MEMBRANE AND SEPARATION TECHNOLOGIES RESEARCH WORKSHOP

8:00 AM – 3:15 PM

JUNE 8, 2017

Navigant and NREL,
on behalf of the **United States Department of Energy**,
welcome you to this workshop on

Separation Processes and Membranes For Energy Efficiency

Introductions and Logistics

- Overall schedule
- Breaks
  - Break: 10:40
  - Lunch: 12:15
- Airport transportation
- Introductions

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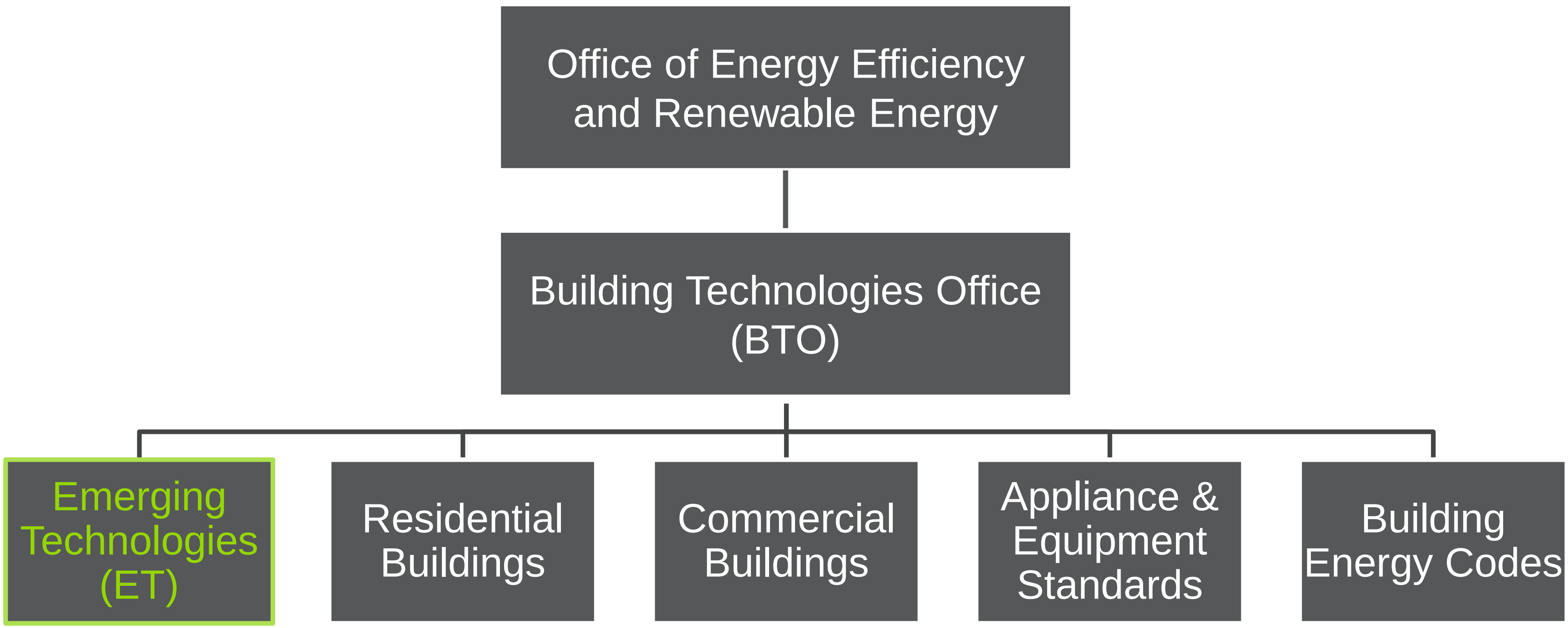
US DOE ORG CHART

BTO “lead(s) a vast network of research and industry partners to continually develop innovative, cost-effective energy saving solutions” for better buildings.



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TECHNOLOGY READINESS LEVELS (TRLS)

The Emerging Technologies group's mission is to support building technology innovation through research primarily on TRL 2 and 3 technologies.

Relative Level of Technology Deployment	Technology Readiness Level	TRL Definition
Basic Technology Research	TRL 1	Basic principles observed and reported
	TRL 2	**Technology concept and/or application formulated**
Research to Prove Feasibility	**TRL 3**	**Analytical and experimental critical function and/or characteristic proof of concept**
Technology Deployment	TRL 4	Component and/or system validation in laboratory environment
	TRL 5	Laboratory scale, similar system validation in relevant environment

BTO EMERGING TECHNOLOGIES RESEARCH PORTFOLIO

Advanced windows

Advanced refrigeration technology

Building energy modeling

Low global warming potential (GWP) refrigerants

Heating, ventilating, air conditioning (HVAC)

Solid state lighting

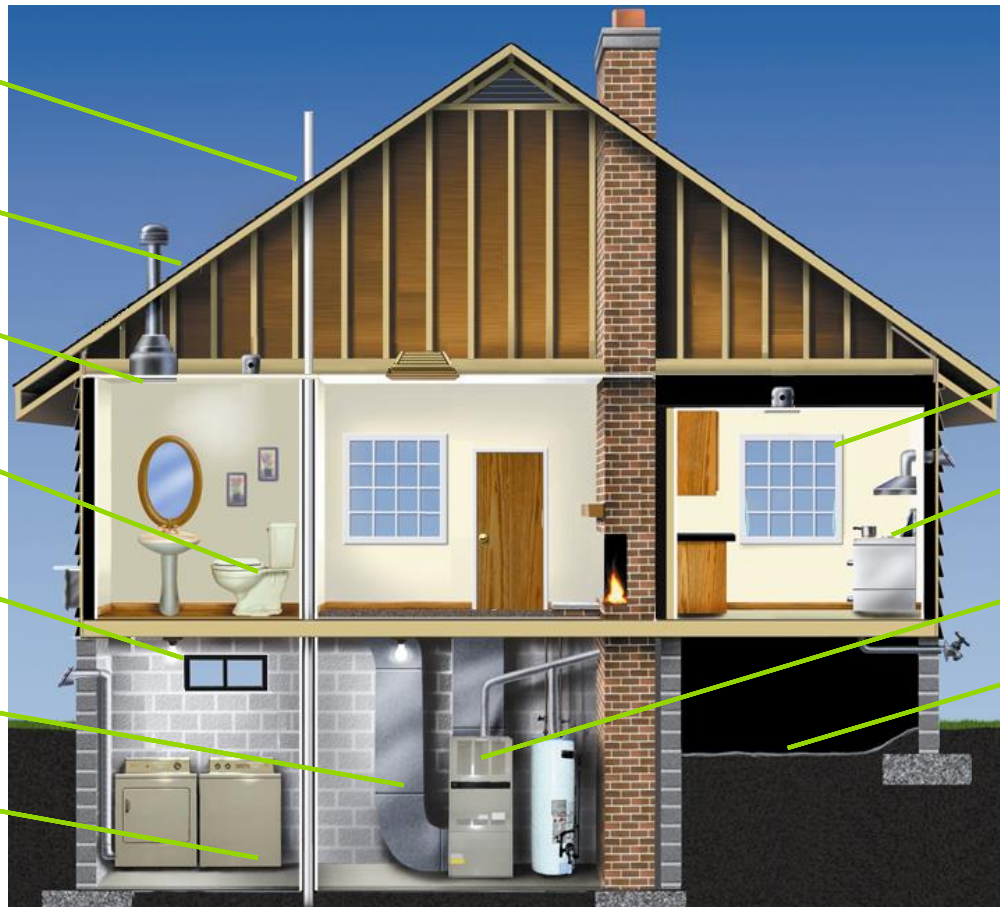
Sensors and controls

Advanced heat pumps:
- **Air source heat pumps**
- **Integrated heat pumps**
- **Heat exchangers**

Water heating and appliances

Building Envelope

POTENTIAL APPLICATIONS OF MEMBRANES AND SEPARATION TECHNOLOGIES IN BUILDINGS



Building-integrated heat & moisture exchange

Envelope moisture barriers

Indoor air quality sensors (CO, CO_2, VOCs, radon)

Waste/grey-water processing

Electric generation (fuel cells, osmotic power)

Energy recovery ventilation

Clothes dryers

Windows (fill-gas generation)

Appliances

HVAC including humidity control

Radon barriers

Other C&I applications:
- CO_2 capture/separation
- Wastewater processing
- Water desalination
- Hydrogen production
- Oxygen-enriched air production

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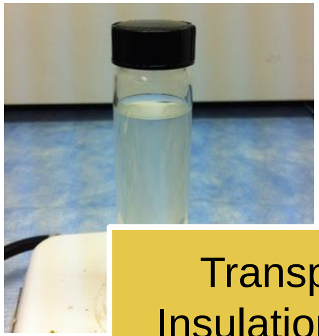
BTO HAS SUPPORTED INNOVATION IN BUILDING TECHNOLOGIES THROUGH NUMEROUS R&D INITIATIVES.

Building-Integrated Heat & Moisture Exchange

Membrane Based Air Conditioning



Transparent Insulation Based on a Porous Silica

Hybrid WH using Electrochemical Compressor

HVAC Load Reduction

Bio-Based Phenolic Foam for Building Insulation

See additional projects on BTO website: http://energy.gov/eere/buildings/hvac-water-heating-and-appliances

RECENT FOA AWARDS

- Advanced membrane A/C – Building Technologies Office
  - Dais Analytic (Florida)
  - http://energy.gov/eere/buildings/downloads/membrane-based-air-conditioning
- Electrochemical compression (ECC) A/C – Building Technologies Office
  - Xergy, Inc. (Delaware)
  - http://energy.gov/eere/buildings/downloads/low-cost-electrochemical-compressor-utilizing-green-refrigerants-hvac
- Fuel Cell Membranes – Office of Basic Energy Sciences
  - Development of durable and inexpensive polymer electrolyte membranes for transportation and stationary applications. Membranes subtopic should be based on proton-conducting non-perfluorinated ionomers, but may include reinforcements or other additives
  - SBIR 2015 – 4 awards: NanoSonic (VA), NEI Corp. (NJ), Amsen Technologies, LLC (AZ), Giner, Inc. (MA)
  - http://energy.gov/eere/fuelcells/articles/sbirsttr-fy16-phase-1-release-1-awards-announced-includes-four-fuel-cell
- Gas Dehydration – Advanced Manufacturing Office
  - Air Products and Chemicals, Inc.
  - http://energy.gov/eere/amo/hollow-fiber-membrane-compressed-air-drying-system

VISION & MOTIVATION

Key Driver:

DOE's goal is to support research to enable innovations that result in dramatically improved efficiency and/or substantial cost reductions for existing efficient equipment.

Why this specific research effort?

- Emerging field with applications in building systems
- Perceived disconnect between separation researchers and the buildings community
- Innovative solutions needed to reach 2030 energy goals

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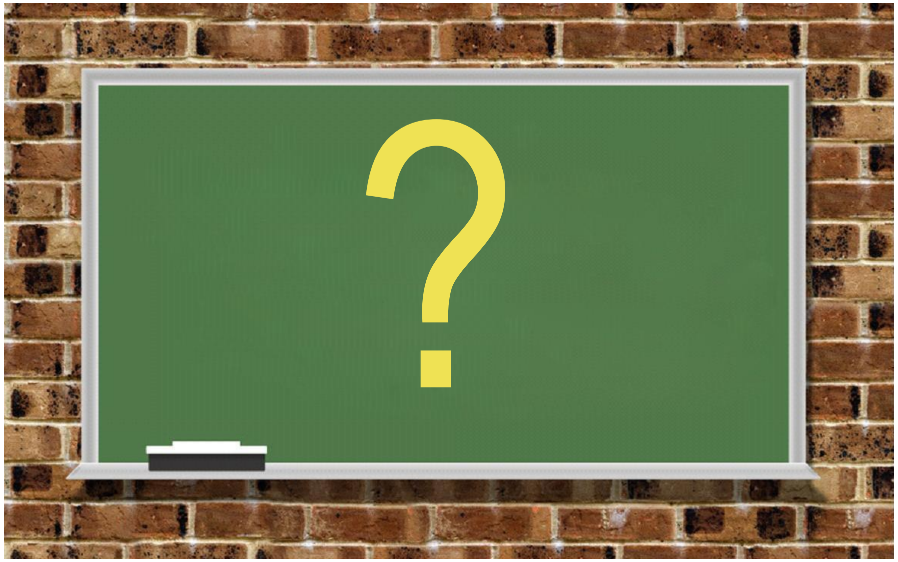
OBJECTIVE OF THIS WORKSHOP

Today's objective:

- Gather input on where the greatest opportunities exist
- Guide prioritization of initiatives for DOE



ptbertram.wordpress.com

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WORKSHOP BOUNDS

- Today we focus solely on early-stage research activities that enable energy/cost savings
- Early-stage research initiatives (i.e. TRLs 2 and 3) focus primarily on basic technology research or research to prove feasibility.

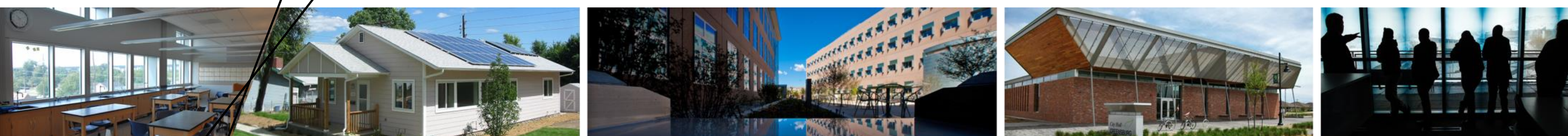
Our discussion <u>excludes</u>:

» Policy issues

» Regulatory actions, such as efficiency standards

» Market transformation activities

Separation processes and membrane science for building applications



Jason Woods

National Renewable Energy Laboratory

BTO Separations Workshop

8-June-2017

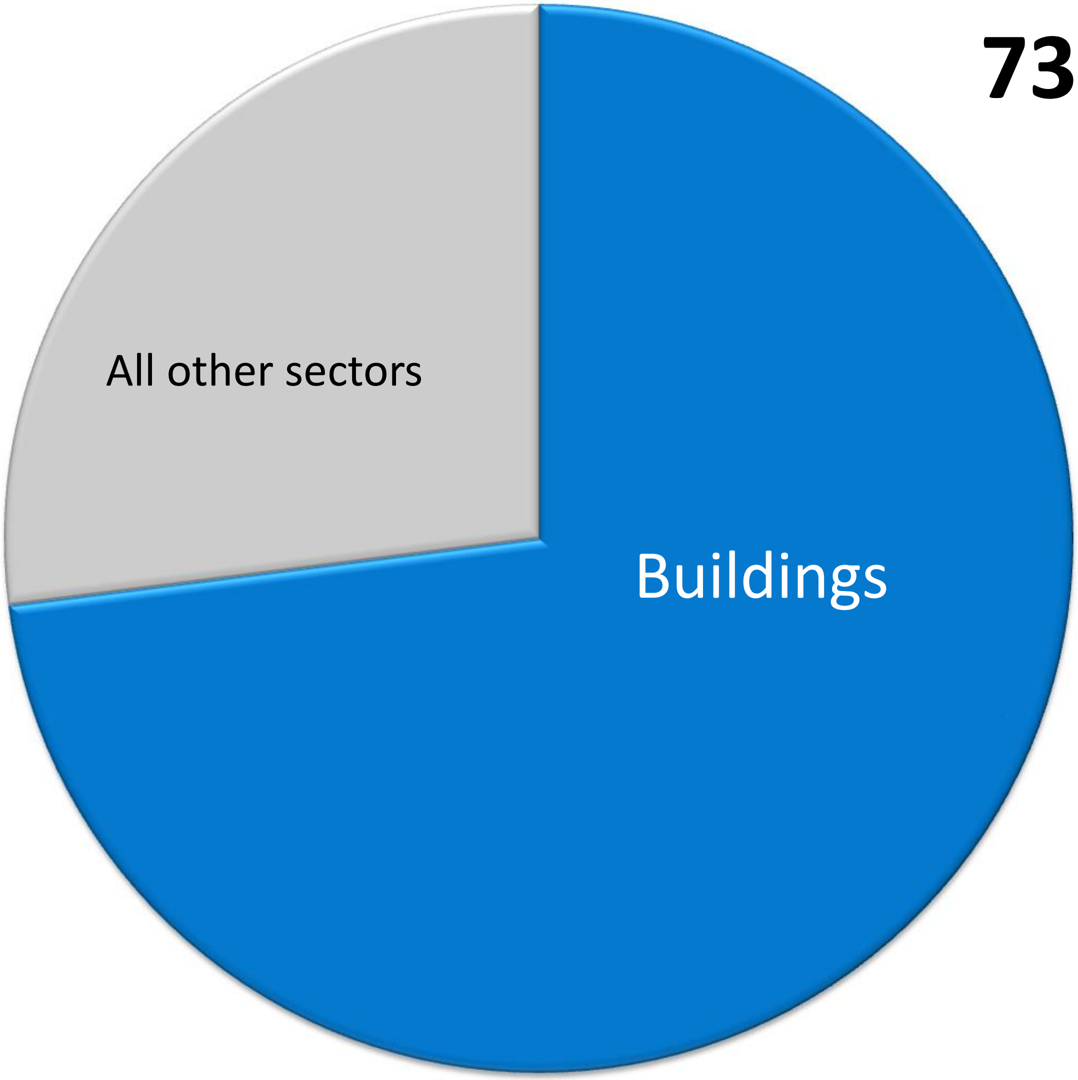
NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

- **Building research needs**
- **Separation and membranes processes**
- **The interface between membranes & buildings**




Building research needs

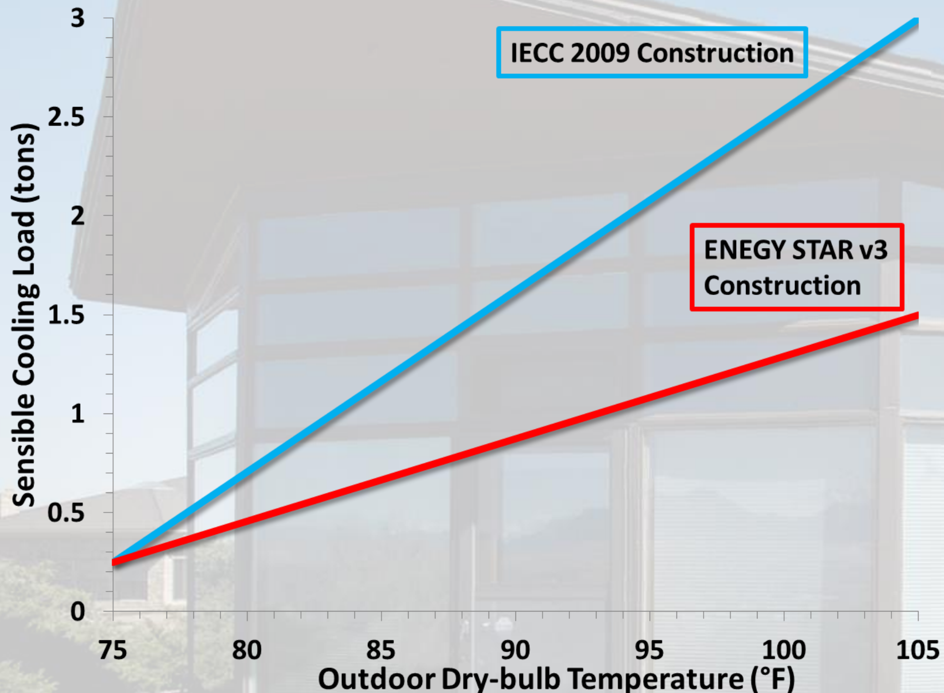
Buildings consume **73%** of US electricity

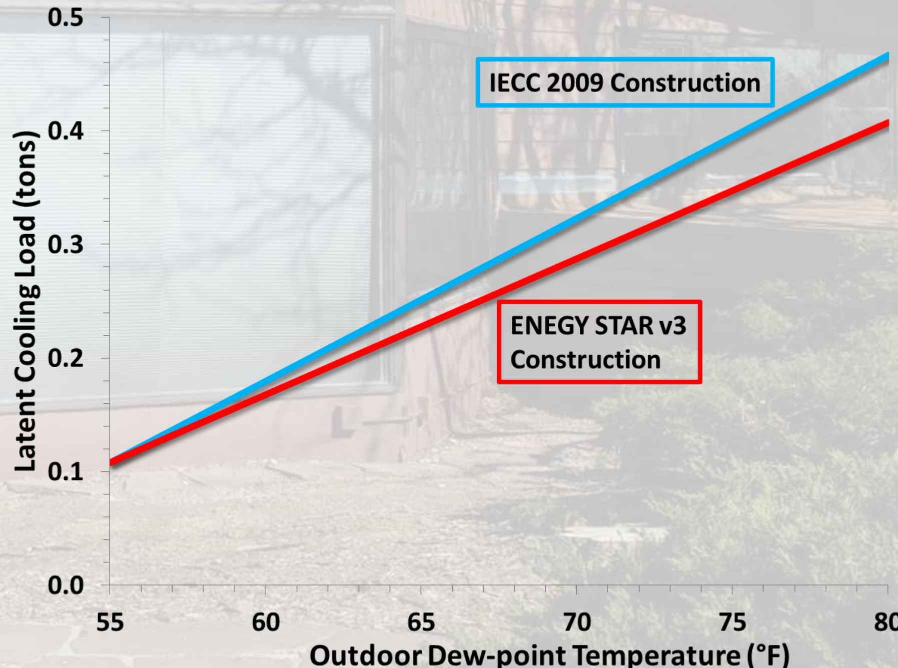


Buildings needs

- **More efficient technology for HVAC and appliances**

New homes behave differently





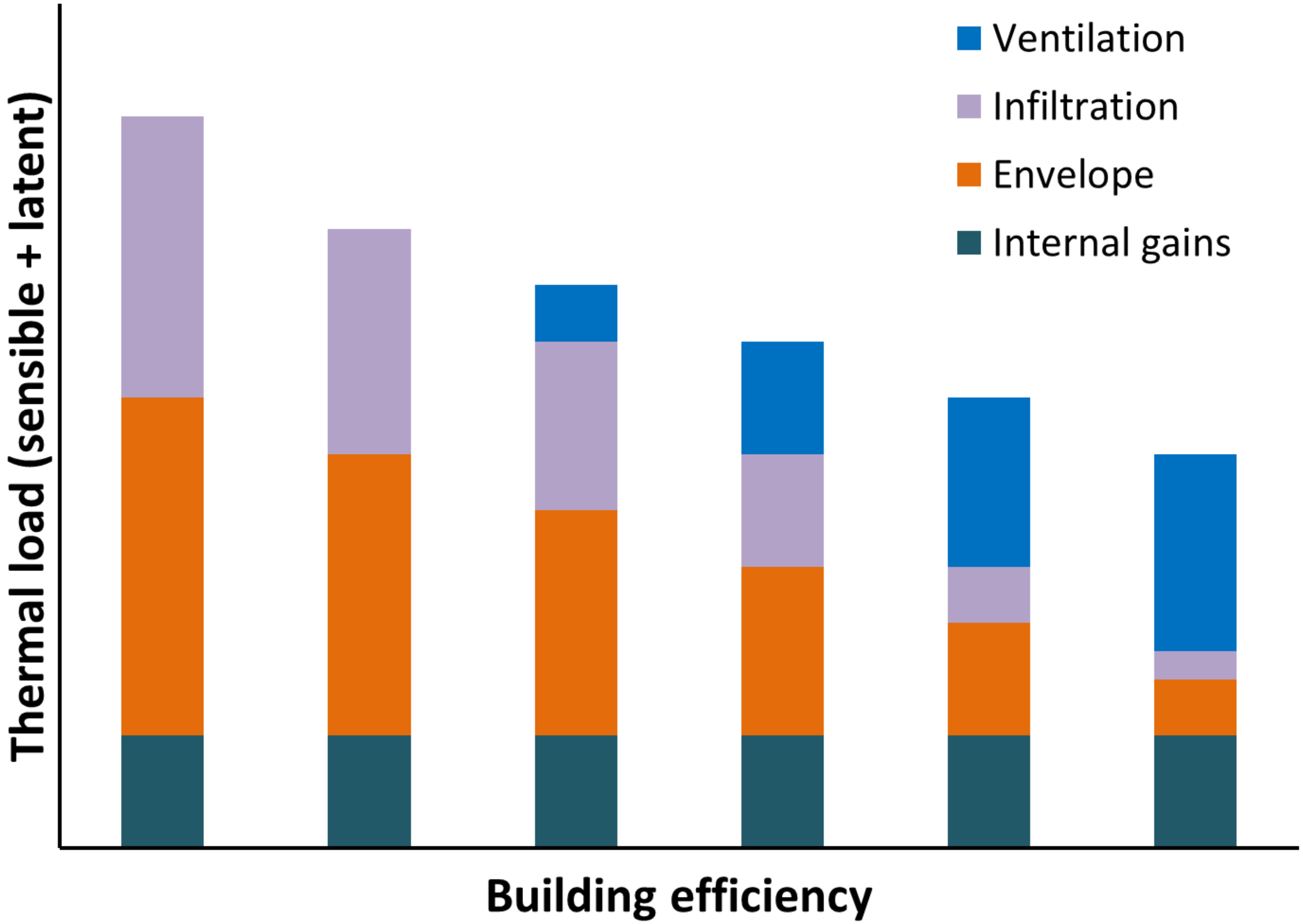
Buildings needs

- **More efficient technology for HVAC and appliances**
- **Improved humidity control**

Buildings needs

- More efficient technology for HVAC and appliances
- Improved humidity control
- Moisture durable walls

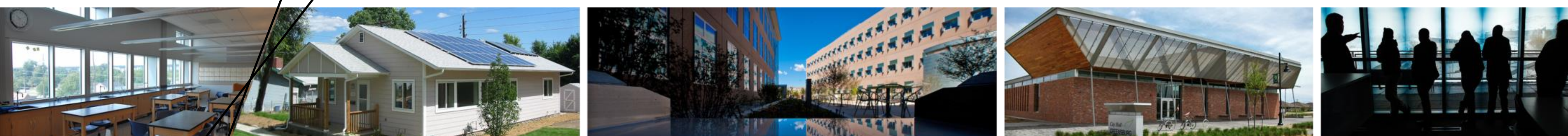
Ventilation becomes more important as building efficiency improves.




Ventilation from outdoors
is not always desirable.

Buildings needs

- More efficient technology for HVAC and appliances
- Improved humidity control
- Moisture durable walls
- Management of ventilation and indoor air quality



Separation processes & membrane science

Separation process

An operation that transforms a mixture of substances into two or more products of different compositions.

Air $\longrightarrow$ Dry air & H_2O

Air $\longrightarrow$ O_2, N_2

Untreated water $\longrightarrow$ pollutants and H_2O

Crude Oil $\longrightarrow$ propane, gasoline, kerosene, diesel, fuel oil

Fractionation / distillation

Pollutant separation

particles (electrostatic precipitator)

SO_2 (Limestone slurry - liquid absorption)

CO_2 (amine liquid absorption)

https://commons.wikimedia.org/w/index.php?curid=767962

Pollutant removal with micro-/ultra-filtration

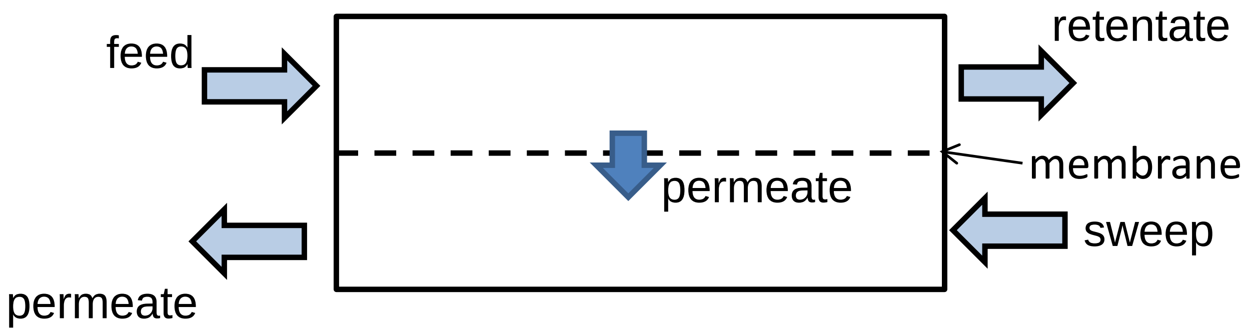
Gas separation

Electrodialysis for purifying or concentrating liquids

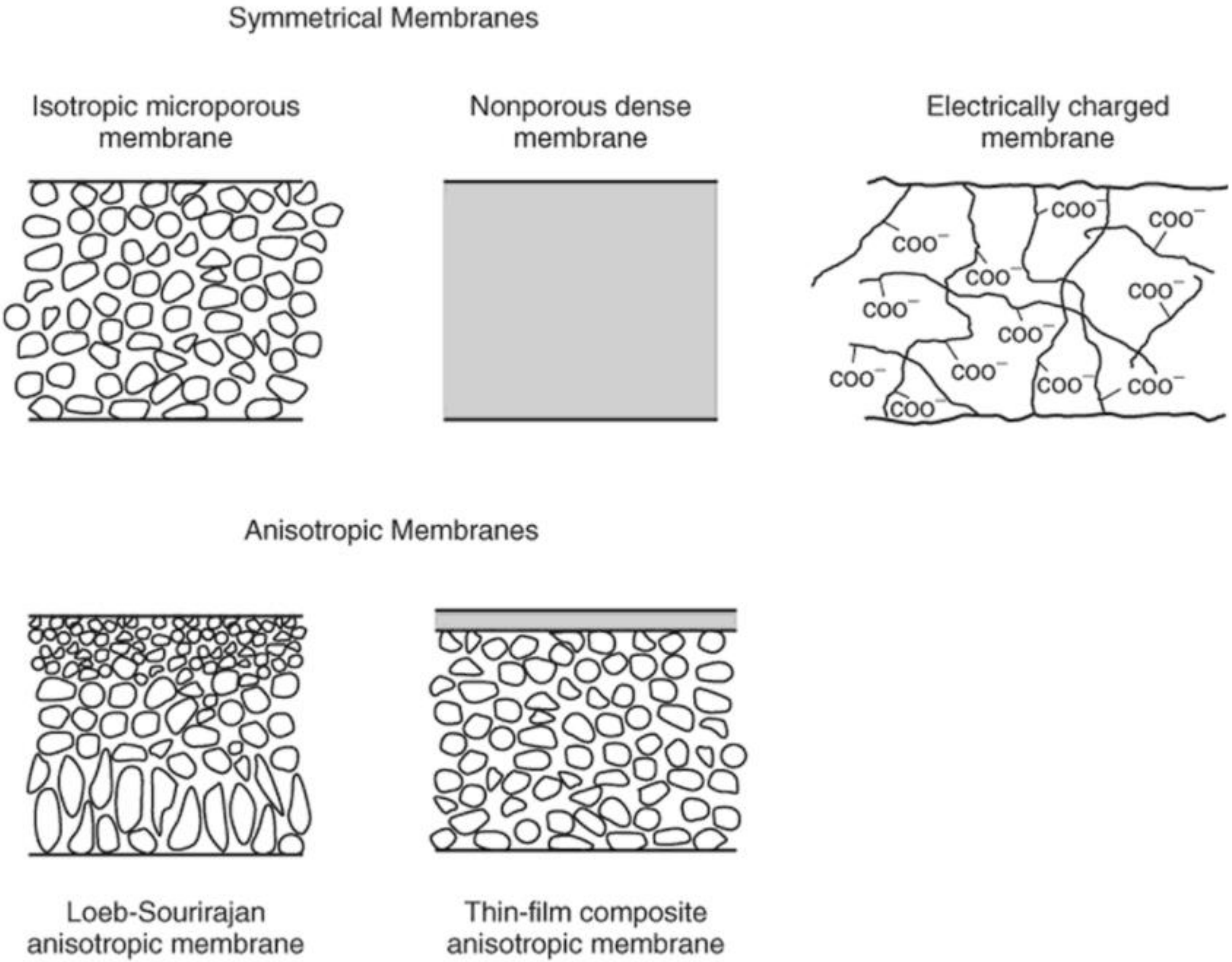
Separation processes

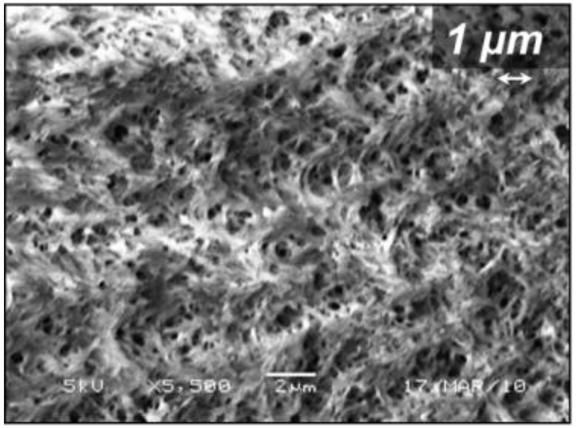
- **Fluid being treated**
  - Liquid
  - Gas
- **Driving potential**
  - Pressure
  - Concentration
  - Electric charge
  - Temperature
  - Phase separation

Separation processes

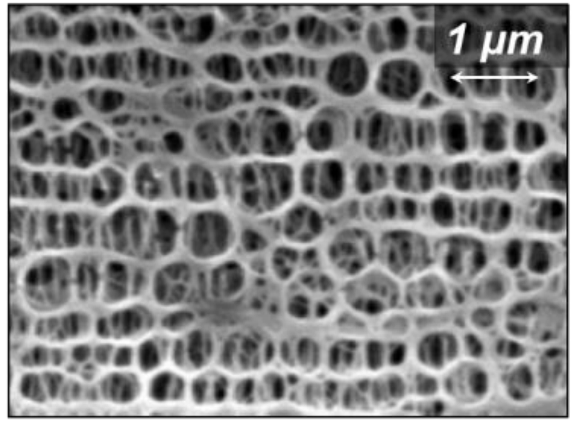


Mass transport
  from bulk fluid to interface
  across interface (or membrane)
  from interface to second bulk fluid

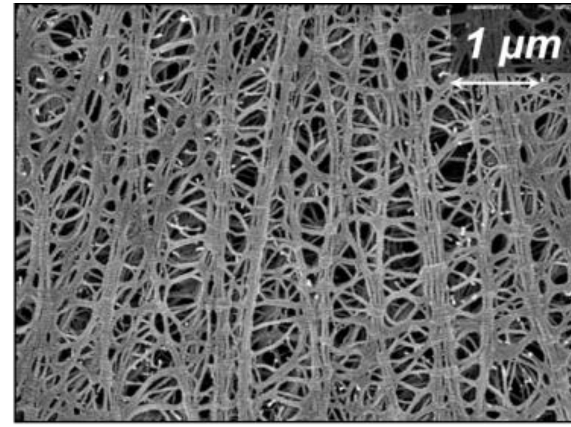

Symmetrical Membranes
Isotropic microporous membrane
Nonporous dense membrane
Electrically charged membrane
COO⁻
Anisotropic Membranes
Loeb-Sourirajan anisotropic membrane
Thin-film composite anisotropic membrane



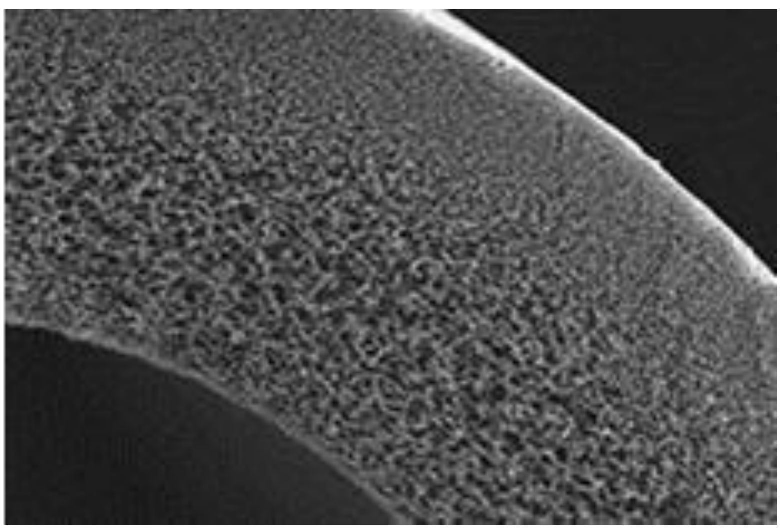
Polysulfone (phase inversion)



Polypropylene (biaxially stretched)

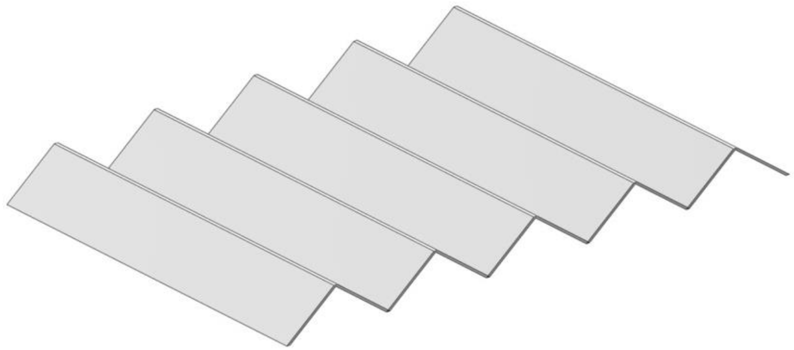


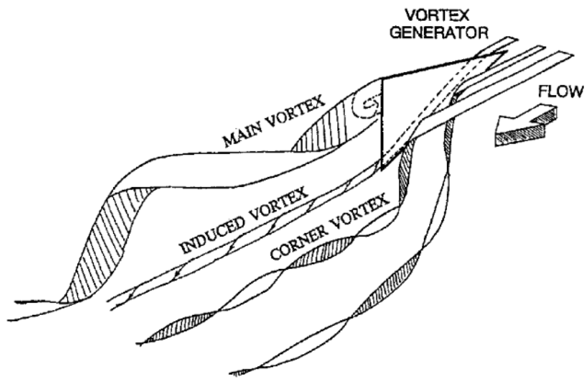
UHMW Polyethylene (phase inv. + stretching)

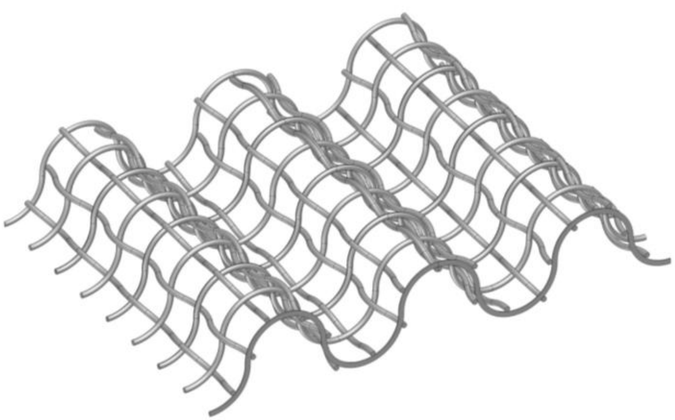


anisotropic membrane

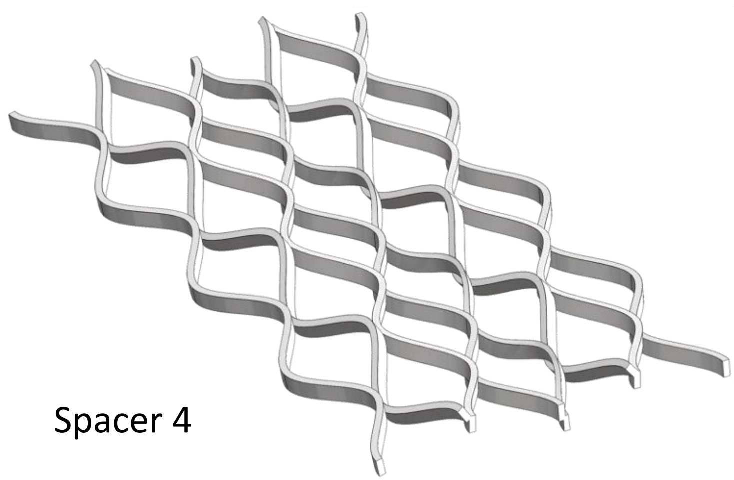
Fluid channel spacers







Spacer 3



Spacer 4

Woods, J. and E. Kozubal, *Heat transfer and pressure drop in spacer filled channels for membrane energy recovery ventilators*, Appl. Therm. Engr. 50(1) (2013) 868-76.




Applying separations and membrane science to buildings

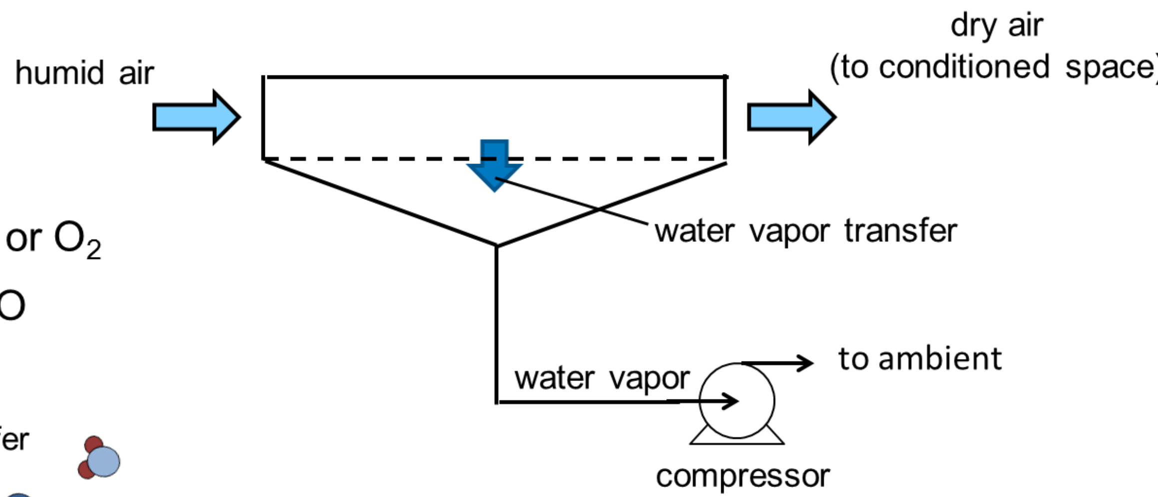

Tyvek

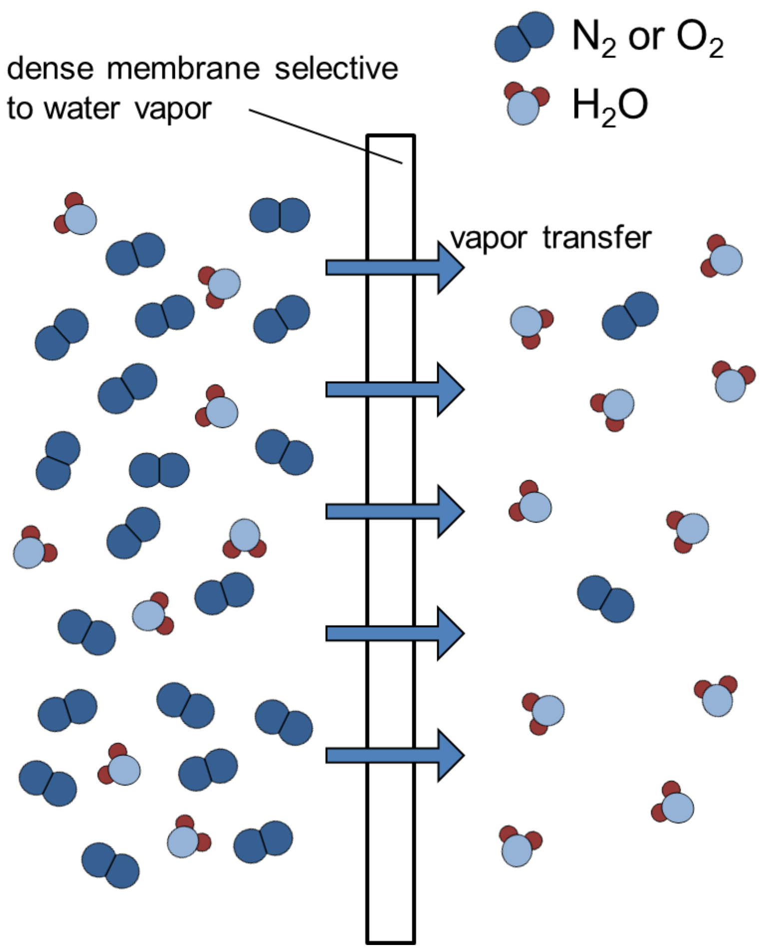
Buildings research needs

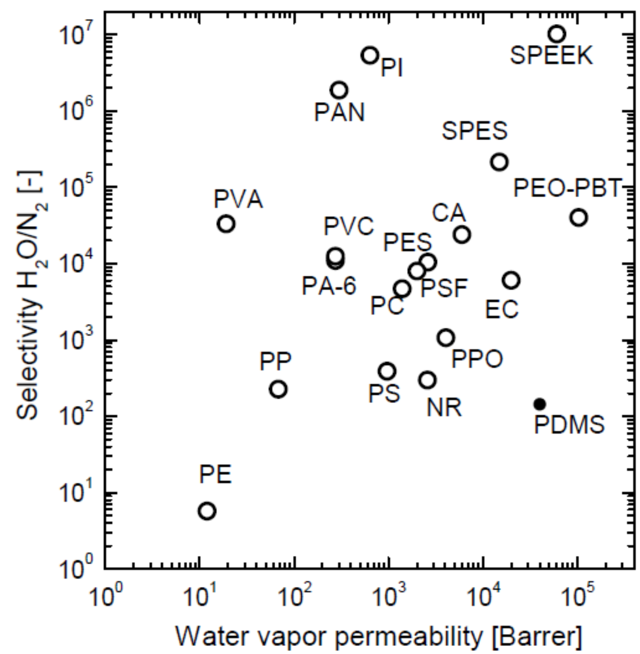
- More efficient technology for HVAC and appliances
- Improved humidity control
- Moisture durable walls
- Managing ventilation and indoor air quality

HVAC, appliances, and humidity control

Gas/vapor separation



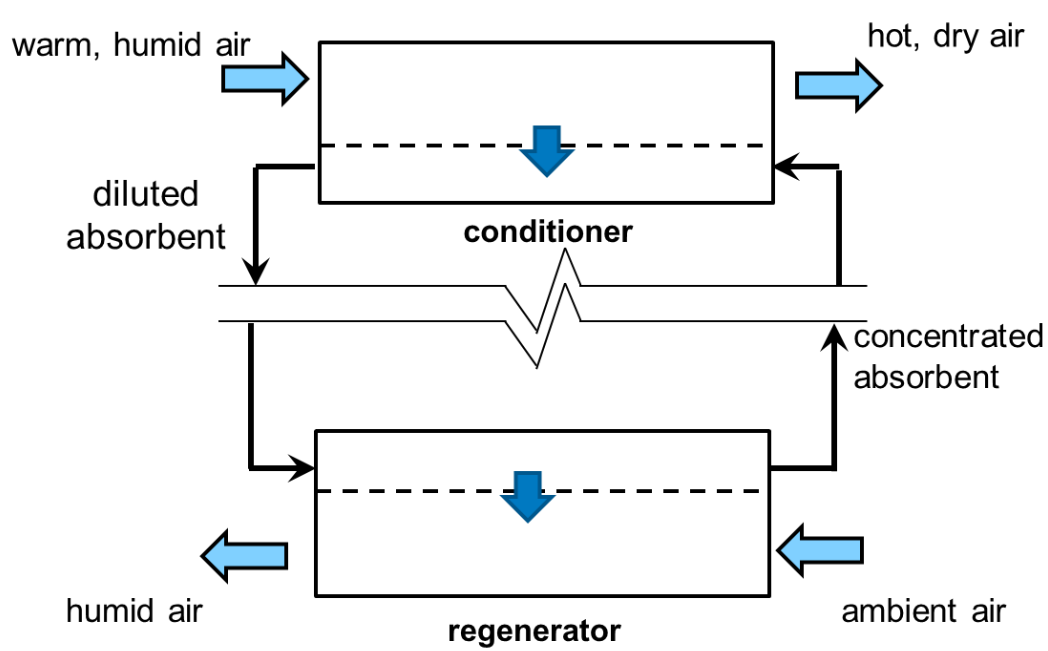


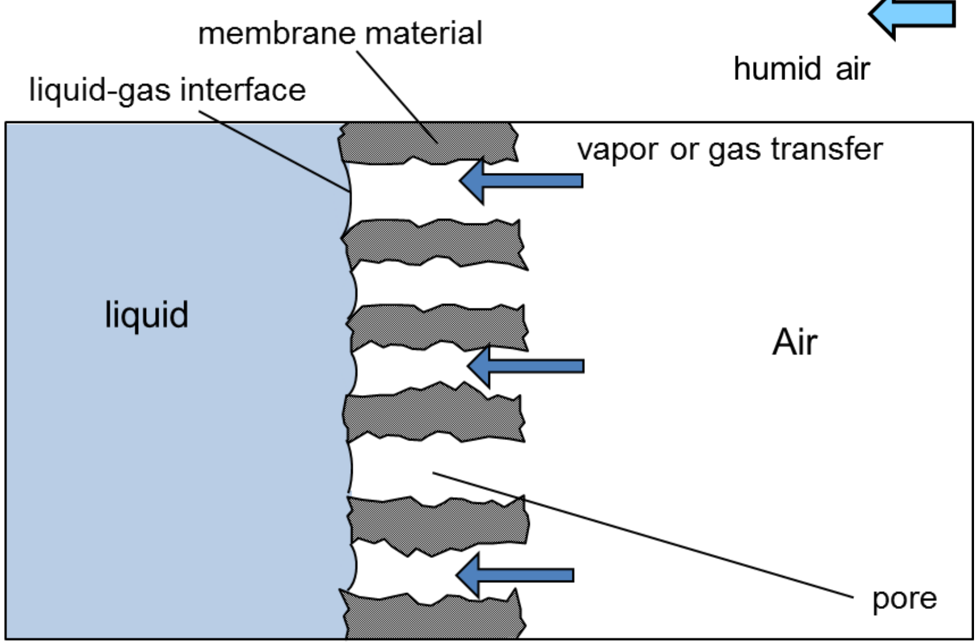


Woods, J., *Membrane processes for heating, ventilation, and air conditioning*, Renewable and Sustainable Energy Reviews. 33(0) (2014) 290-304.

HVAC, appliances, and humidity control

Liquid absorption





Woods, J., *Membrane processes for heating, ventilation, and air conditioning*, Renewable and Sustainable Energy Reviews. 33(0) (2014) 290-304.

HVAC, appliances, and humidity control

Liquid absorption – internally cooled

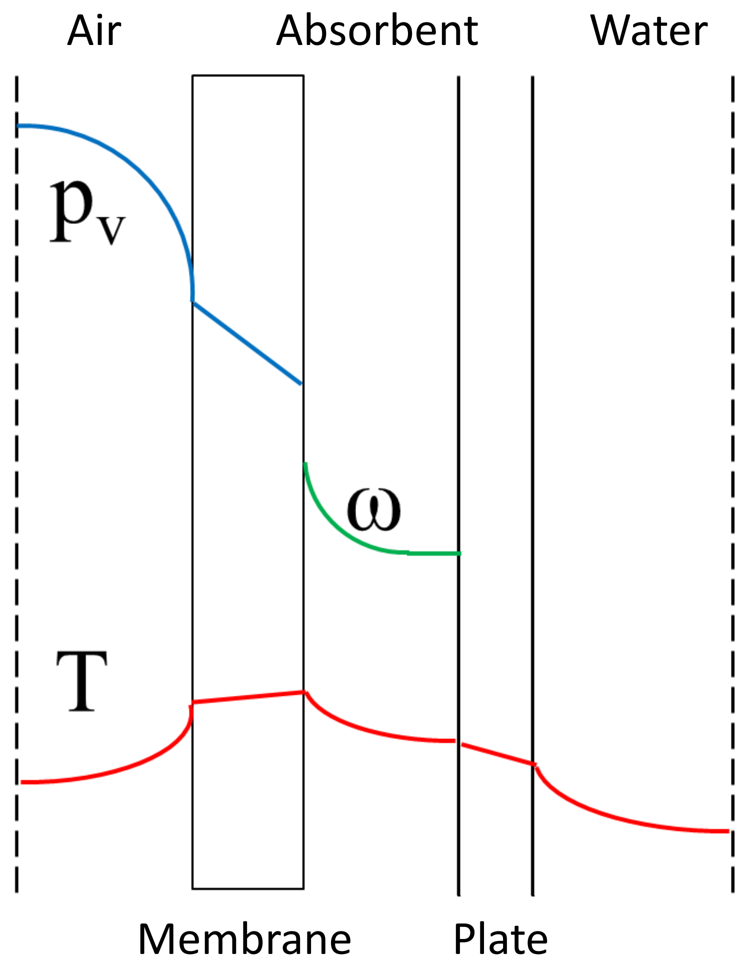
Profiles:

p_v = vapor pressure

T = temperature

ω = concentration

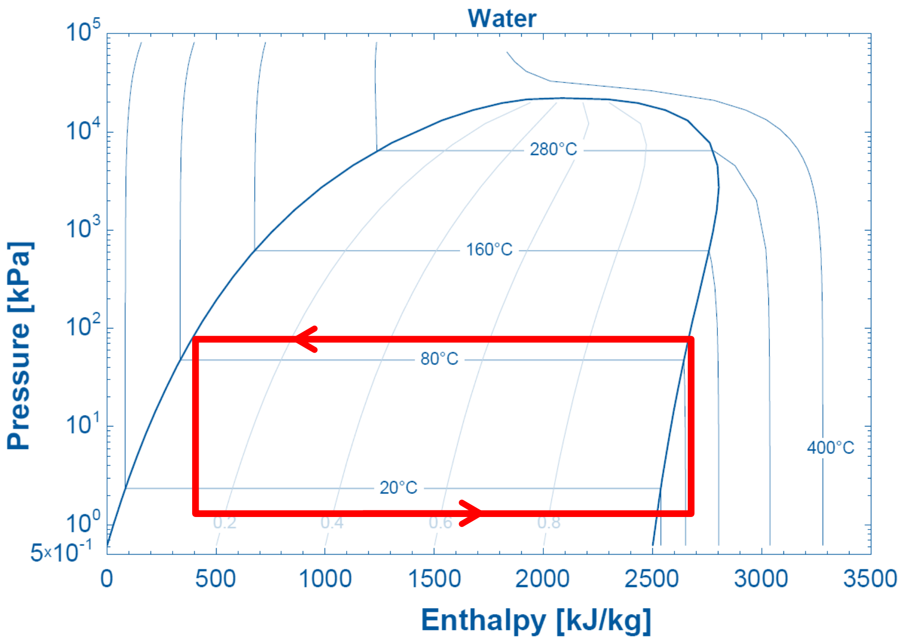
Cross section view

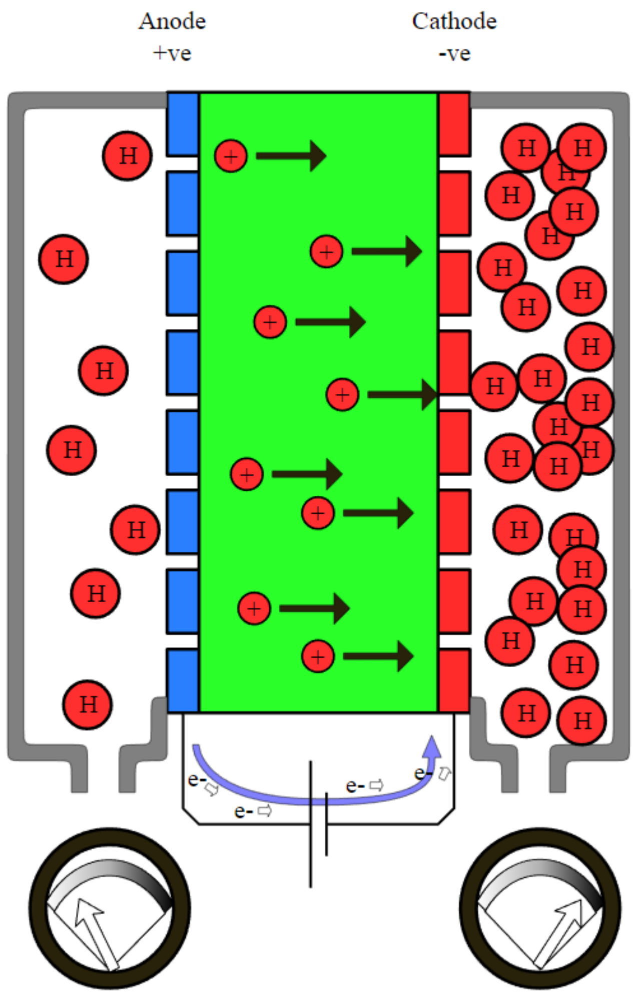


HVAC, appliances, and humidity control

Electrochemical compression

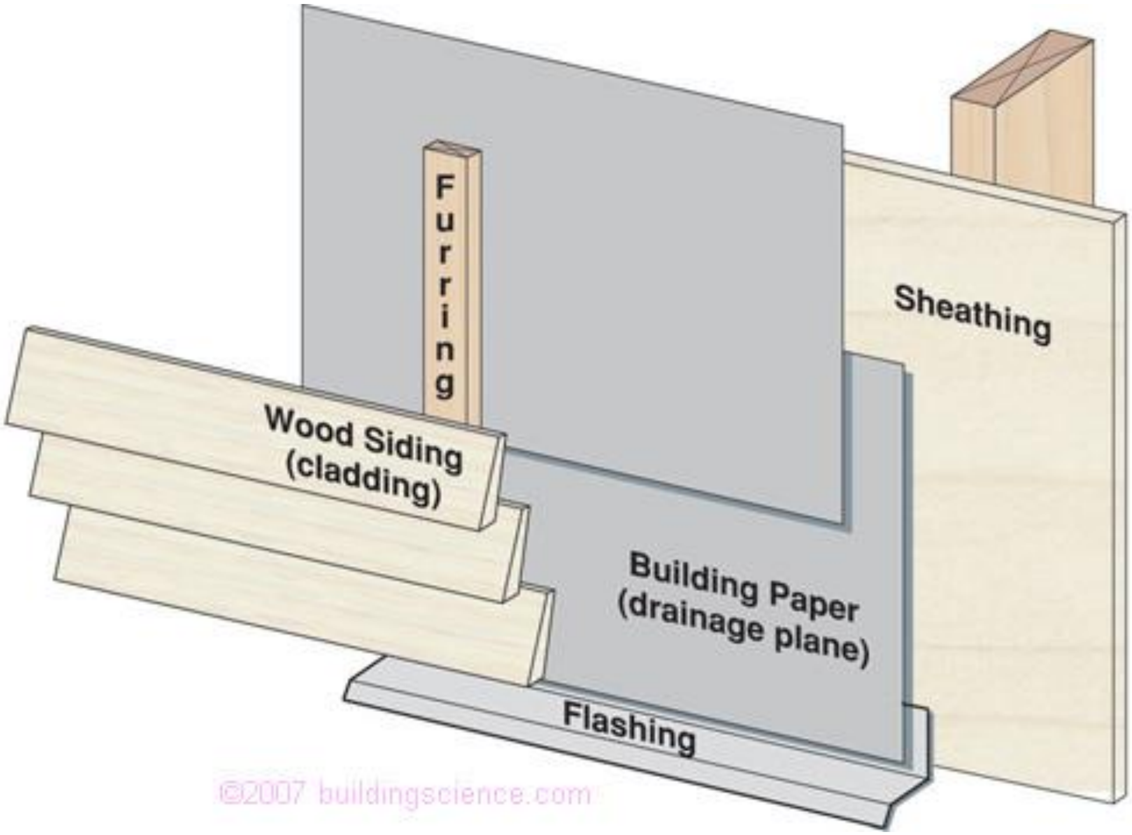
heat pump process



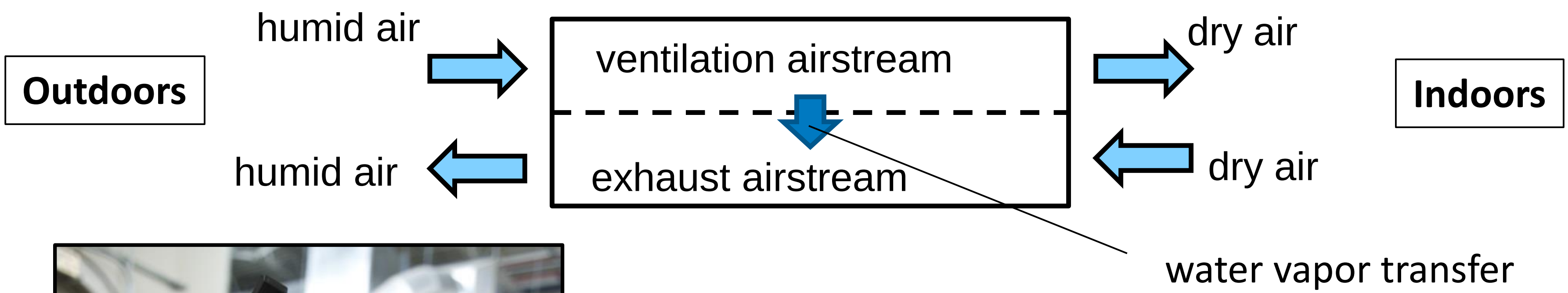


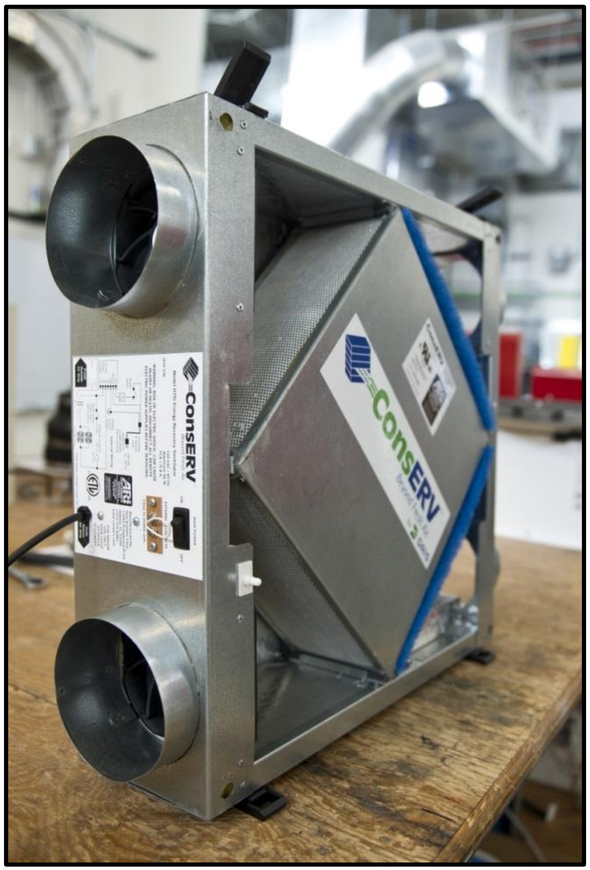
By Evan Mason - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=20284870

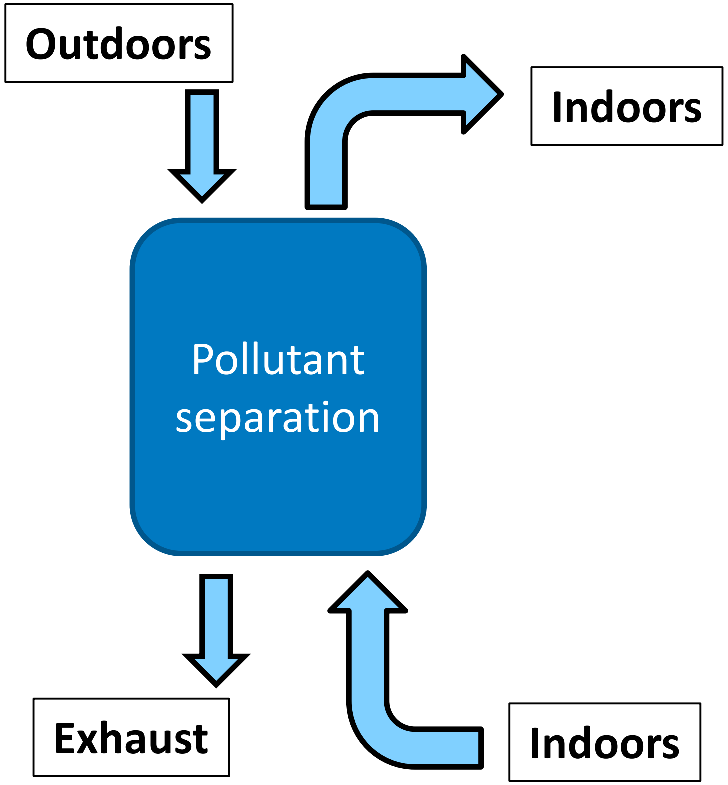
Moisture durable envelopes



Indoor air quality and ventilation





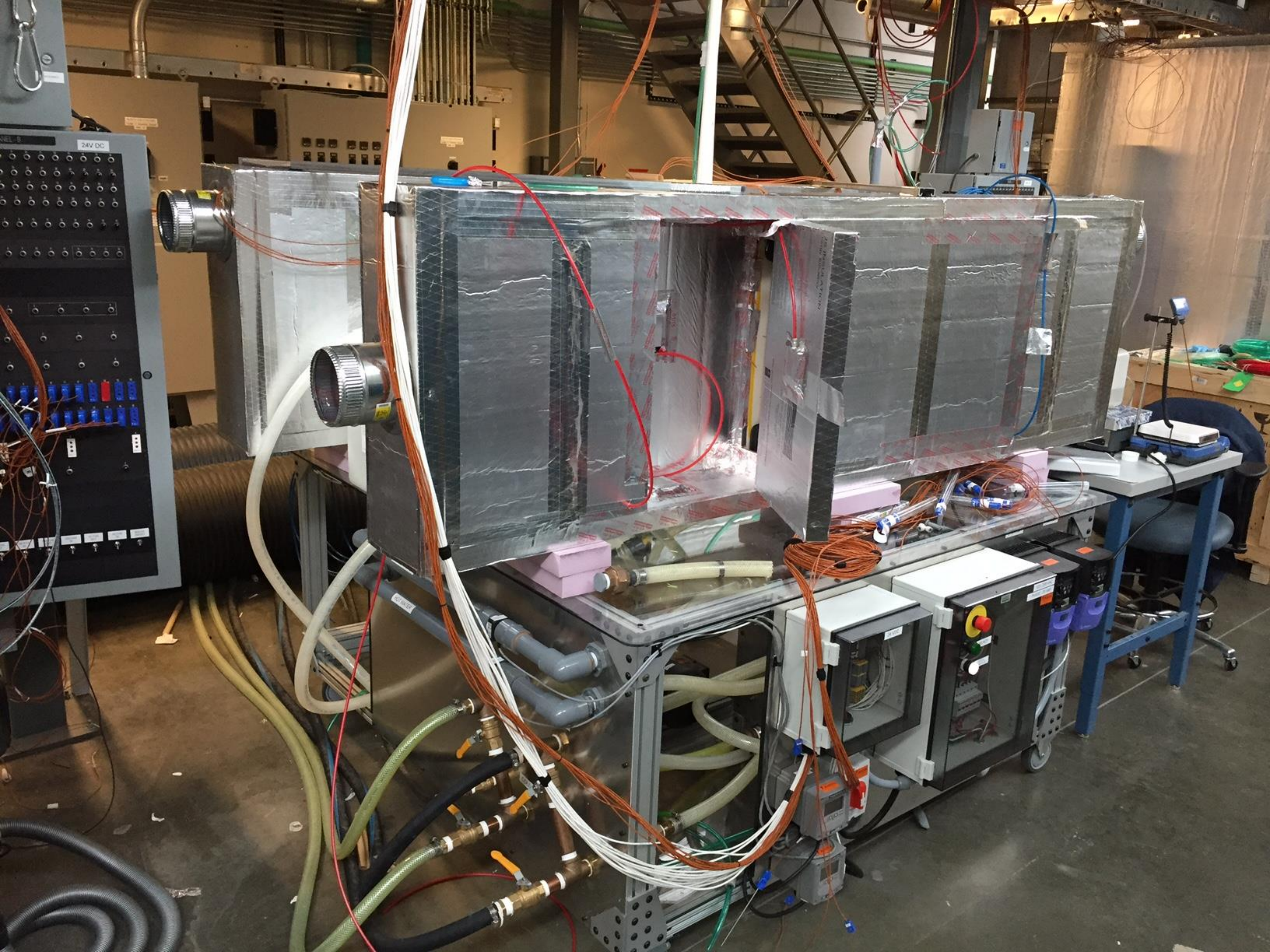


NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Jason Woods, PhD (jason.woods@nrel.gov)
Buildings and Thermal Sciences

Research needs

- Improved capacity of absorbents / adsorbents
- Stronger, more durable membranes that resist degradation (e.g., ozone) and fouling (e.g., pollutants or surfactants), but without sacrificing performance
- Novel fabrication or bonding techniques
- Improved transport to membrane surface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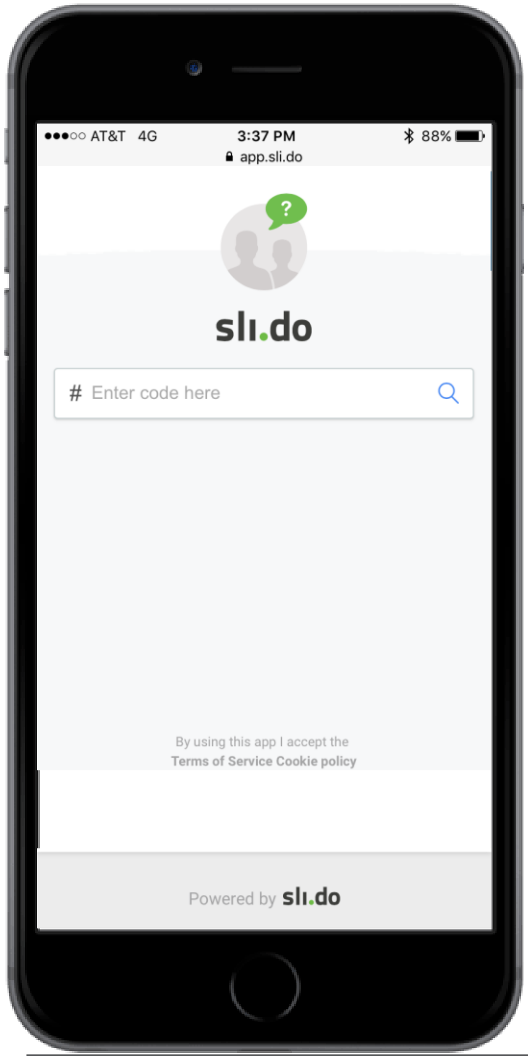

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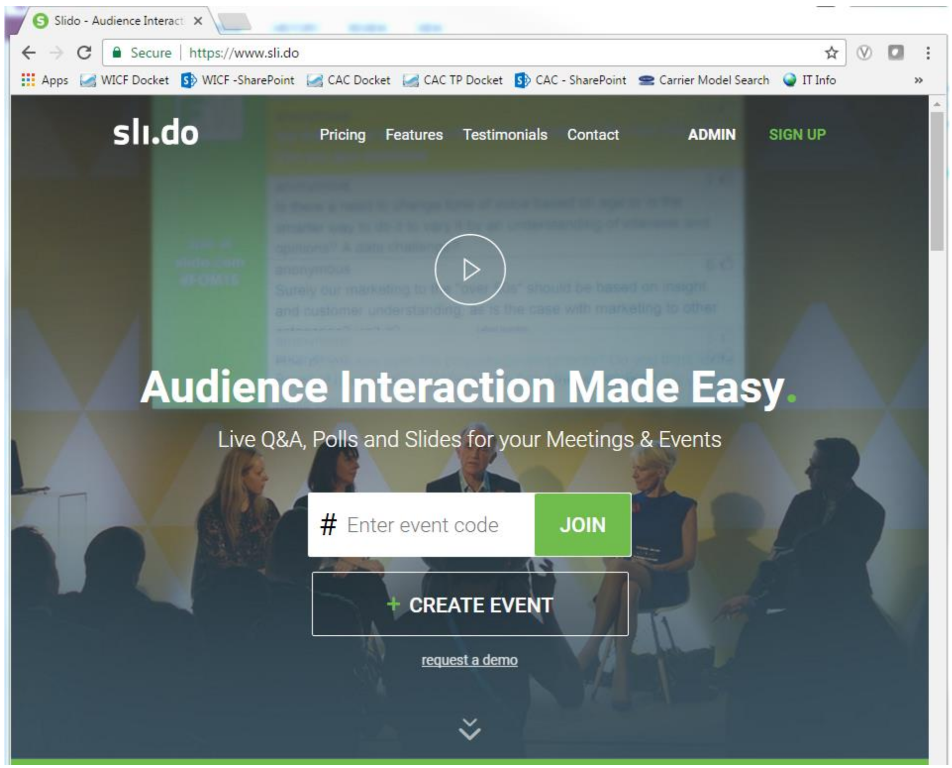
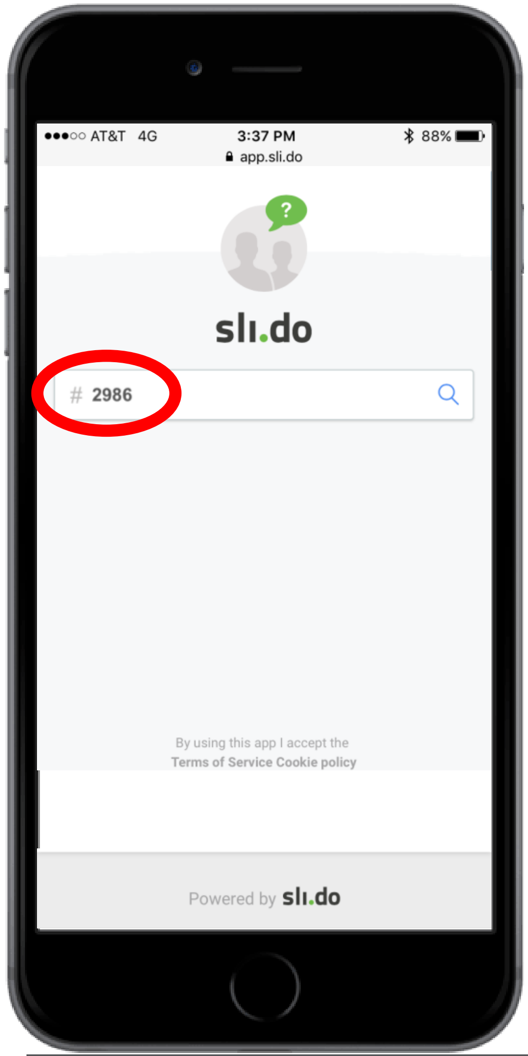


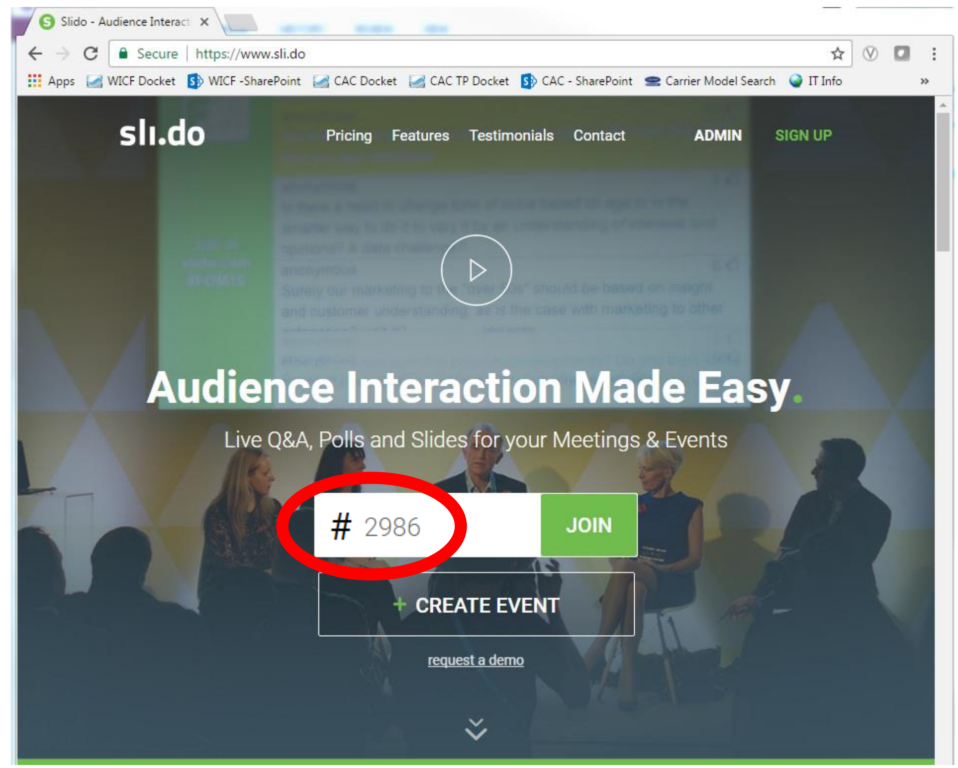
Mobile or Computer

SLI.DO INTRODUCTION

Event Code:
2986

Step 2: Enter Event Code – 2986





Mobile or Computer

SLI.DO POLL – TRIVIA

Event Code:
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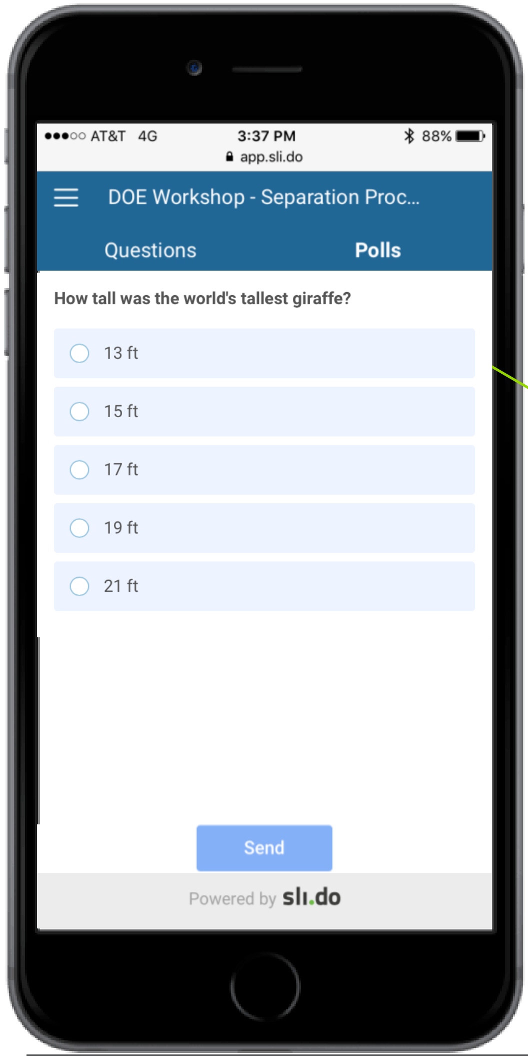

How tall was the world's tallest giraffe?

- 13 ft
- 15 ft
- 17 ft
- 19 ft
- 21 ft

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SLI.DO POLL – INTRODUCTIONS

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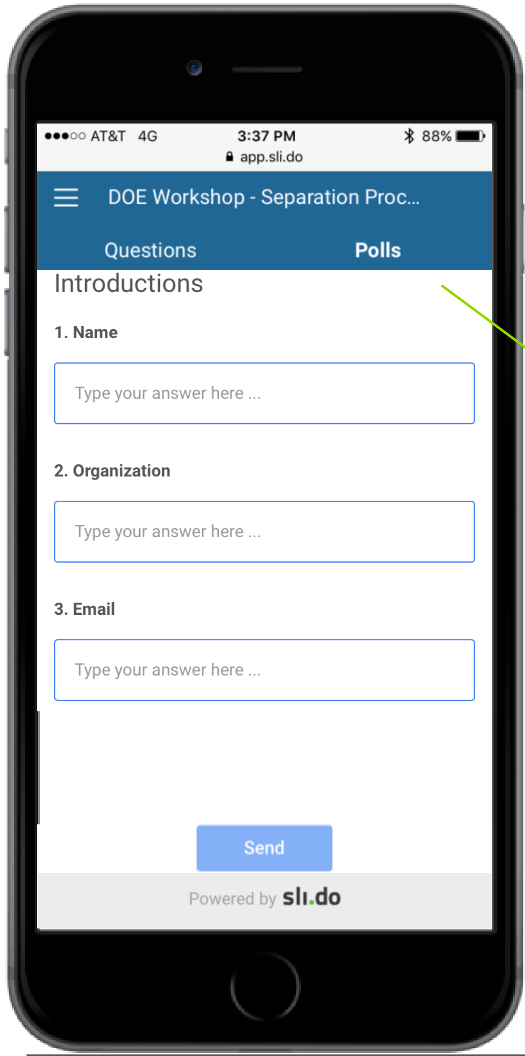
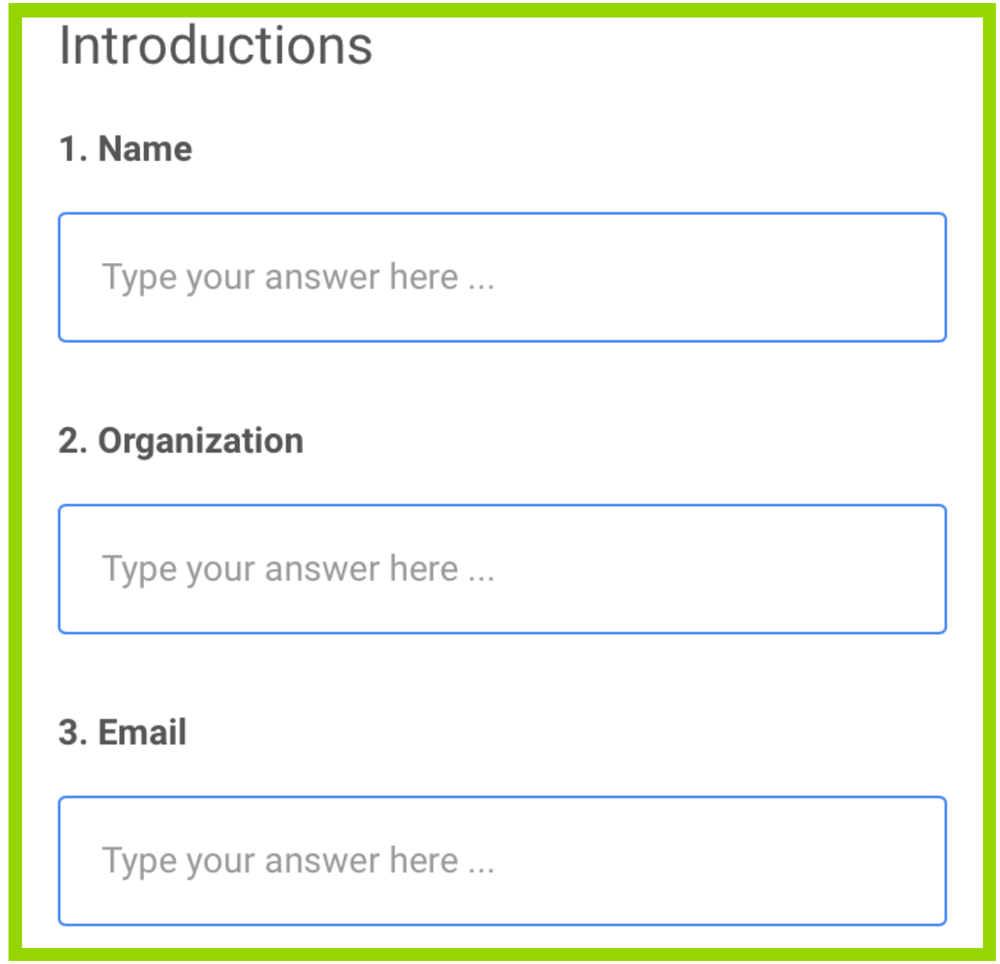
2986





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SLI.DO POLL – LARGE GROUP INTRODUCTION

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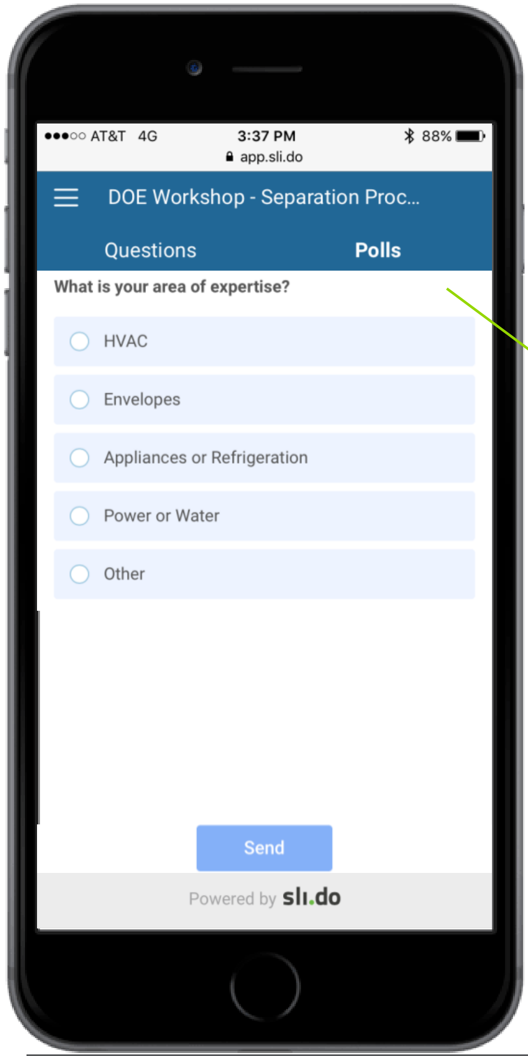

What is your area of expertise?

- HVAC
- Envelopes
- Appliances or Refrigeration
- Power or Water
- Other

*Multiple answers permitted

NAVIGANT

Event Code:
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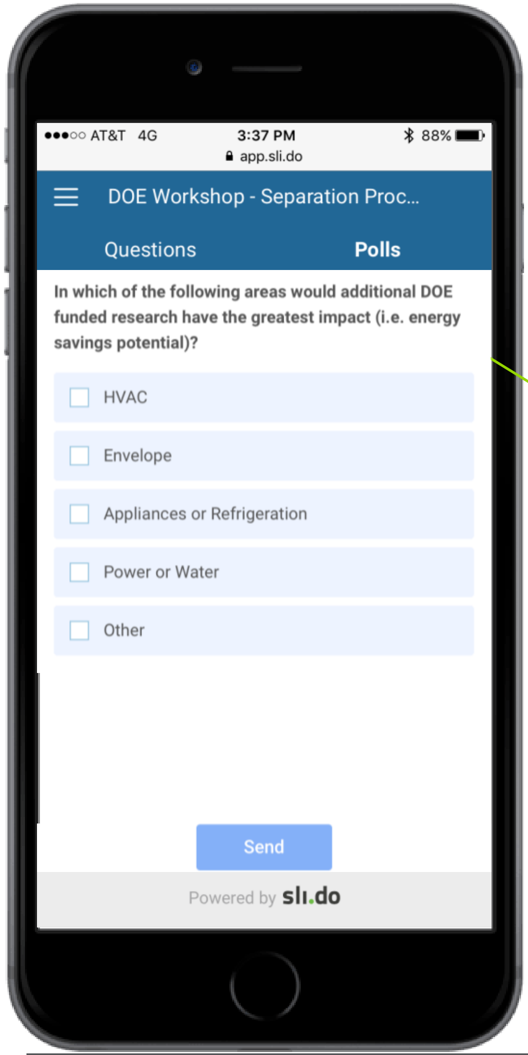
SLI.DO POLL – LARGE GROUP DISCUSSION



In which of the following areas would additional DOE funded separations-related research have the greatest impact (i.e. energy savings potential)?

- ☐ HVAC
- ☐ Envelope
- ☐ Appliances or Refrigeration
- ☐ Power or Water

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SLI.DO POLL – LARGE GROUP DISCUSSION

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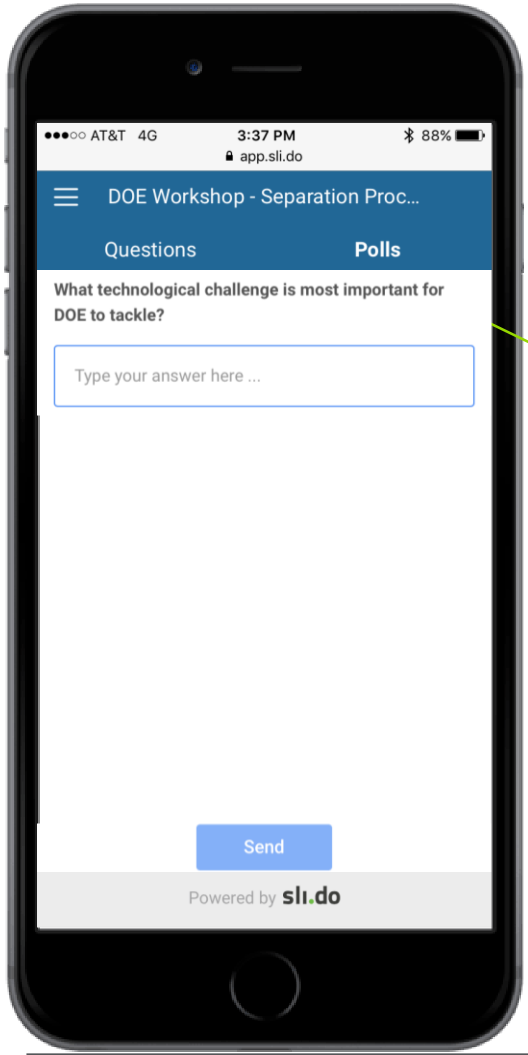

What is an important building-related separations/membrane challenge for DOE to tackle?

Type your answer here ...

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LARGE GROUP DISCUSSION

- What trends do you see in the membrane/separation industries (including research areas, applications, etc.)?

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ELEVATOR TALKS

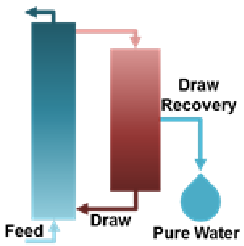
- 3-4 minute presentations by each of the following:
  - Ryan Huizing
  - Jeff McCutcheon
  - Saeed Moghaddam
  - Bamdad Bahar
  - Peter Luttik
  - Roderick Jackson

The McCutcheon Lab at UConn

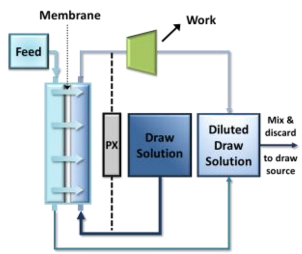
UCONN
SCHOOL OF ENGINEERING

Membrane Processes

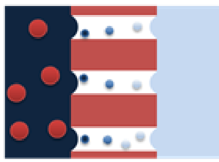
Forward Osmosis



Pressure Retarded Osmosis

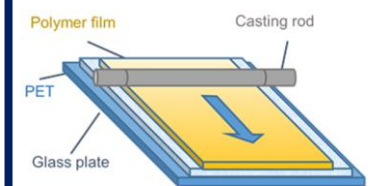


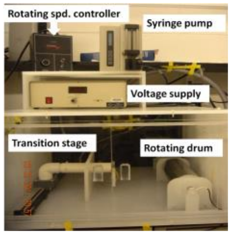
Membrane Distillation

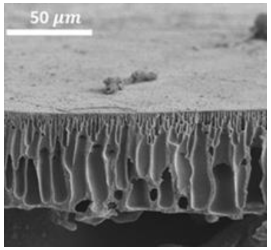


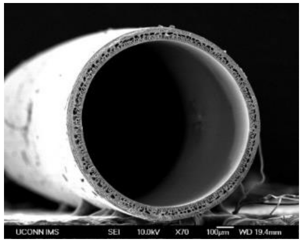
Reverse Osmosis

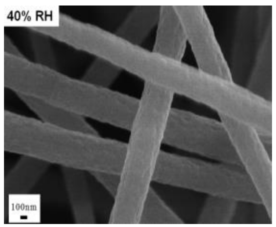
Membrane Fabrication



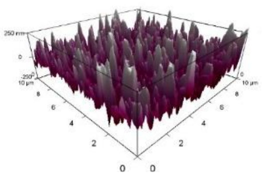


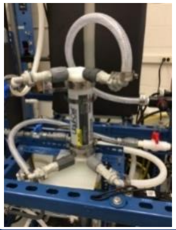


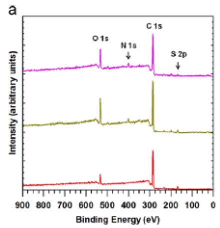


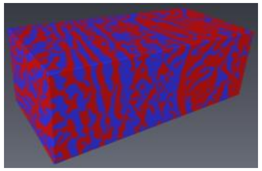


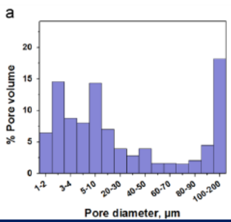
Membrane Characterization



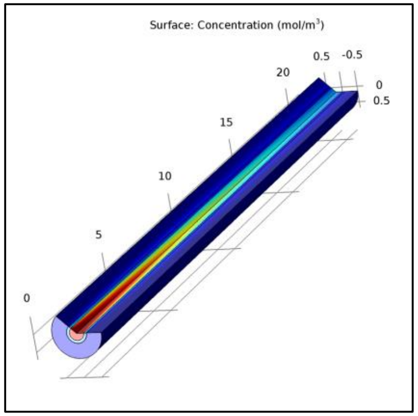








Membrane Design and Prototyping



Fraunhofer Center on Membranes

UCONN SCHOOL OF ENGINEERING

Fraunhofer

Connecticut Department of ENERGY & ENVIRONMENTAL PROTECTION

UCONN

Manufacturing
- Gas separations
- Wastewater
- Energy recovery and storage

Oil & Gas
- Produced waters
- Oil removal
- Brine dewatering
- CO_2 removal

Agriculture
- Biofuels
- Wastewater
- Anaerobic digestion
- Food processing

Food and Beverage
- Dewatering
- Clarification
- Process water

Utilities and Power
- Gas purification
- Energy storage
- Water reuse

Pharmaceuticals
- Drug purification
- Molecular separation
- Wastewater

What this center provides:
- Contract research services
- Separations solutions across disciplines (water, solvent, vapor, gas)
- Scale-up and techno-economic assessment services
- Access to UConn infrastructure

We will serve:
- End users of membrane products
- Companies seeking a proving ground for new separations technology
- Membrane producers

Membrane-based Absorption Cycles for High Performance Heat-driven Cooling, Dehumidification, and Water Heating

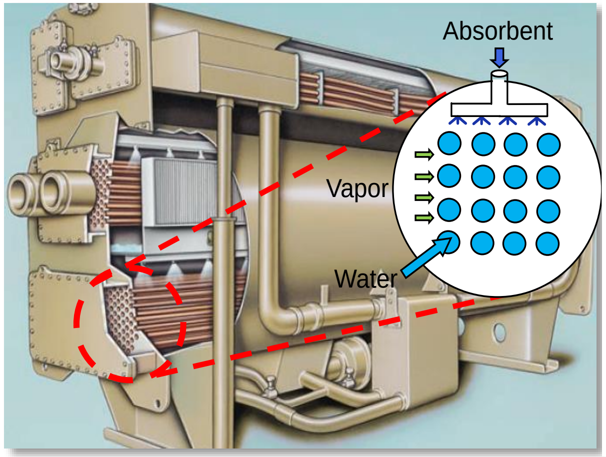
Saeed Moghaddam

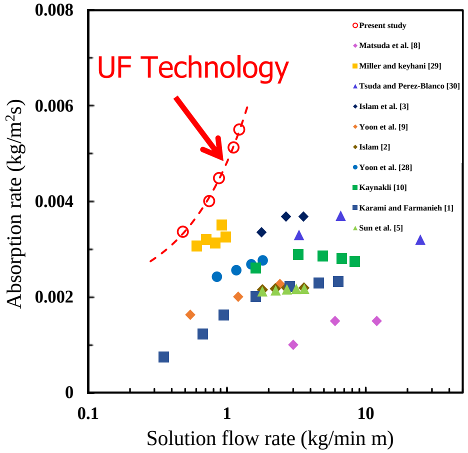
Nanostructured Energy Systems (NES) Laboratories

NREL, June 8th, 2017

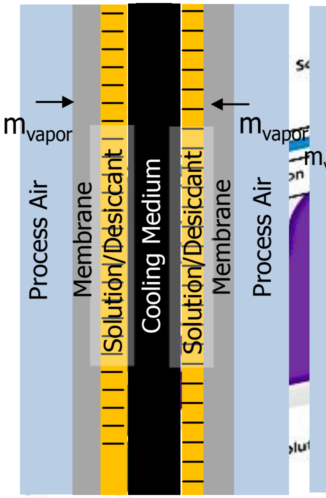
UF UNIVERSITY of FLORIDA
The Foundation for The Gator Nation

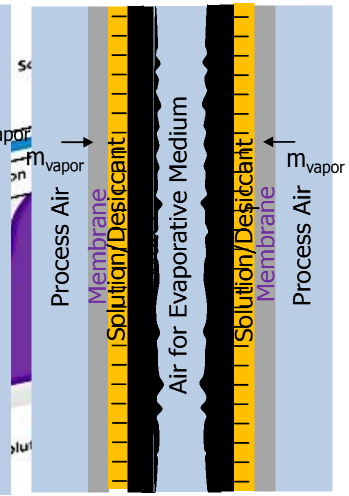
Why membrane-based absorption?

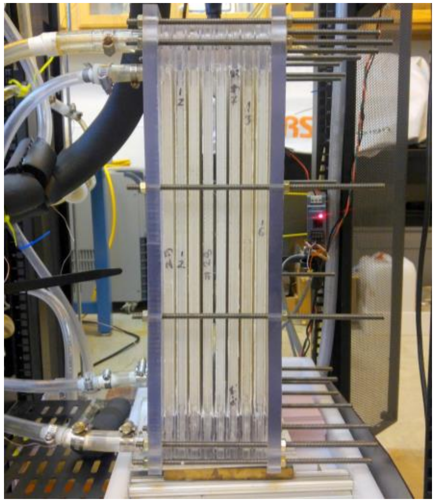




- Enables compact, light, and low-cost absorption systems for small-scale applications
- Enables significant increase in absorption rate, implementation of ILs
  - $COP_{cooling,cycle}$ ~ 1.7





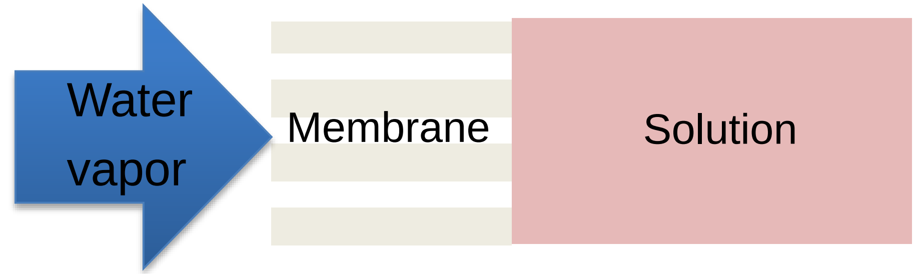


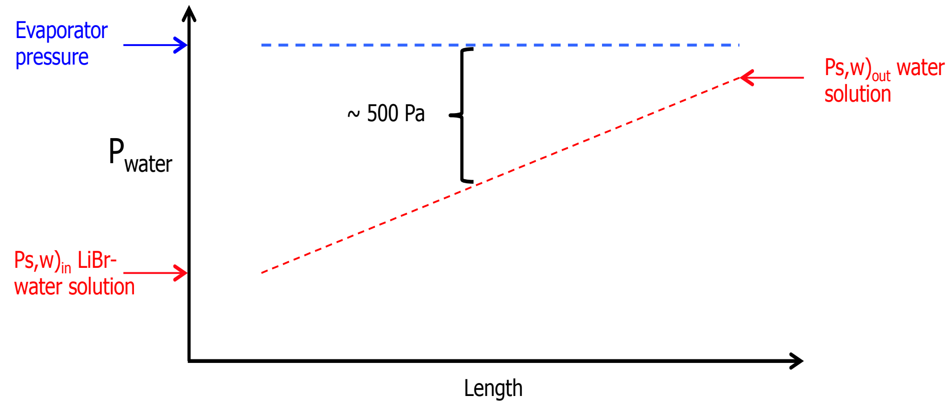
- Enables compact plate-and-frame heat and mass exchangers (HMXs)
- Prevents desiccant entrainment
- Enables high COP

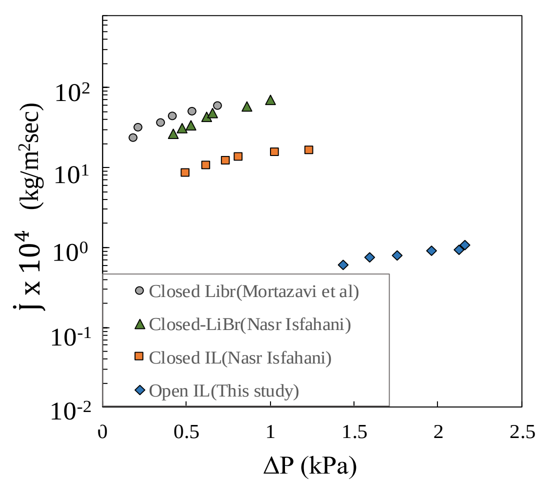
- These systems and their hybrid configurations can:
  - address humidity challenges in buildings in all climates
  - by handling latent load separately, greatly enhance HVAC systems efficiency

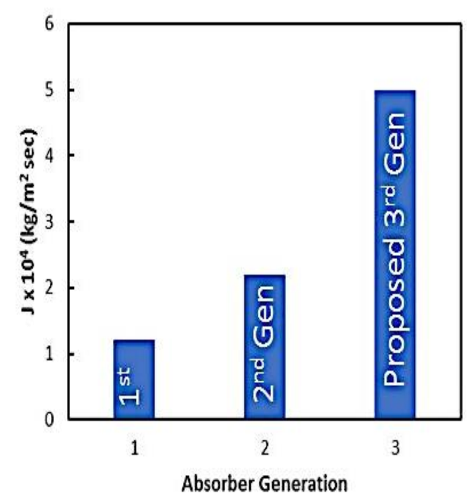
What Kind of Membranes?

- Surface properties
  - Hydrophobic (to constrain the absorbent)
  - Hygroscopic membranes allow the solution to migrate to the airside
- Transport characteristics
- Durable
  - 10-15 years of reliable operation
  - Chemically inert to not react with anything in air
- Bondable
  - Depends on the substrate material
- Cost
  - Depends on the system
    - < $\$1/ft^2$ for dehumidification



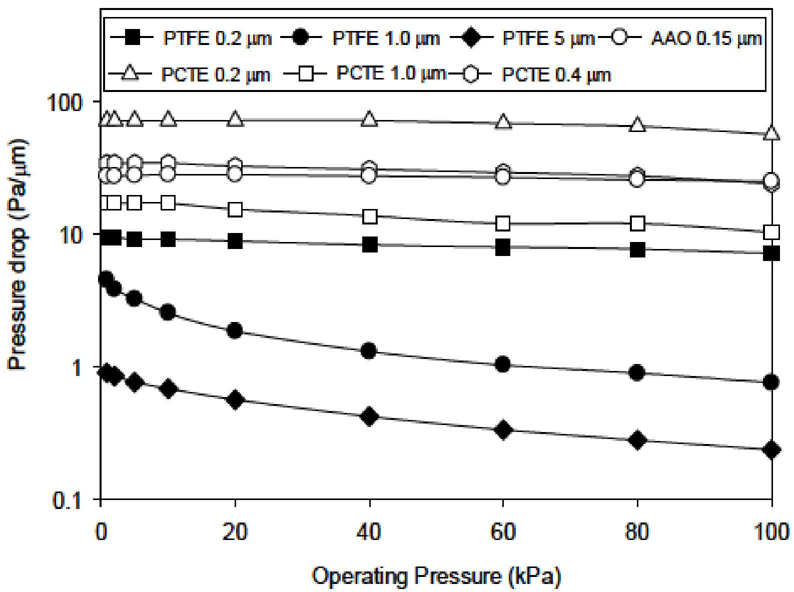


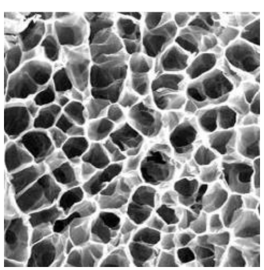


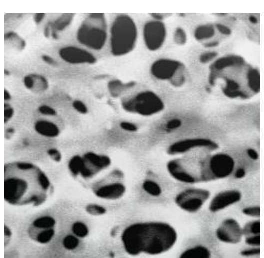


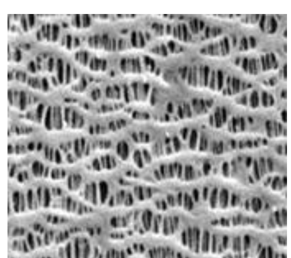
What Kind of Membranes?

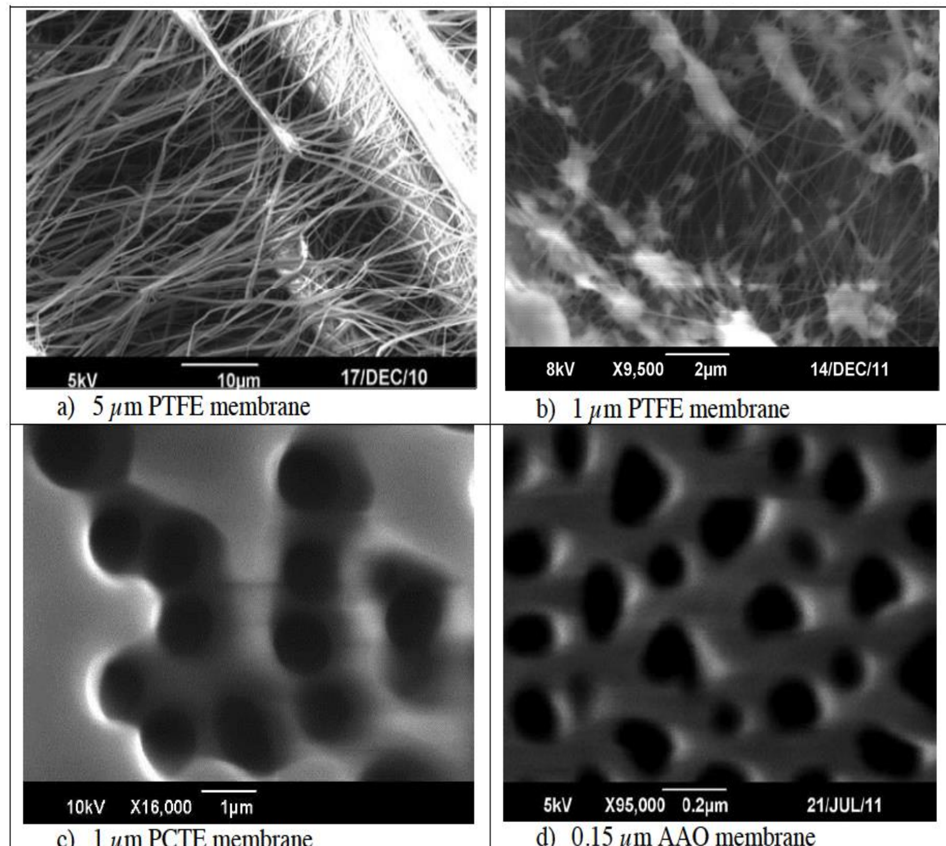
- Membrane properties are vastly different
- Type of membrane, material properties, thickness, hybridization, selectivity, etc. have to be carefully tuned for an ideal membrane











a) 5 μm PTFE membrane
b) 1 μm PTFE membrane
c) 1 μm PCTE membrane
d) 0.15 μm AAO membrane

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NREL/BTO Membrane workshop

B. Bahar
Xergy Inc.
06/08/17

XERGY

Why Ion Exchange Membranes For Energy Conversion

Ion transport is fundamental to **nearly every** process involving the transfer or conversion of chemical to electrical energy. Ion-transport membranes underpin many biological systems and are crucial to a diverse array of energy-related applications including: fuel cells, electrolyzers, batteries, electrochromics, chemical separators, membrane reactors, and sensors.

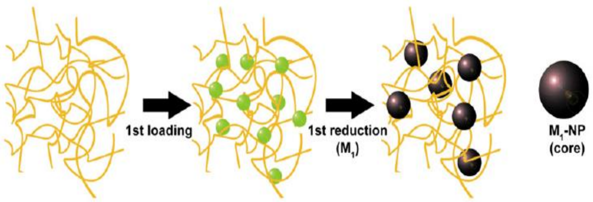
Controlling the movement of ions and molecules through nanoscale channels offers revolutionary pathways for development of new products. **This technology is new, transformational, disruptive, and value added.**

NO ONE CHEMISTRY can address all the opportunities in this arena. Must be open minded with respect to ion exchange chemistries, and be willing to work with any and all chemistries for any specific application.

I do, however, believe that **ALL** chemistries are improved by “compositing” or “reinforcement” technology. Our company is focused in this area, with an emphasis on intelligent microstructural design of **composite** membranes with improved stability, operational range, impurity tolerance, and transport efficiency and selectivity.

Ion Exchange Membranes: The Problem

Fundamental understanding of ionic transport in novel, nanostructured systems can drive dramatic improvement in energy conversion efficiencies.



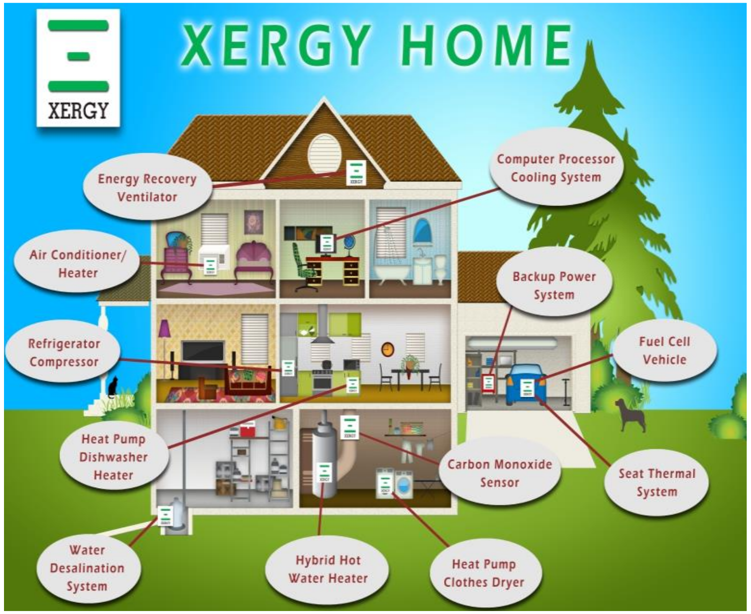
- **The Problem:**
  - Ion Exchange Media are inherently weak. Therefore have to be reinforced by compositing to become stronger.
  - Result: Ultra-thin, Ultra-strong, Ultra-high performance.
  - Its important also to know how package them into useful devices, creating great products for critical applications.
- **The Solution:** Ion Exchange Media - Two Key Properties
  - Can transport Ions under electric field (cations, anions).
  - Can transport polar molecules (pervaporation). Difference in concentration, temperature, pressure.
- **DOE Support:**
  - Xergy originally developed Compositing systems to meet BTO cost and performance targets for Electrochemical Compressors
  - Most recently received 3 ARPA-E awards to further develop Anion Exchange membranes

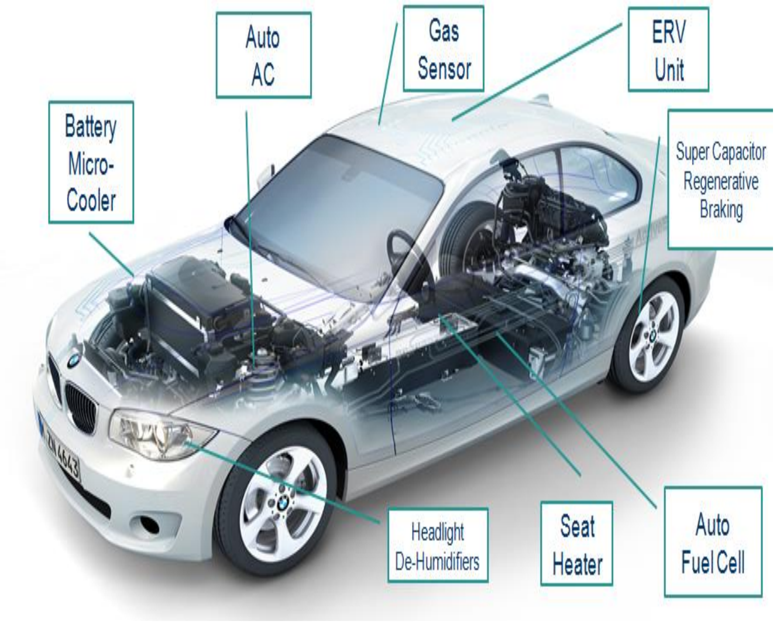
Composite Membrane Innovation

Composite membranes are key, because of their thinness and high performance. However, proper packaging membranes into functioning devices is non-trivial.

- 10 times thinner means 10 times lower cost
- Thinness means shorter distance for ions or molecules to travel. Means lower resistance, higher performance.
- Thinness without compromising on strength. Compositing provides mechanical reinforcement for otherwise weak materials.
- Lower cost plus higher performance = Leads to new possibilities i.e. Innovation

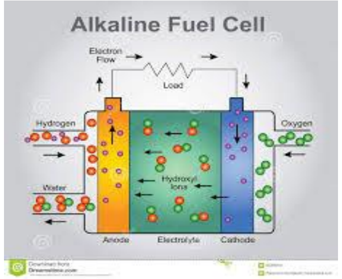
Suddenly, we have literally hundreds of product opportunities.
- Several Billion dollar scale applications.

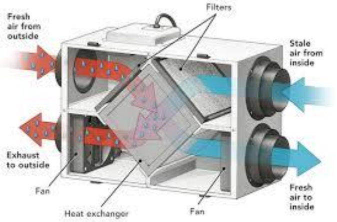


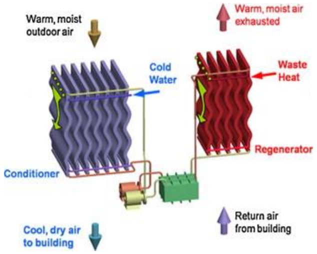


Recent Case Studies

- Alkaline Fuel Cells
    - New class of fuel cells with much lower precious metal Catalyst loadings!
- Advanced Energy Recovery Ventilators
    - New class of ERV's with higher performance
- Vacuum Membrane Desalination
    - New class of Desalination/Purification
- Ionic Liquid Desiccants
    - New class of desiccants to improve HVAC systems
- Sensors
    - New classes of low power, non-invasive sensors that Can dramatically improve smart systems (CO2, etc.)







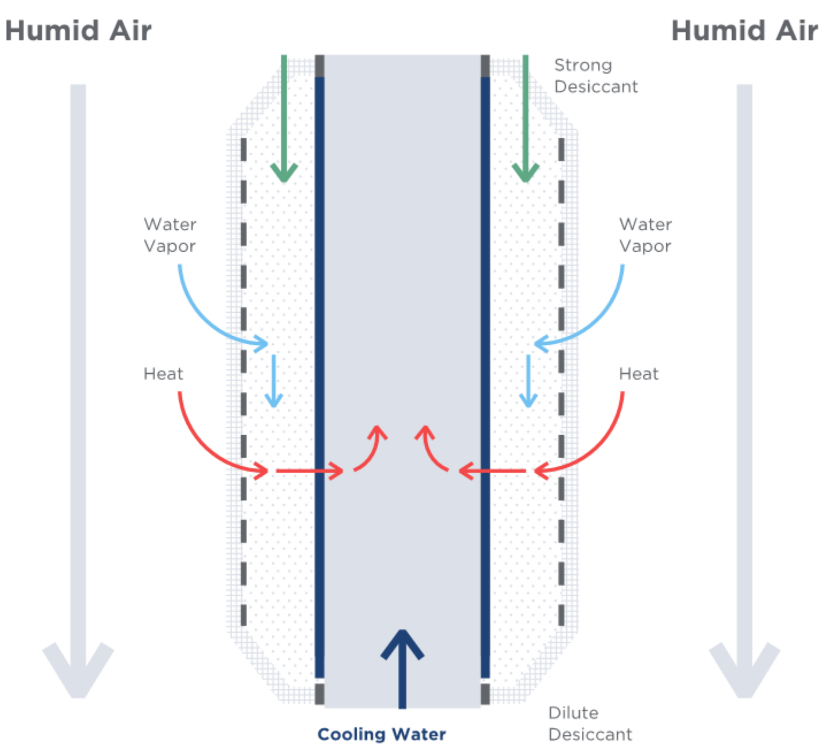
DOE's GOAL should be to create the **'membrane production Infrastructure'** and then the new applications will 'come'! It would be good if DOE can also sponsor a few 'low hanging' decent applications to establish markets and a decent 'business' base for the membrane producers! Eventually, entrepreneurs will take over and apply new Membranes to new applications.

Membrane enabled LDAC

DOE workshop June 8, 2017

Confidential

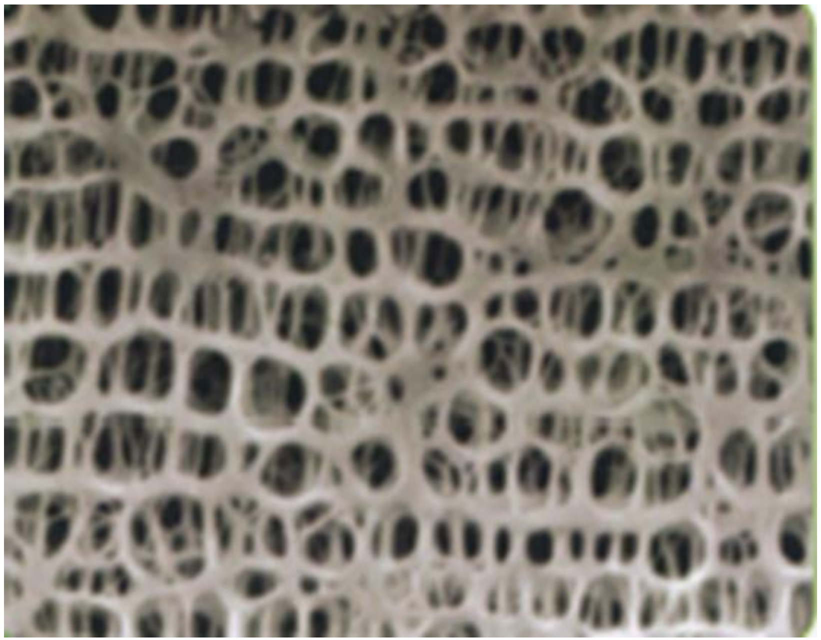
7AC Core Technology – Conditioner Module



Independent Sensible and Latent Heating and Cooling

- 3-way all-plastic heat exchanger
  - Air – Desiccant – Water
- Desiccant absorbs moisture from the air stream
- Cooling water cool the air and carry away heat generated by the moisture absorption
- 7AC technology minimize the desiccant required to 1/10 of the chilled water flow

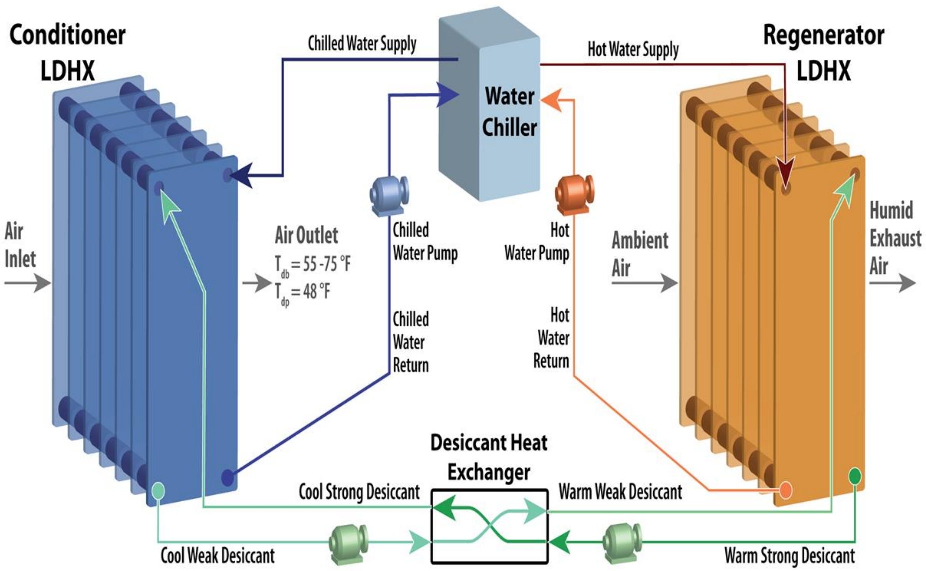
The Membrane Difference



No Desiccant Carry-Away

- Desiccant is separated from the air stream by a thin layer of membrane
- Gas permeable membrane allows cold, concentrated desiccant to absorb moisture in the air stream
- Thin membrane also allows heat transfer between the air and desiccant
- Membrane facilitates standard face velocity at <0.5” pressure drop

The LDAC System

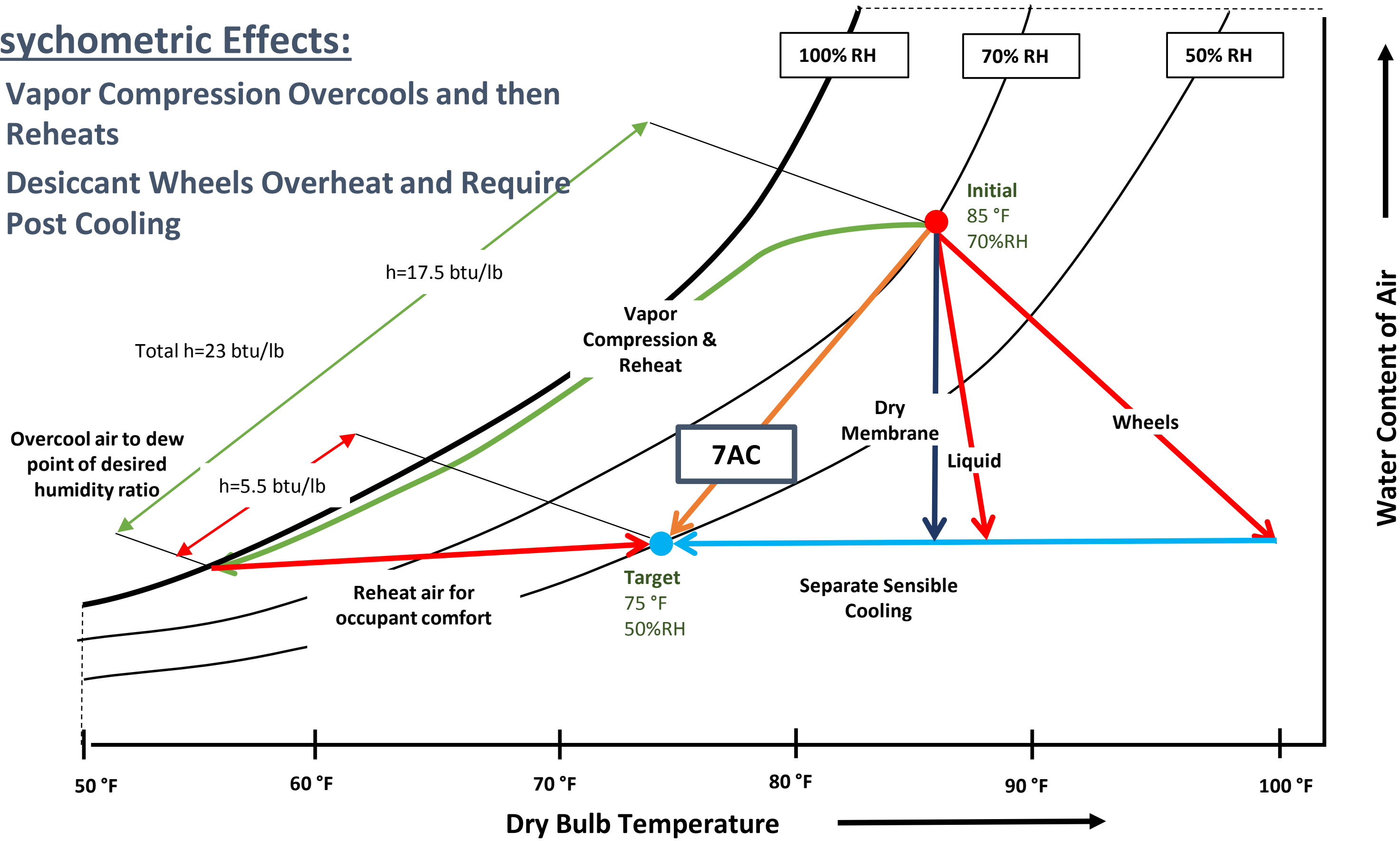


- A full system is consisted of
  - Conditioner
  - Regenerator
  - Close circuit desiccant management system
  - Water chiller
- Chilled water (chiller evaporator) “power” the conditioner to provide cool, dry air to building
- Hot water from chiller (condenser) is re-used to re-concentrate the desiccant

Efficient dehumidification and cooling

Psychometric Effects:

- Vapor Compression Overcools and then Reheats
- Desiccant Wheels Overheat and Require Post Cooling



LDAC system solutions for each of 8AC Zones™

1 *Evaporative cooling*

2 LDAC + dilution

3 LDAC + ACC or dilution

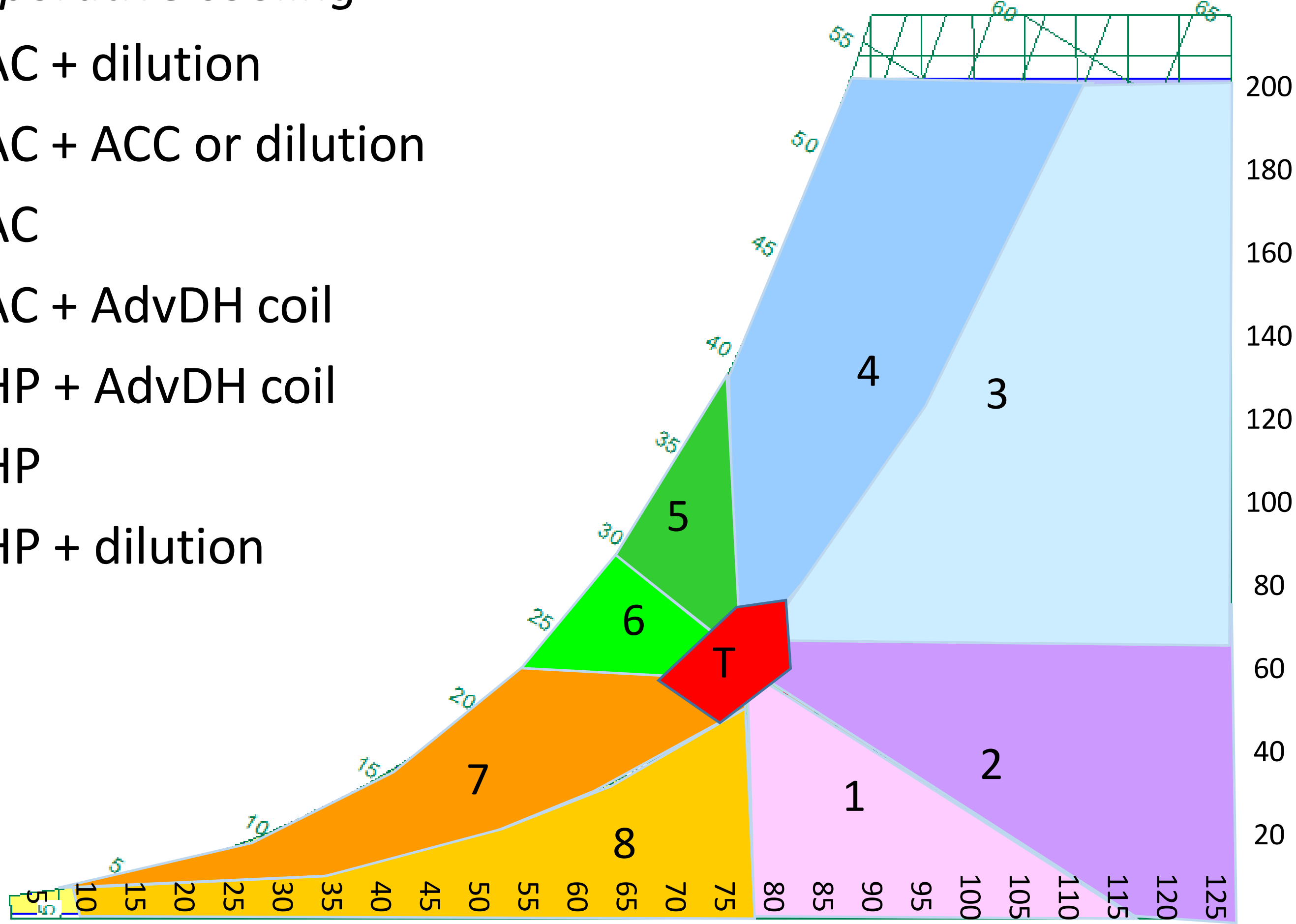
4 LDAC

5 LDAC + AdvDH coil

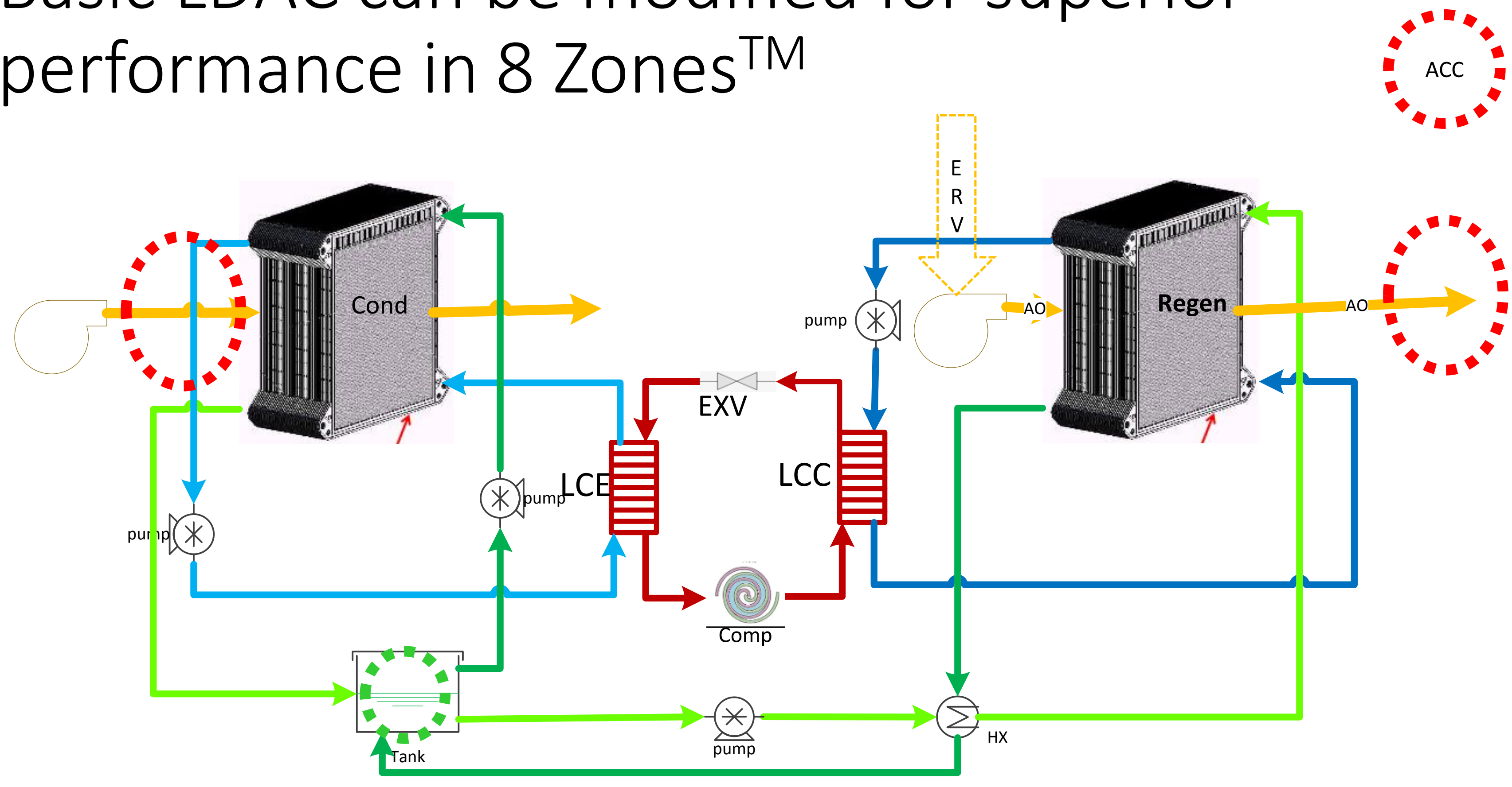
6 LDHP + AdvDH coil

7 LDHP

8 LDHP + dilution



Basic LDAC can be modified for superior performance in 8 Zones^{TM}



Benefits

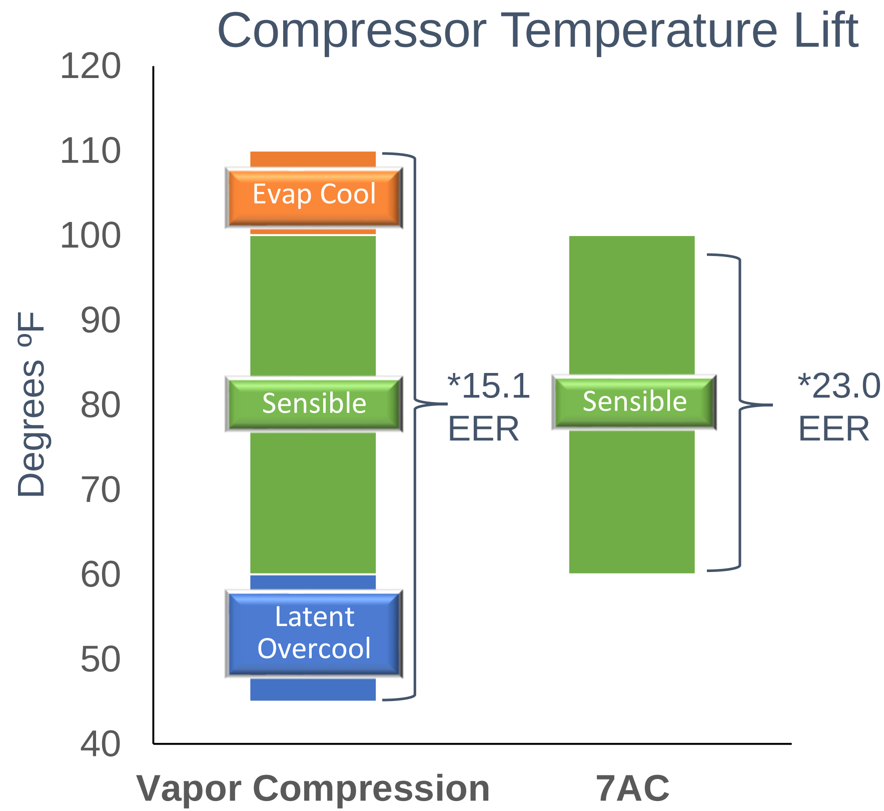
- High efficiency from reduced lift without reheat /post cool
- Improved comfort from Independent humidity control
- No condense/no defrost cycle
- Simplified ERV
- Water based systems

7AC's Efficiency Benefit

Lower temperature lift improves compressor efficiency up to 66%

- Lower condensing temperature due to evaporative cooling of condensing (~10°F)
- Conventional system has lift about 65°F compare to 40°F for 7AC
- Higher evaporating temperature due to removal of latent cooling requirement (~15°F)

Low lift benefits for advanced HP solutions and heat driven solutions



*Based on 10 Summit Copeland Compressor
* Single Point EER

Drivers?

- ASHRAE standards for efficiency, ventilation and humidity management
- Building and district heating and cooling optimization incl. cogeneration and other waste heat use
- Heat pumps humidity and frost control
- Compatible with low lift innovative heat pump technologies
- Optimized evaporative cooling
- Compatible with flammable global warming potential refrigerants and zero refrigerant

7AC experience supports DOE innovation strategy

1. DEVAP License exclusivity was critical for investors
2. 7AC funded CRADA supports system test verification and system modelling
   - Intergration with OEM systems
3. DOD/DOE demonstration confirmed performance potential
   - Further demonstration support would accelerate industry acceptance, including end user adoption
4. IN2 partnership supports testing of advanced solutions
   - Vouchers to further intensify cooperation
5. HPC partnership explores molecular level membrane performance
   - Optimize hydrophobicity/hydrophilicity characteristics
   - Understand near Knudsen flow characteristics during evaporation and absorption
   - Optimize membrane design including manufacturability issues
6. Industry partnerships for market access and commercialized product
   - Stage gate process
   - Early adoption OEMs
   - 2018 deadline
7. Roll to roll manufacturing support to accelerate next generation low cost solutions
8. Advanced solutions require further support
   - Heat driven solutions with Mass CEC
   - Advanced heatpumps applications
   - Net zero solution
   - Integration of LDAC model in energy plus

TABLE OF CONTENTS

TABLE OF CONTENTS – BREAKOUT DISCUSSION 1

NAVIGANT

BREAKOUT DISCUSSION 1 - LOGISTICS

As a small group:

Discuss items driving towards our key objective (described on next slide)

Develop a list of potential initiatives

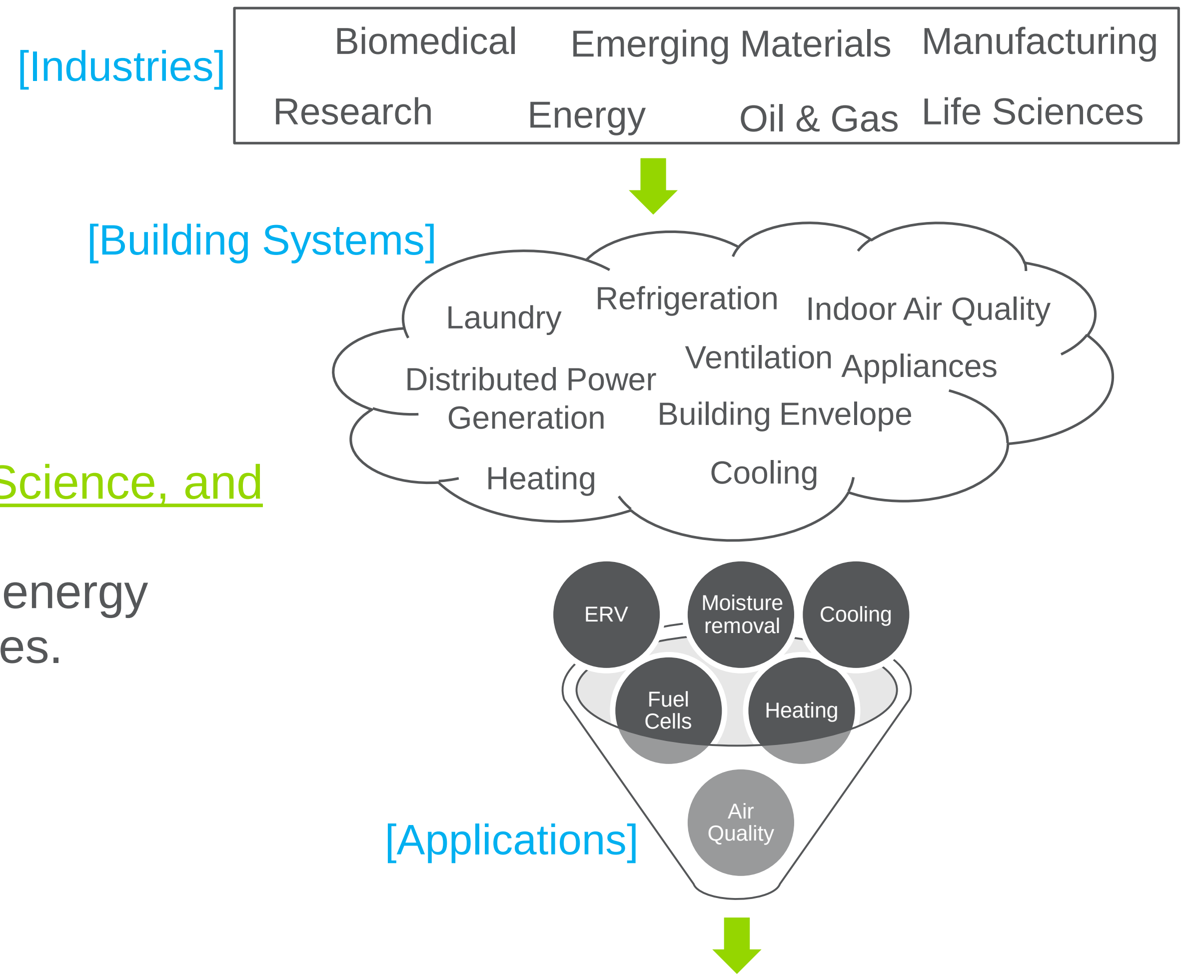
[60 mins]

Report back your best ideas to the larger group

[6-7 mins/ group]

There will be an opportunity at the end of each breakout session to capture (via Sli.do) any topics of interest we did not have time to discuss.

BREAKOUT DISCUSSION 1 – OBJECTIVES



Top Opportunities for Innovation

Objective:

Discuss Concepts, Enabling Science, and applications that can result in membrane/separation-based energy savings in building technologies.

NAVIGANT

BREAKOUT DISCUSSION 1 – ROOM ASSIGNMENTS

Group 1 (ROOM 1 – X248)	Group 2 (ROOM 2 – X324)	Group 3 (Room 3 – X326)
Bill Goetzler (Facilitator)	**Matt Guernsey (Facilitator)**	**Jason Woods (Facilitator)**
Omar Abdelaziz	Bambad Bahar	Daniel Betts
Steven Baker	Brian Bischoff	Uwe Beuscher
Youssef Bargach	Mark Buelow	Panos Datskos
Tony Bouza	Frederick Cogswell	Jason DeGraw
Chaiwat Engtrakul	Michael Geocaris	Debra Deininger
Michael Hu	Chioke Harris	Ryan Huizing
Jason Lustbader	Roderick Jackson	Eric Kozubal
Jeffrey McCutcheon	Brian Johnson	Sven Mumme
Saeed Moghaddam	Peter Luttik	Jim Peters
Sameer Rao	Lu Mi	Michael Wofsey
Ed Trudeau	John Pellegrino	John Zhai
Jeffrey Urban	Robert Tenent	

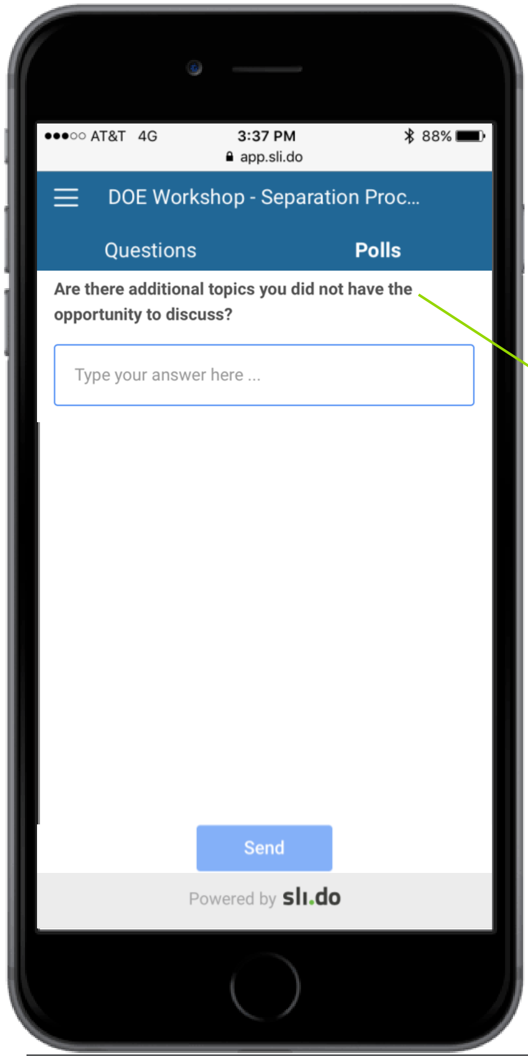
BREAKOUT DISCUSSION 1 – REPORT OUT

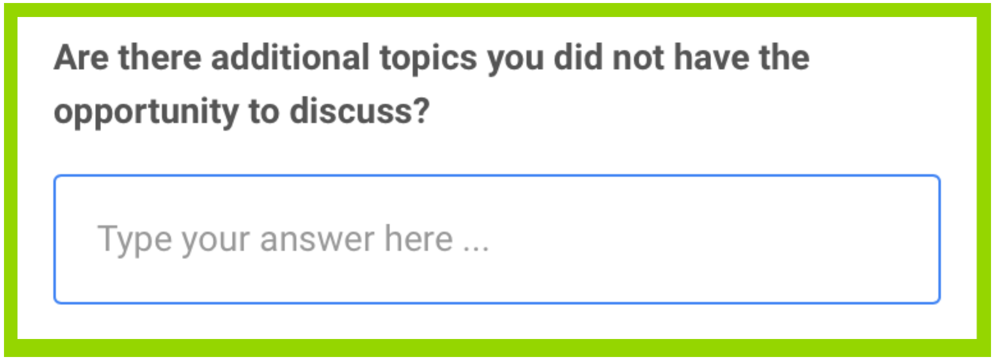
Report back on the initiatives discussed

[25 mins]

SLI.DO POLL

Event Code:
2986





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Event Code:
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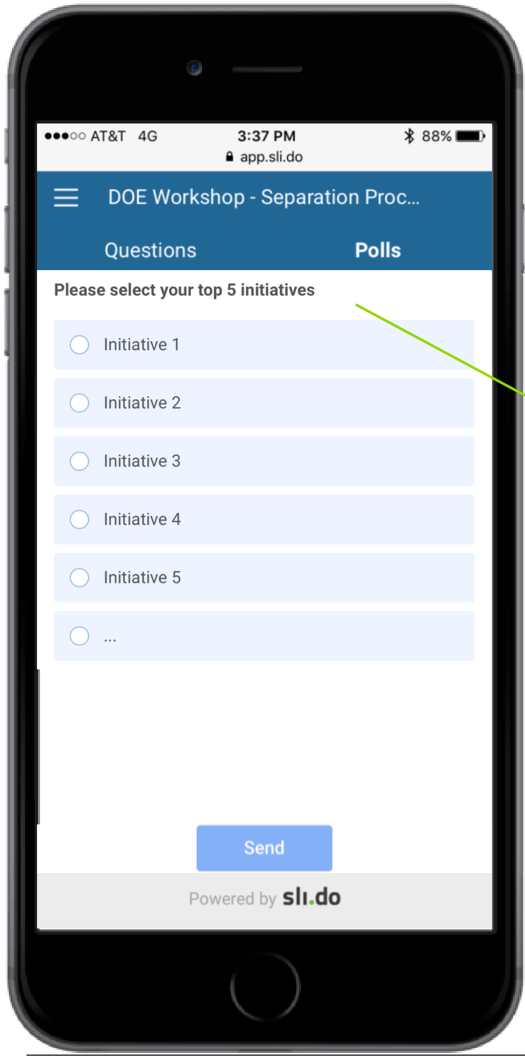
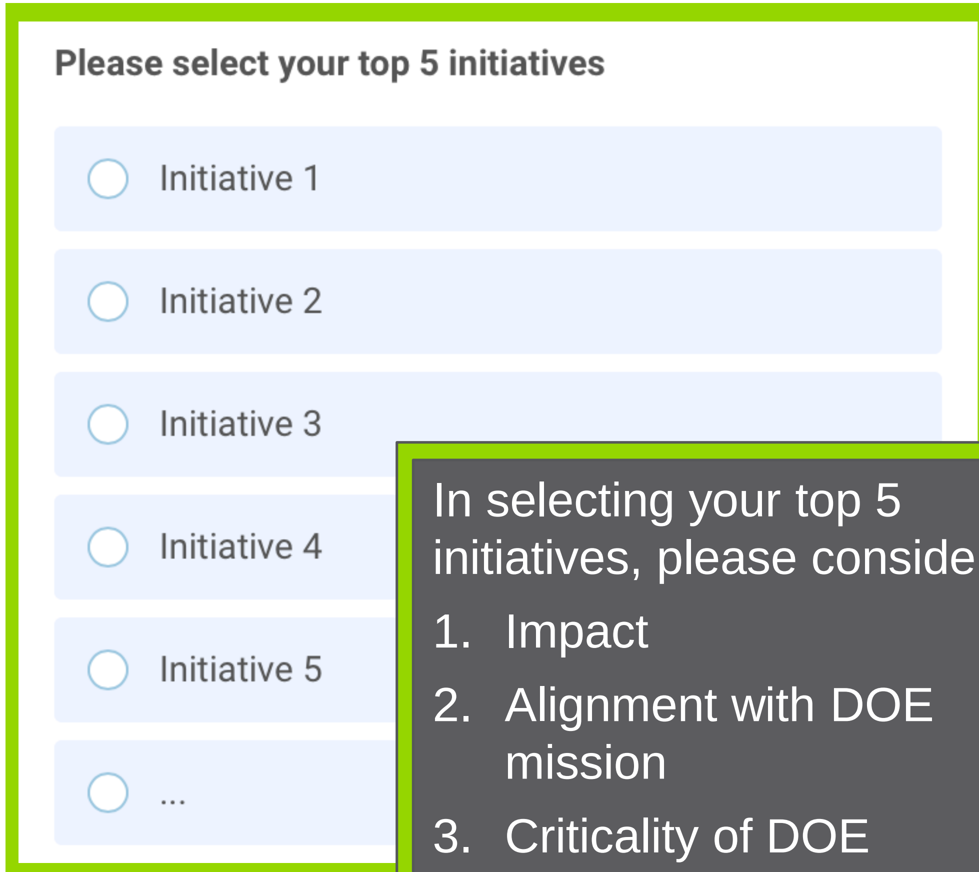
SLI.DO POLL – PRELIMINARY PRIORITIZATION





In selecting your top 5 initiatives, please consider:

1. Impact
2. Alignment with DOE mission
3. Criticality of DOE involvement

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TABLE OF CONTENTS – BREAKOUT DISCUSSION 2

BREAKOUT DISCUSSION 2 - LOGISTICS

Based on the Sli.do responses, each group will collaborate to refine the highest-voted initiatives.

- Group 1 will discuss Initiatives 1, 4, and 7.
- Group 2 will discuss Initiatives 2, 5, and 8.
- Group 3 will discuss Initiatives 3, 6, and 9.

Each group will report back on each of the respective top-initiatives.

Table Discussion
[45 mins]

Reporting Back to Large Group
[20 mins]

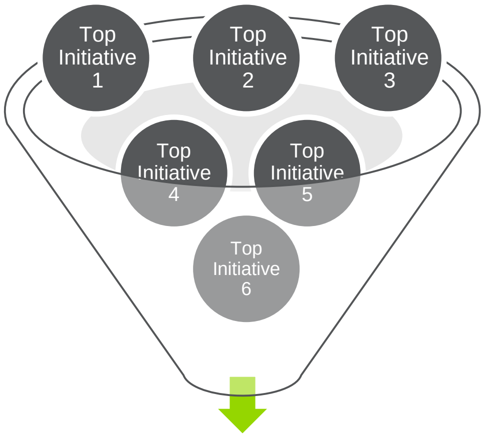
Go back to the same room you were in for the morning session.

There will be an opportunity at the end of each breakout session to capture (via Sli.do) any topics of interest we did not have time to discuss.

BREAKOUT DISCUSSION 2 - OBJECTIVES

Further flesh-out the previously discussed initiatives in order to:

1. Refine initiative title and objective(s)
2. Identify detailed technical challenges
3. Determine most promising applications
4. Identify partnership and collaboration opportunities
5. Characterize desired high-level outcomes (consider both energy and non-energy benefits)



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BREAKOUT DISCUSSION 2 – REPORT OUT

Preliminary Initiative List

Preliminary Initiative List

Sample Initiative 1
Sample Initiative 2
Sample Initiative 3
Sample Initiative 4
Sample Initiative 5
Sample Initiative 6

Report back on the best initiatives discussed
[25 mins]

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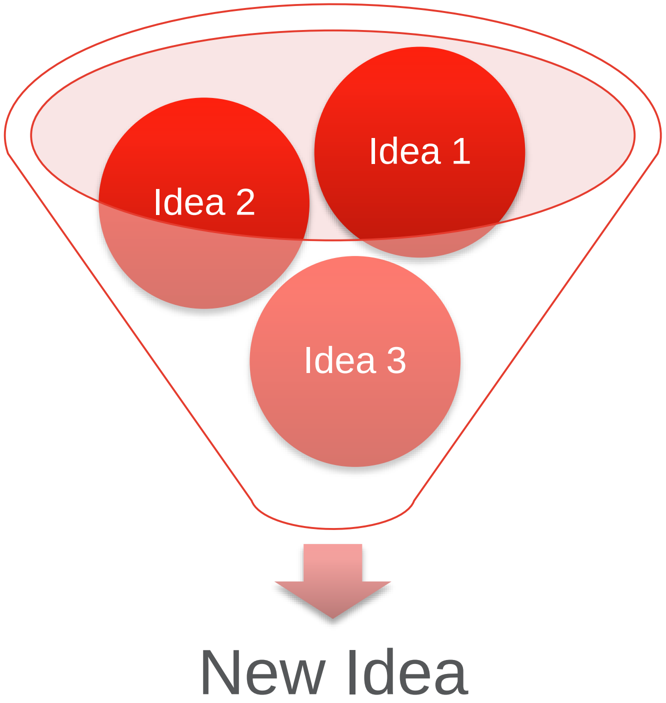
FINAL DISCUSSION

- Any additional thoughts or ideas that we have not yet discussed?

- Combinations of existing ideas?
- New ideas?
- New twists?
- Important but missing details?
- New perspectives?
- Closing thoughts?



Thank you for your inputs

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