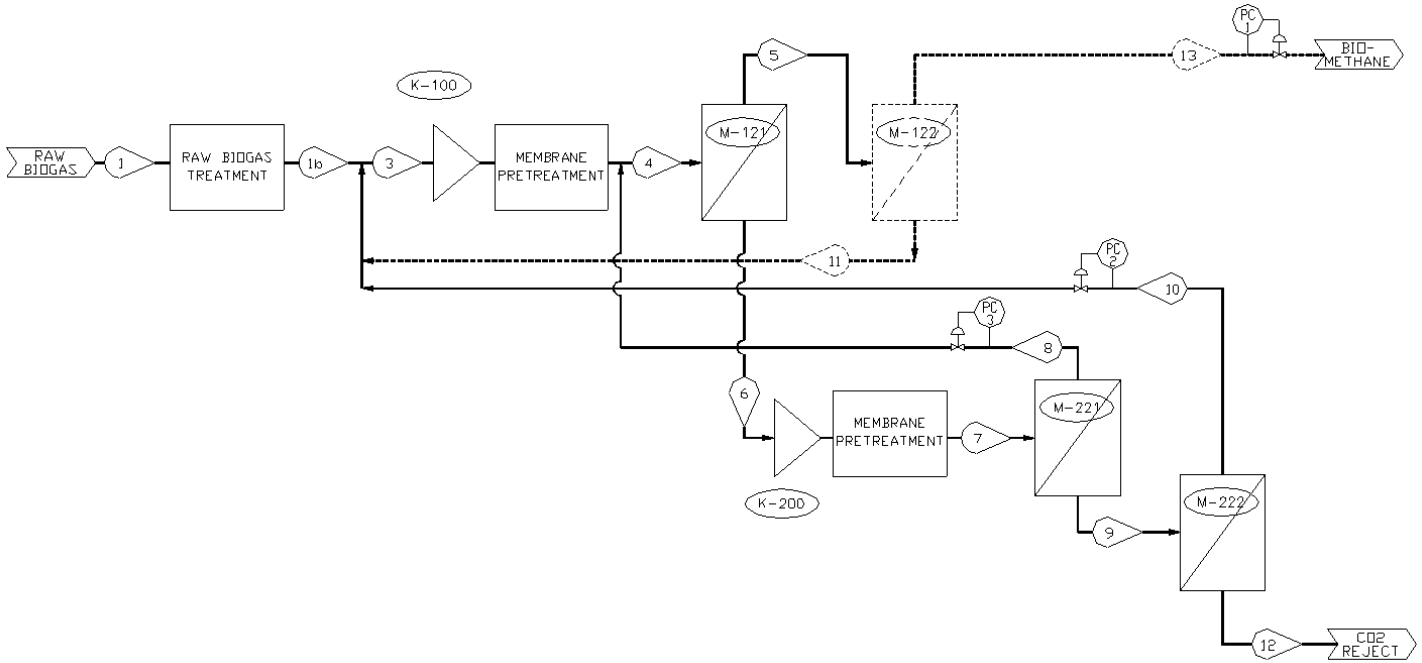
- Membrane upgrading to produce bio-LNG (Rocket fuel quality!)
- Uses proven sweep technology
- Liquefication and membrane process are integrated
- Bio-LNG used as fuel grade for transportation



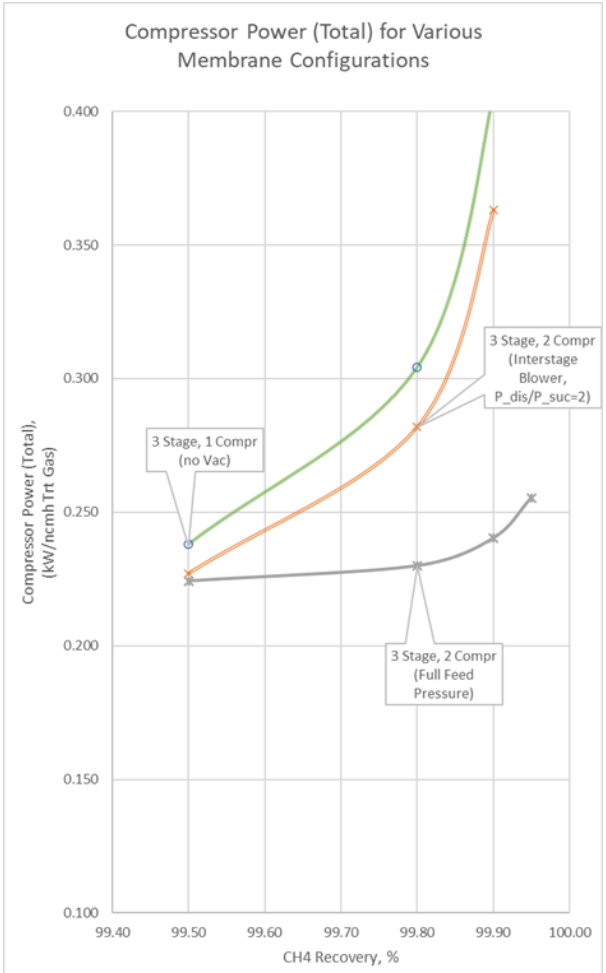
Case history 3 – High CH4 recovery for emission compliance

Emission compliance by using innovative membrane upgrading configuration

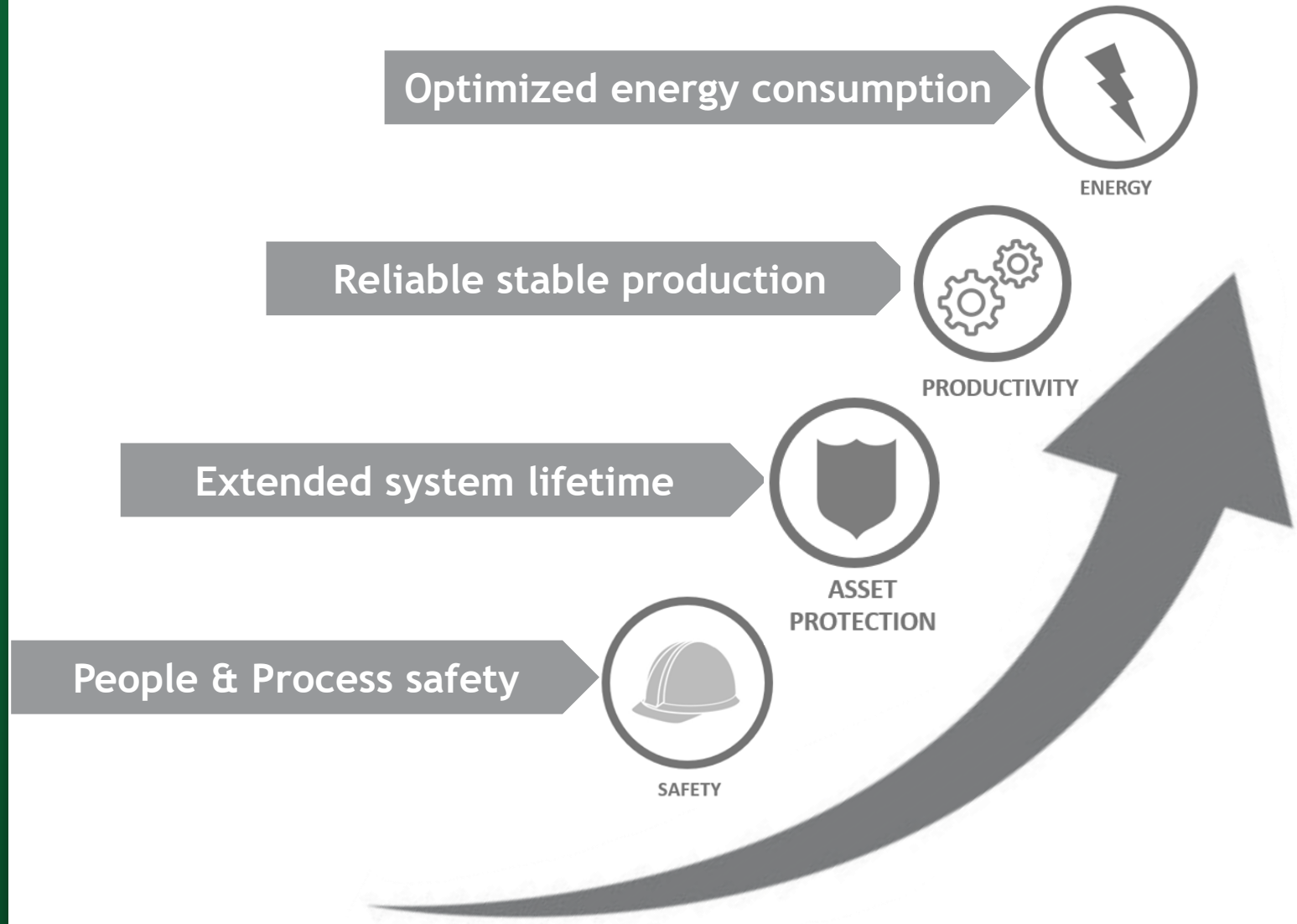
- Air Products patented configuration
- Higher CH4 recovery (>99.9% recovery)
- Lower power consumption vs. 3 stage systems



Patent number US11285434



What can membranes do for you?



Membrane upgrading has a unique positioning vs. other technologies as membranes bring value as stand-alone as well as hybrid solution

High performance membrane separators

Biogas upgrading system design

Technical and application support

Simulations tools and design manuals

System analysis & Performance review

Global experienced support network

AIR PRODUCTS Membrane Solutions

Thank you for attending

Tell us more about your upgrading challenges

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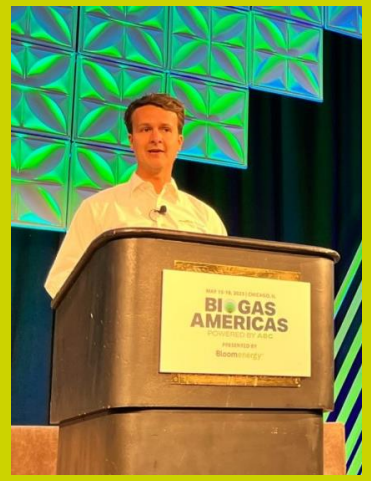
Questions and Answers



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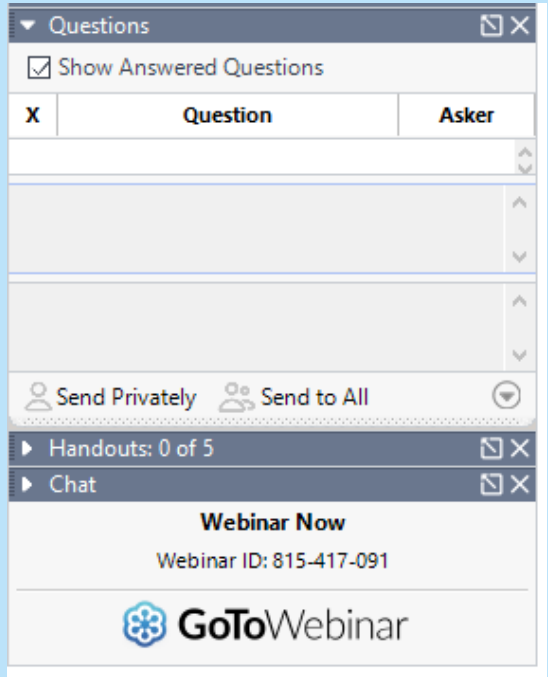

Thank you!

Don’t forget to fill out the survey after the webinar

Become a member!

-Receive regulatory and policy intelligence

-Connect with other biogas and anaerobic digestion leaders

-Support the industry’s growth and outreach

See you at Operator School in August and BUSINESS OF BIOGAS in October!

Thanks for attending!