Metal Organic Framework – A Novel Sorbent for a Greener World

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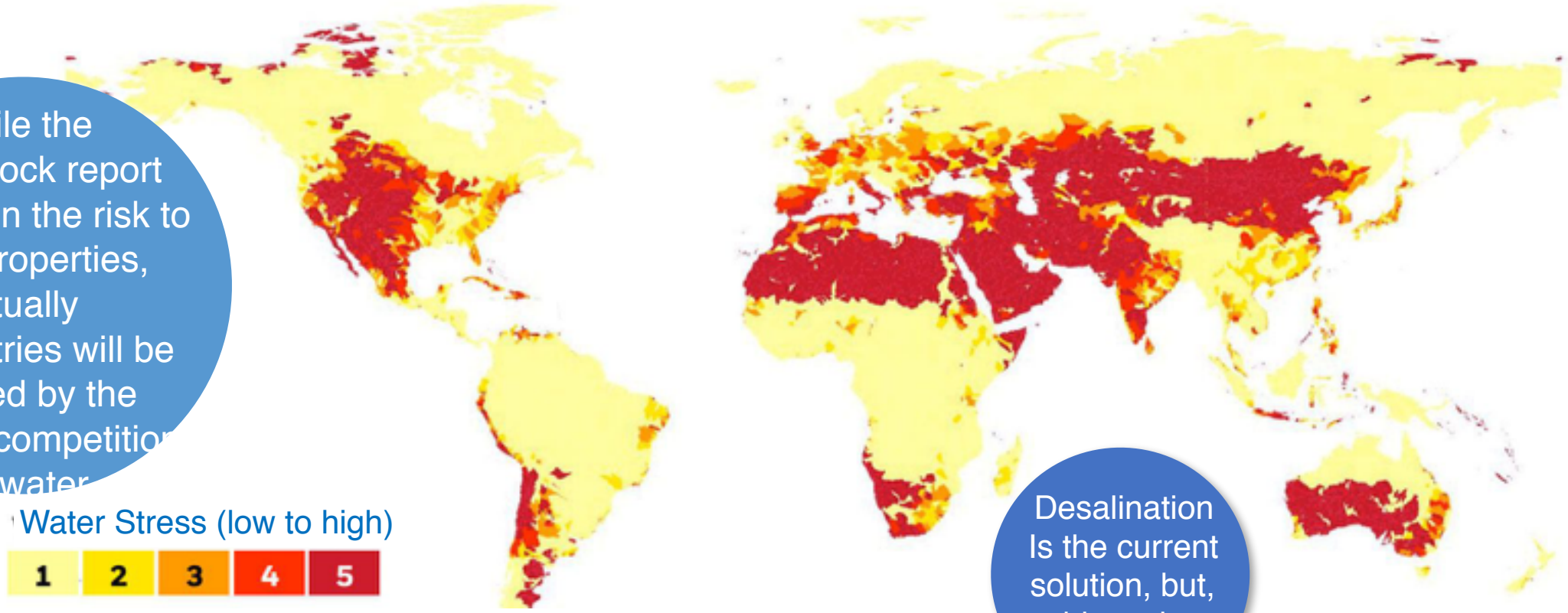
- 113 US and Worldwide Patents

Projected water stress around the world by 2030

While the BlackRock report focuses on the risk to REIT properties, virtually all industries will be affected by the growing competition for water



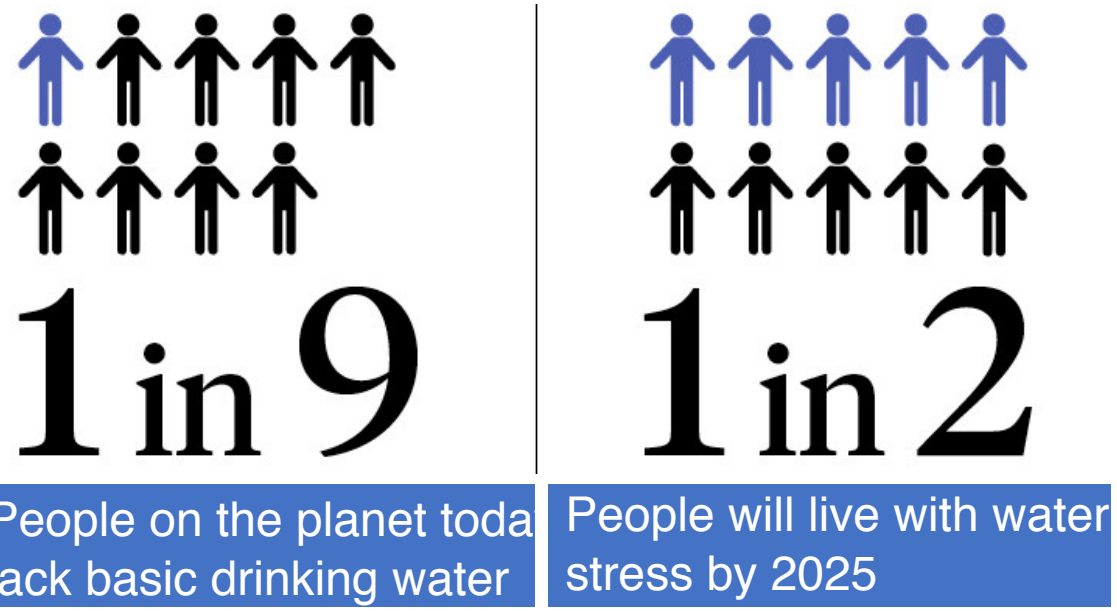
Source: BlackRock Investment Institute and BlackRock Sustainable Investing, with data from WRI, July 2020

Desalination Is the current solution, but, problems loom

Growing Problem: Scarcity and Quality

Drivers

Population Growth and Economic Growth



Challenges

Sustainability and Resilience

- Compromised Supply
  - Dwindling sources
    - Groundwater over extraction
    - Aquifer depletion
    - Climate change
  - Contamination
- Delivery challenges
  - Aging infrastructure
  - Carbon footprint of transport

A Major Natural Resource

- 3,000,000,000,000,000,000,000 (three sextillion)
  Liters of water in the air at any one time

- 160 Countries import their water

- 1/3 of the world population has no access to clean water

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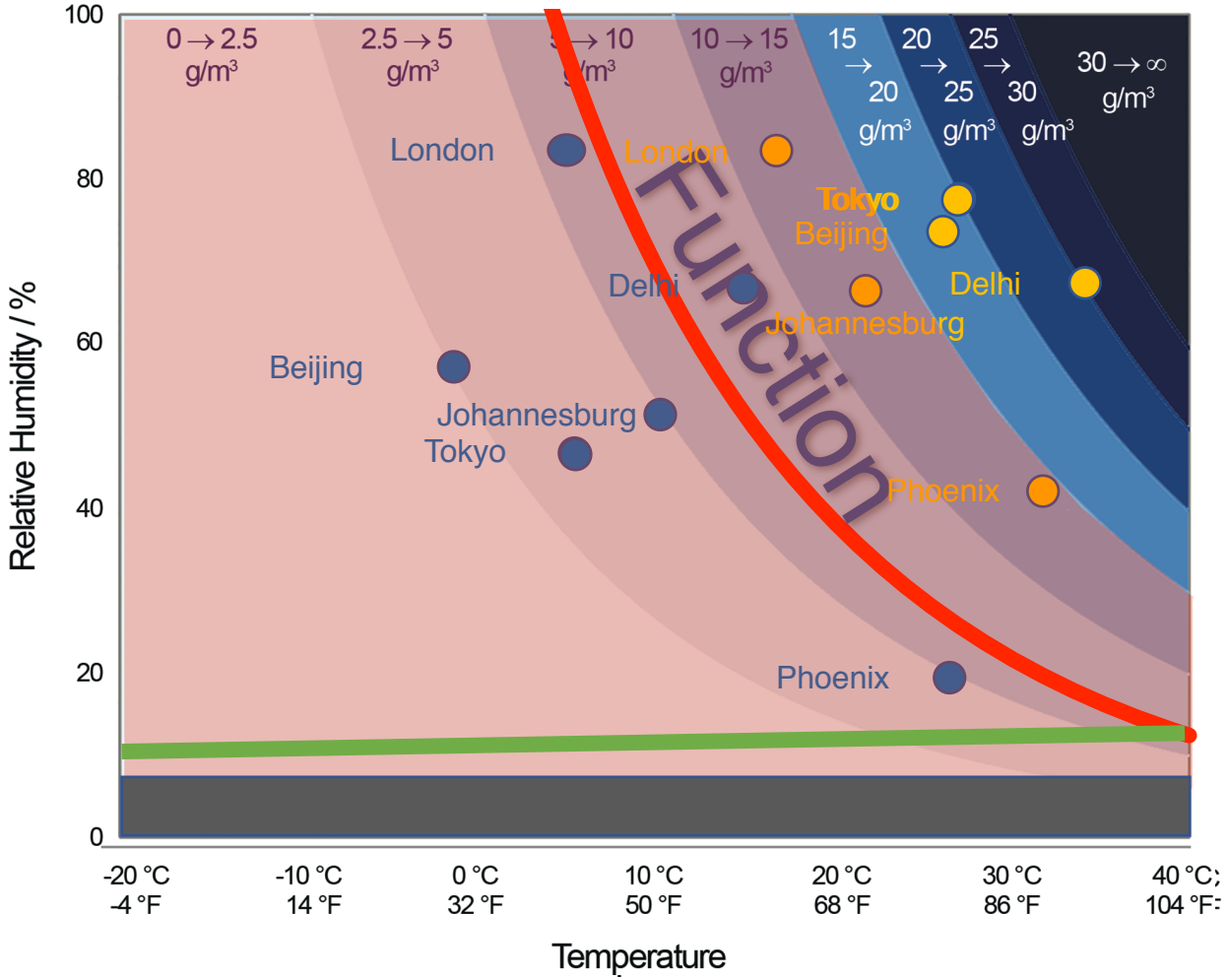
Atmospheric Water Generation Depends on Weather

Below 15g/m³, AWG Condensing Solutions Degrade or Fail Altogether

Performance of AWG Systems is Dependent on Absolute Humidity, which is Determined by the Relationship Between RH and Temp



Tokyo in August
28°C
RH 72%

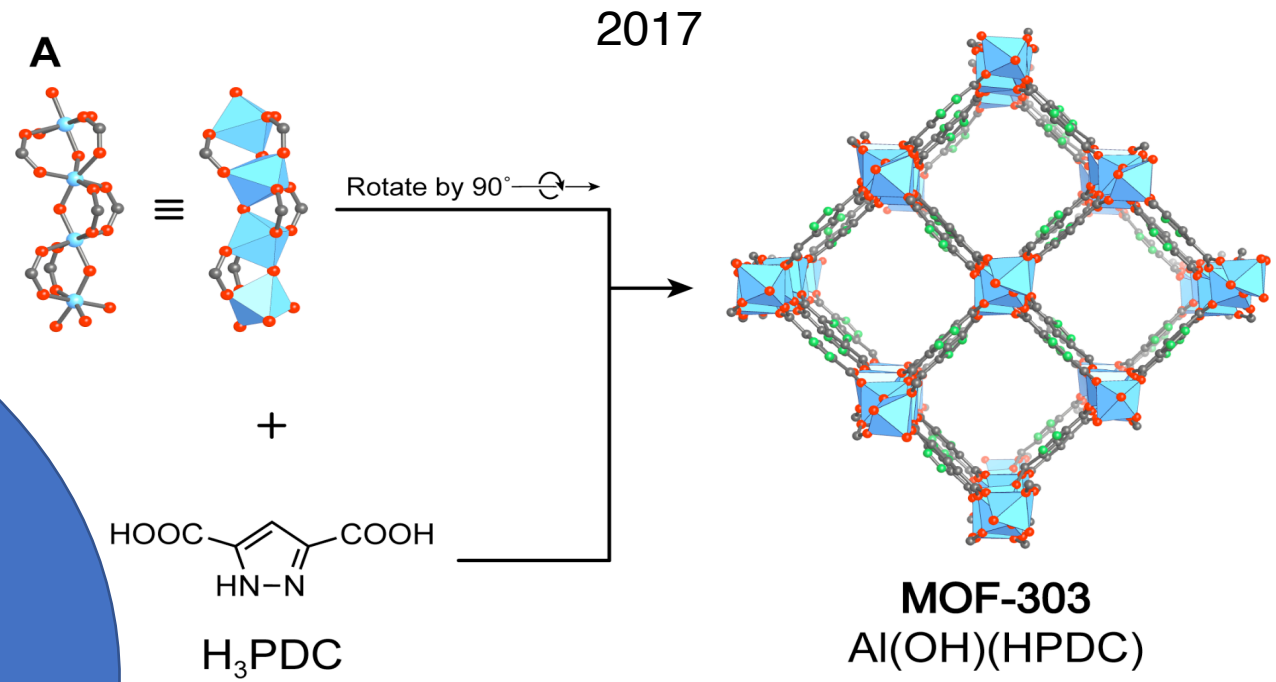
Tokyo in January
5°C
RH 51%

Denotes Summer

Denotes Winter

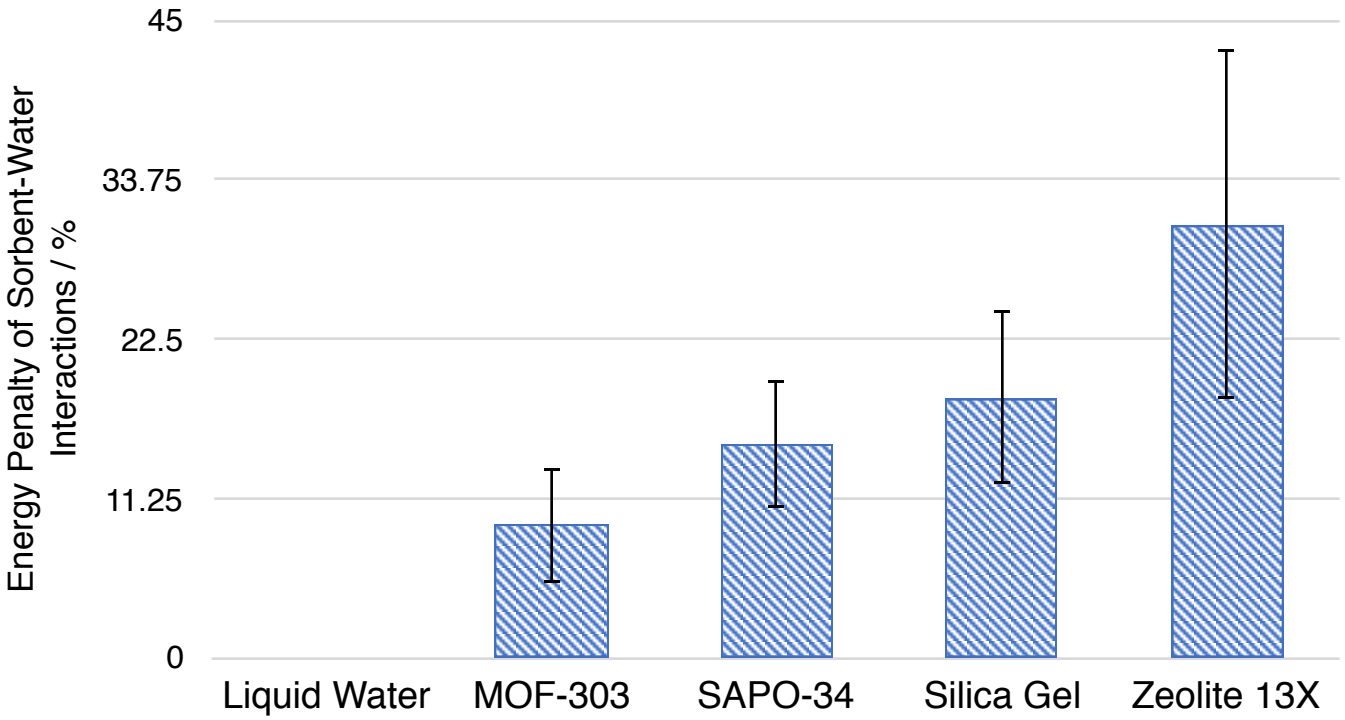
Metal Organic Framework (MOF)

- Pioneered (1995) by Professor Omar Yaghi @ UC Berkeley
- Extreme Porosity: 50 % of volume is empty space
- Extreme Surface Area: 1 gram can cover a football field
- Can be designed to selectively capture water, hydrogen, natural gas, and carbon dioxide



Water capacity at 25 °C at RH of 25%
0.33 Liters per 1 kg of MOF-303

Energy Efficiency is also Sorbent Dependent



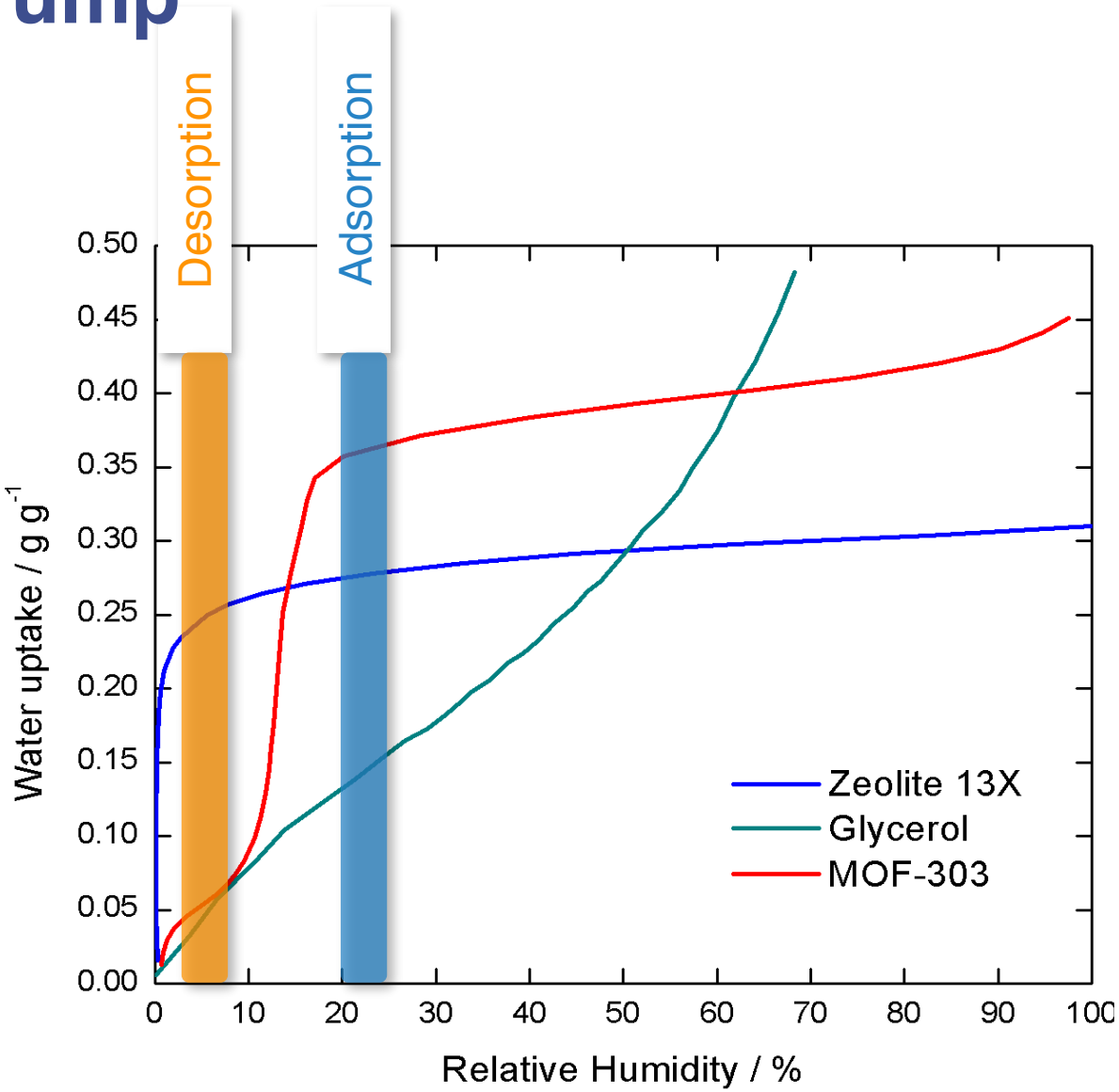
Where Q_{st} is the heat of adsorption, h_{fg} is the latent heat of vaporization of liquid water and A is the cumulative energy of sorbent-water interactions

The lower the A value, the lower is the energy of adsorption which in turn drives the energy-efficiency
of water harvesting systems

The lower the value of energy of adsorption the lower the required temperature of desorption, which in turn determines the coefficient of performance of
water harvesting systems

MOF-303 provides WaHa with the highest coefficient of performance

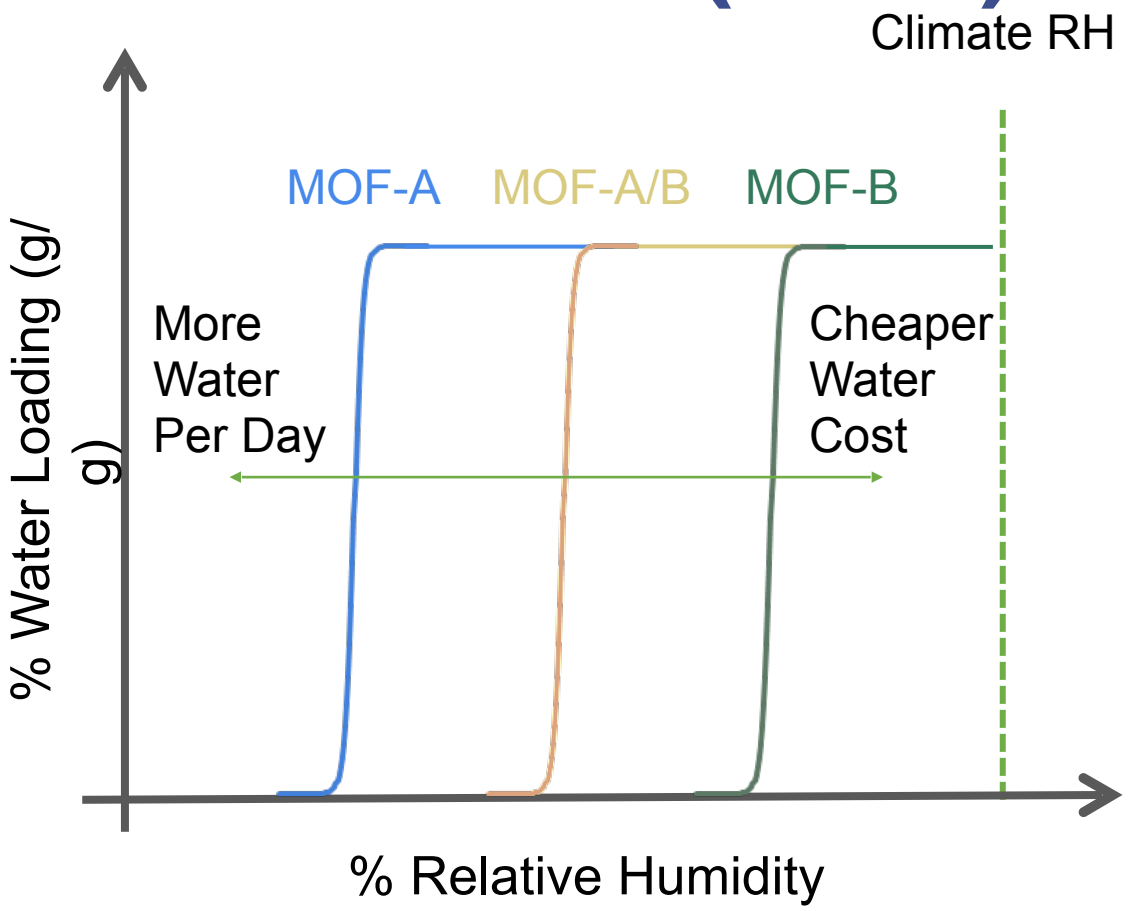
MOF: Step Isotherm enables Energy Efficiency with a Heat Pump

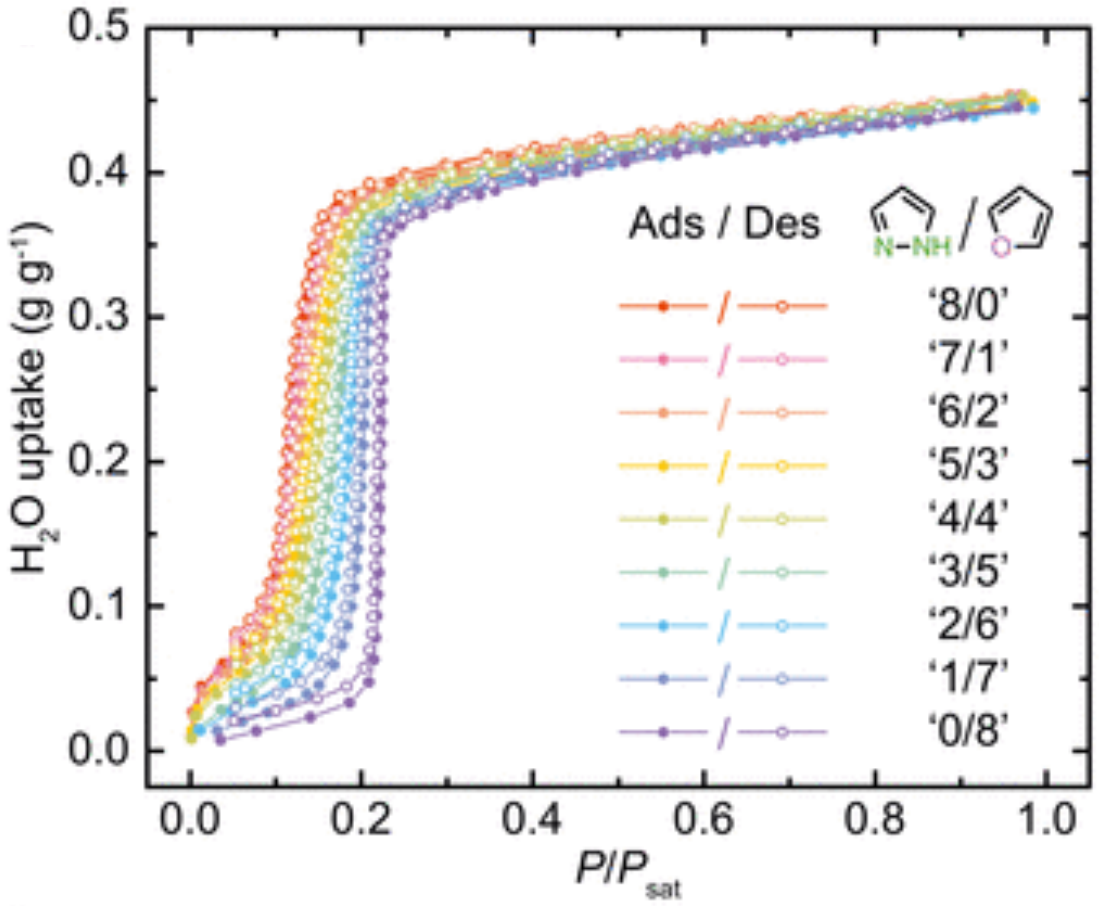


- Zeolite
  - Capable of adsorption at low RH, albeit not as much uptake as MOF
  - However, adsorption energy is very high (2x of MOF), and it is difficult (and costly) to get water out
- Glycerol
  - As a liquid, has a fairly low surface to volume ratio, hence hard to get water in & out
  - Isotherm shows low uptake under ~50% humidity, hence not adequate in arid areas
- MOF-303

  Exhibits ideal, Step function isotherm, with inflection near 15% RH and high adsorption capability

MulTiVariate (MTV) MOF





- More hydrophilic MOF-A makes more water per day albeit at higher energy cost
- More hydrophobic MOF-B makes less water per day at lower energy cost
- MTV-MOF-A/B makes as much water as needed at desired energy cost

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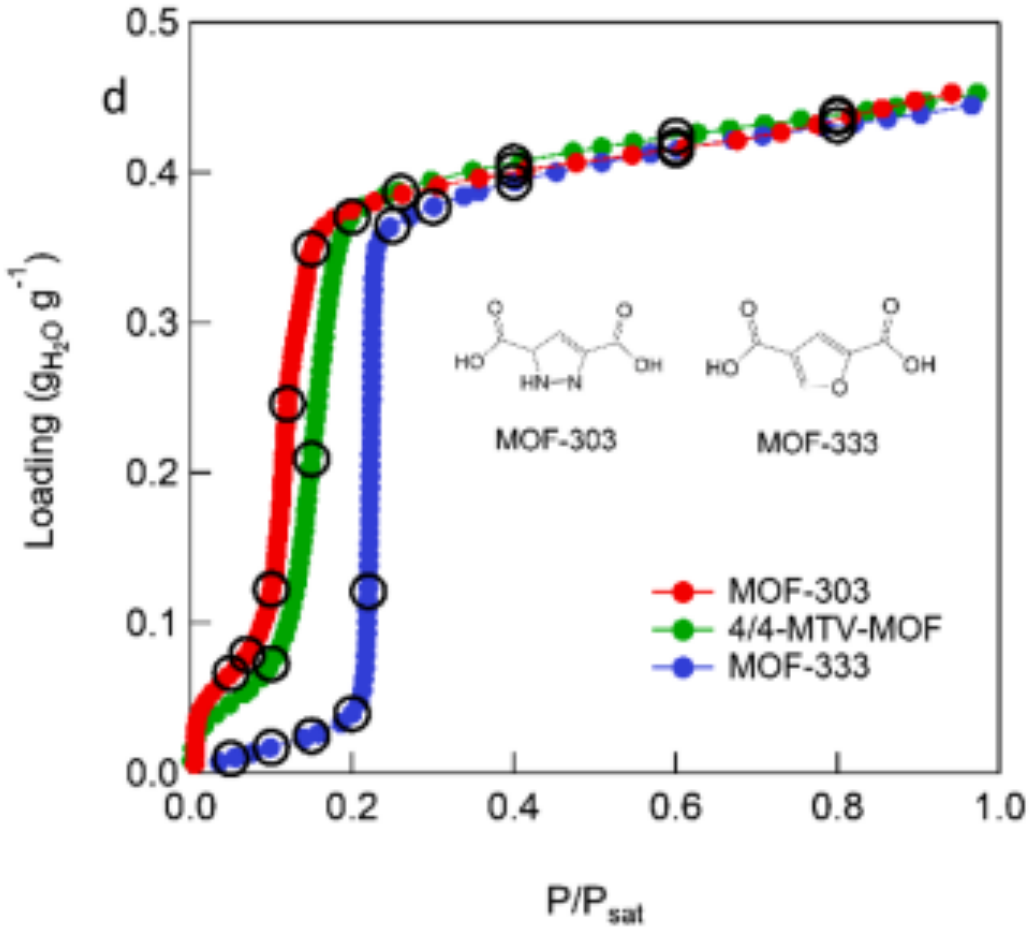
Wide Variety of MOF's with Different Isotherm Steps



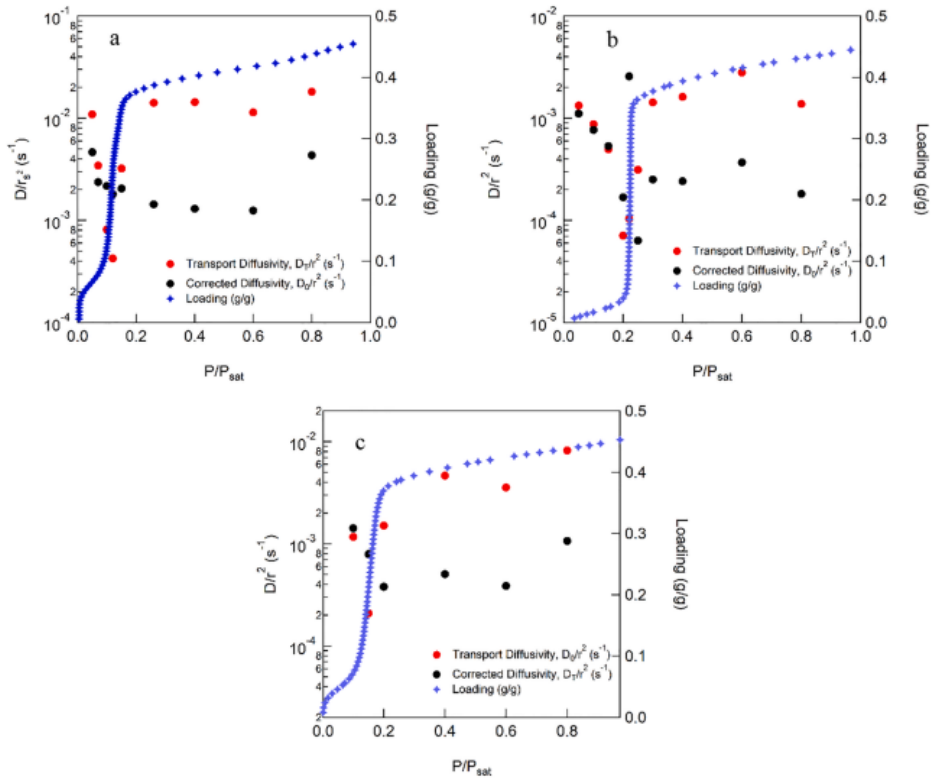
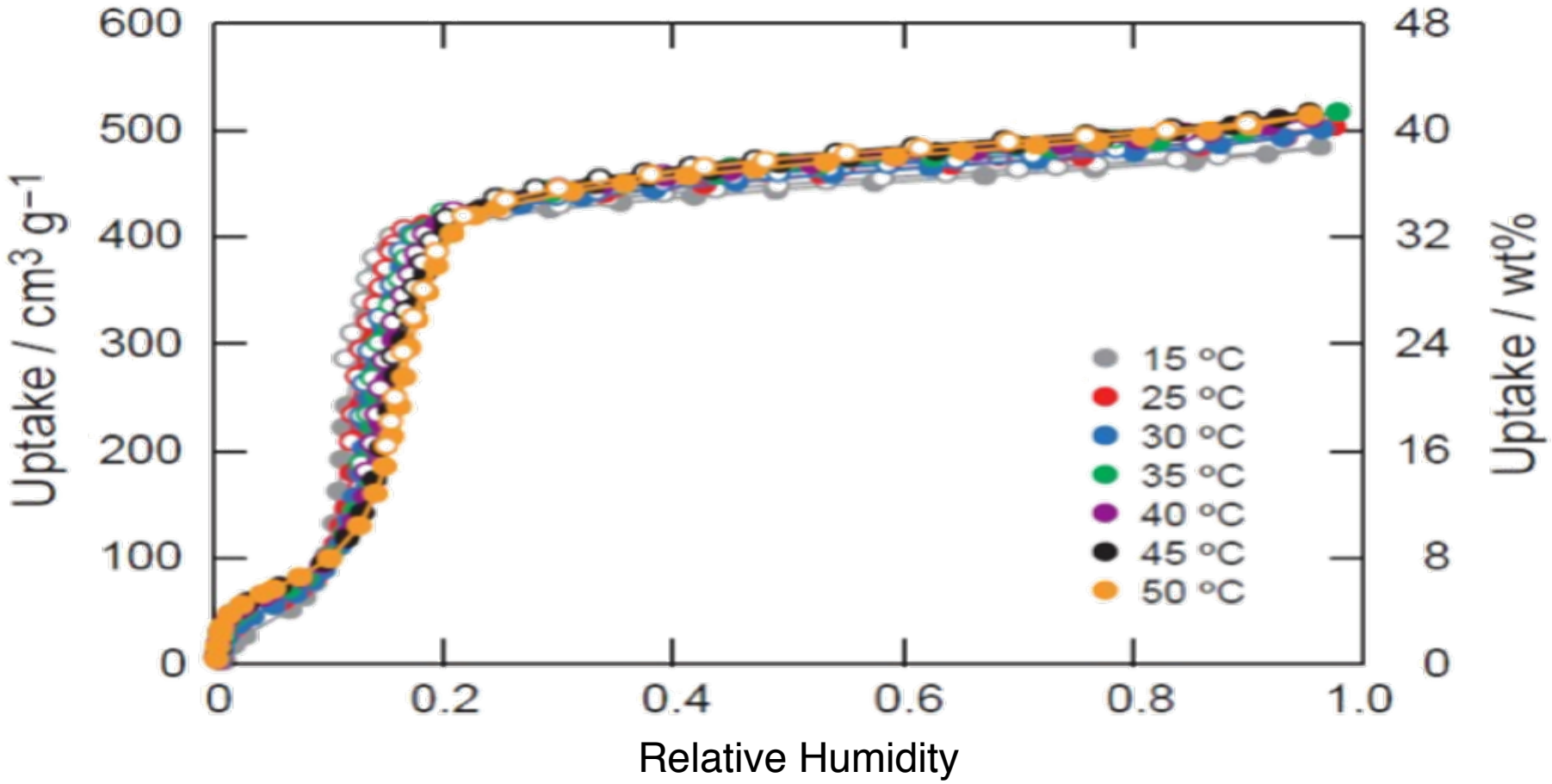


Fig. 5. Corrected and transport diffusivities for water in (a) MOF-303, (b) MOF-333, and (c) 4/4-MTV-MOF, overlayed with adsorption isotherms to illustrate the impact of equilibrium effects on transport diffusion measurements. Isotherms as from Figure 1 (Hanikel et al., 2019; Hanikel et al., 2021).

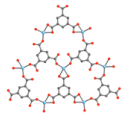
"Mass transfer in atmospheric water harvesting systems", Thomas Lassitter a , Nikita Hanikel b , Dennis J. Coyle c , Mohammad I. Hossain a , Bryce Lipinski c , Michael O'Brien c , David B. Hall c , Jon Hastings a , Juan Borja c , Travis O'Neil c , S. Ephraim Neumann b , David R. Moore c , Omar M. Yaghi b , T. Grant Glover a,* Chemical Engineering Science Volume 285, 5 March 2024

Temperature Dependency of MOF Isotherms



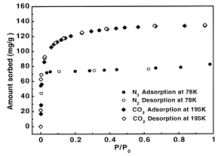
Evolution of MOFs and WaHa

1990s

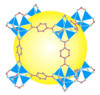


1995
- Crystallization of MOFs.
- The term MOF introduced

1998
Proving permanent porosity of MOFs

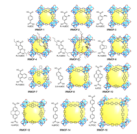


2000s

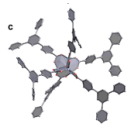


1999
MOF-5 having ultrahigh porosity exceeding all previous records (4X)

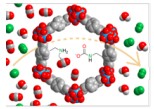
2002
Demonstration of pore functionalization and expansion *by design*



2004
New record of ultrahigh porosity

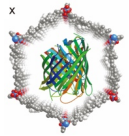


2005
Adsorption sites of gases identified in single crystals by x-ray diffraction

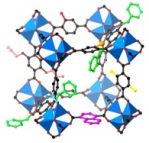


2010s

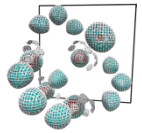
2010
Multivariable MOFs with emergent properties



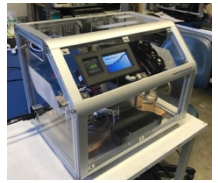
2012
Demonstration of proteins in MOF pores

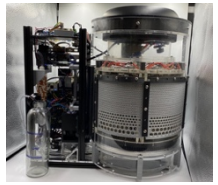


1998, 2006, and 2014
Carbon capture in MOFs



2018
- **Company Founded**
- UC Berkeley MOF Water Harvester (Active) Test – Mojave, CA
- Secured Exclusive Commercial Rights Agreement with UC Berkeley





2017
First UC Berkeley MOF Water Harvester (Passive) Test – Scottsdale, AZ

2019
- Initiated Engineering Testbed Prototype Development
- Completed MOF Testing
- Developed Countertop System
- Demonstrated Engineering Testbed Prototype
- Fabricated initial Countertop Prototype

2020s

2020
- Validation and Optimization of Personal Prototype
- Filed 2 patents
- One patent in preparation for filing

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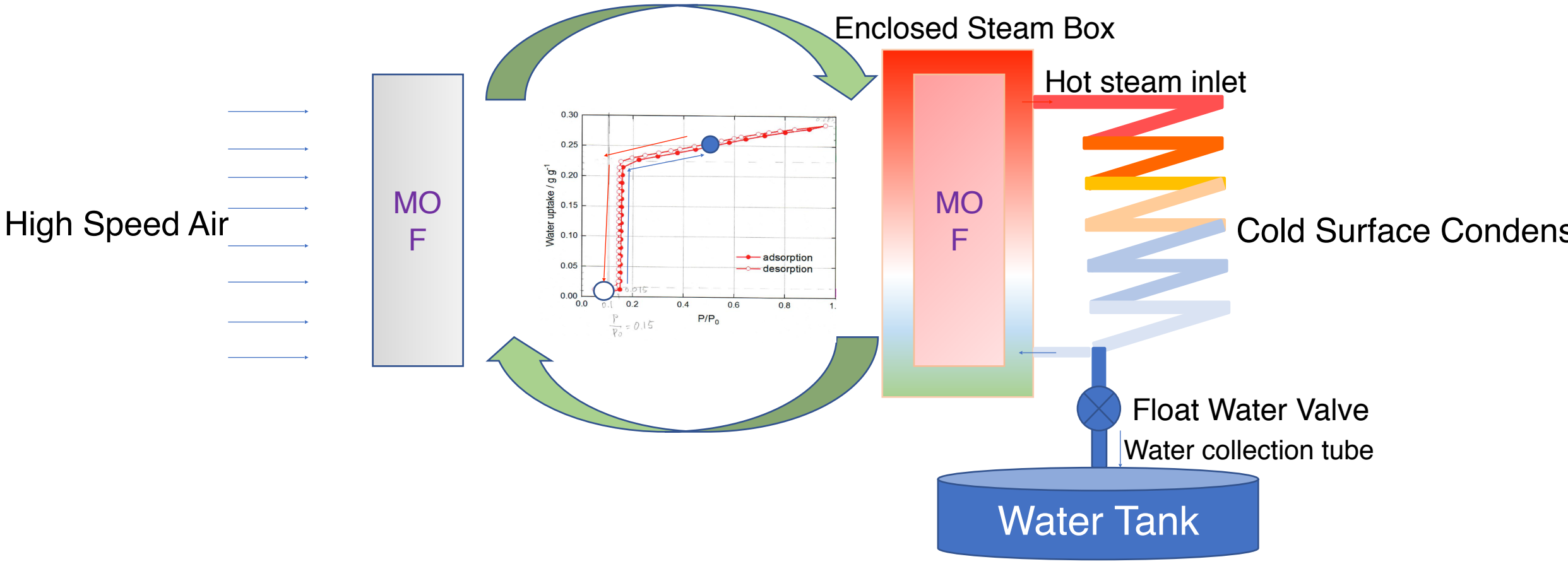
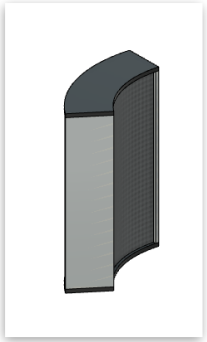
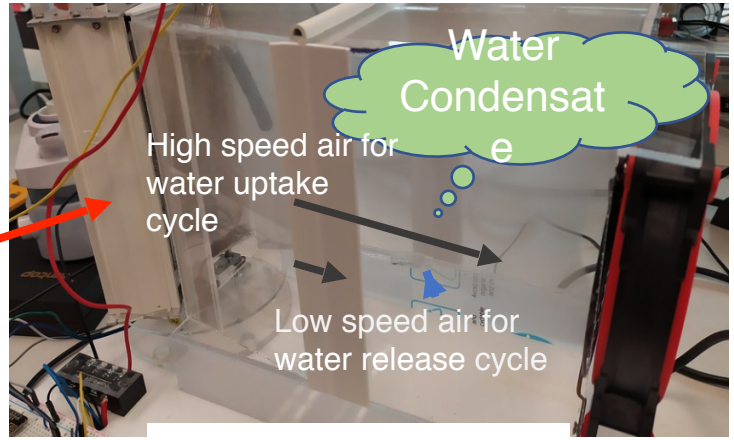
Adsorption and Desorption/Condensation



Countertop Unit 4L/day

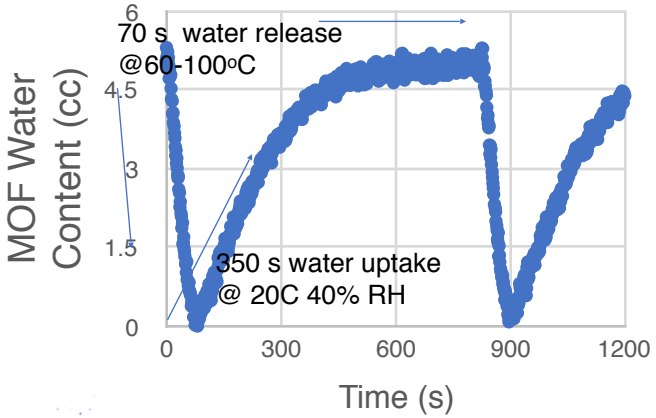


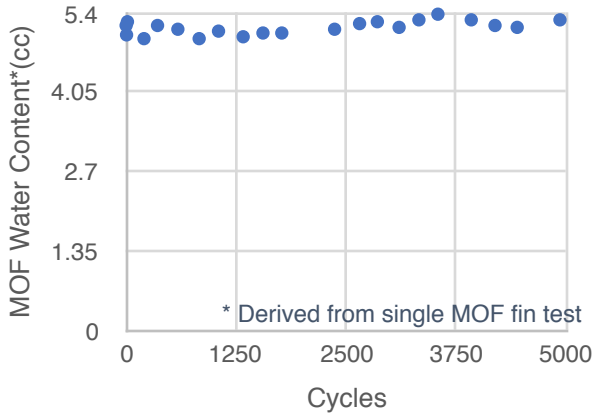


Water Cycle Test

Showcase in the Smithsonian
Dec 2021-July 2022

Saturation





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New Founding Team

Frank R. Ramirez, JD, MBA

CEO & Board of Directors

Serial Entrepreneur
Energy Storage, ClimateTech, Dental Pharma & Finance

Stanford MBA
UC Law School
Serial Entrepreneur

Eugene Kapustin, PhD

CTO

MOF Synthesis & Characterization, Performance Optimization
7 patents

Professor Yaghi's Protege
MOF Expert

David S. Kuo, PhD

EVP, Engineering

Exp: Thermal Science Heat Transfer expert, Adv. Product Design,
110 Patents

Experienced RD/Product Lead
Heat Mass Transfer Expert

Chris Kay

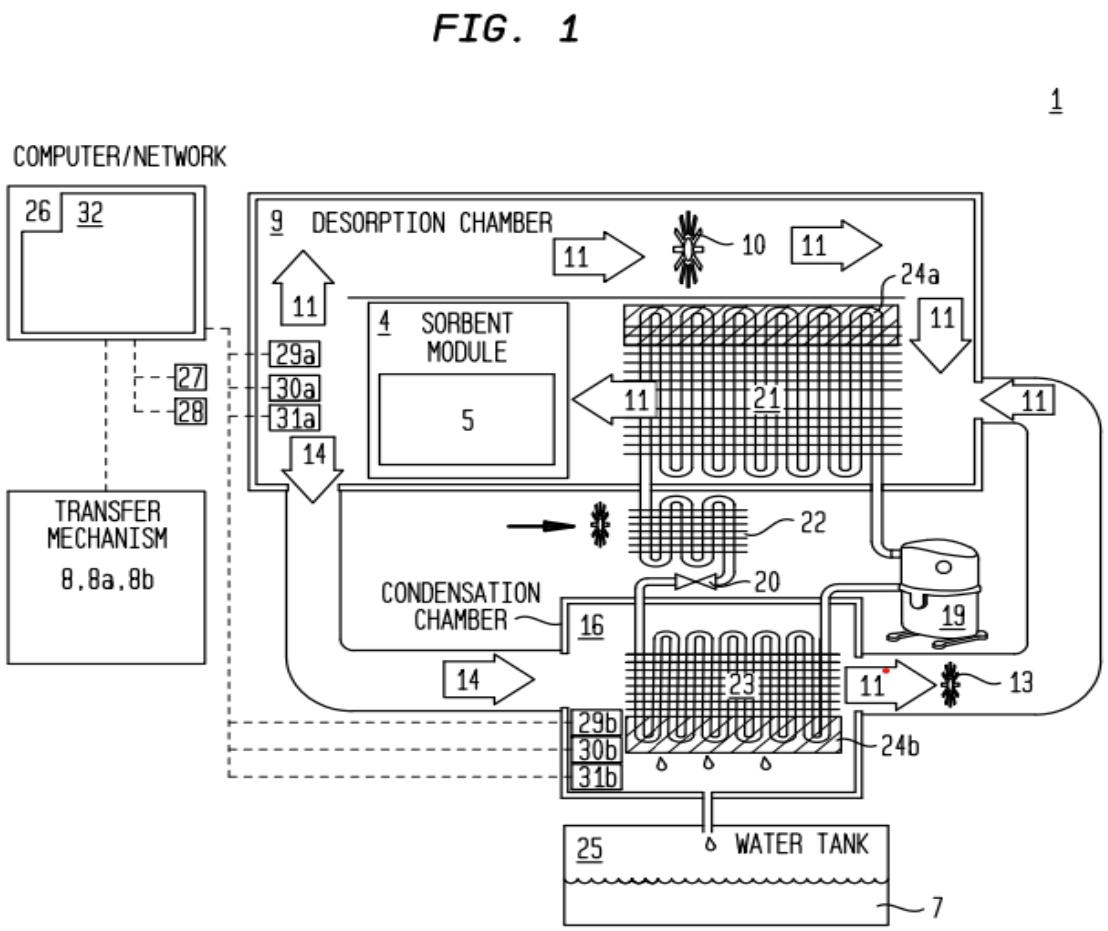
COO

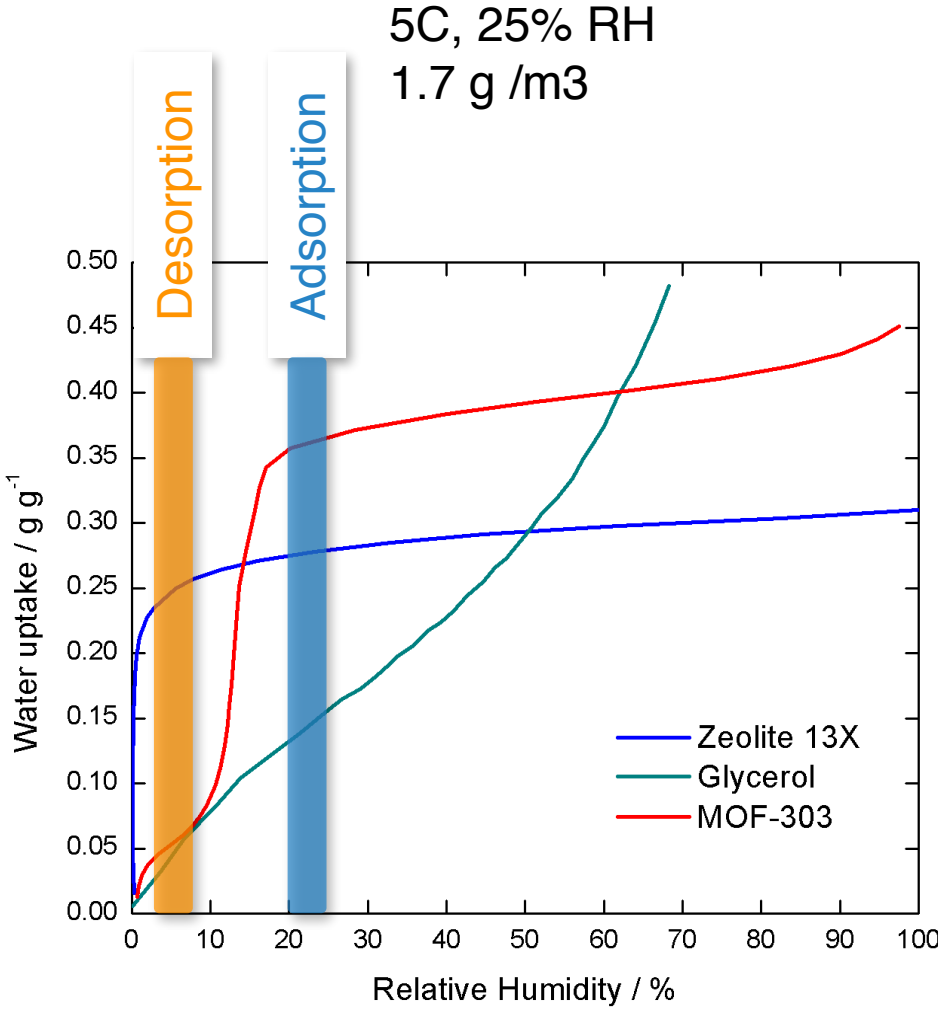
Serial Entrepreneur
Med Device, Software, and Energy Storage,
5 patents

Serial Entrepreneur
Business Development

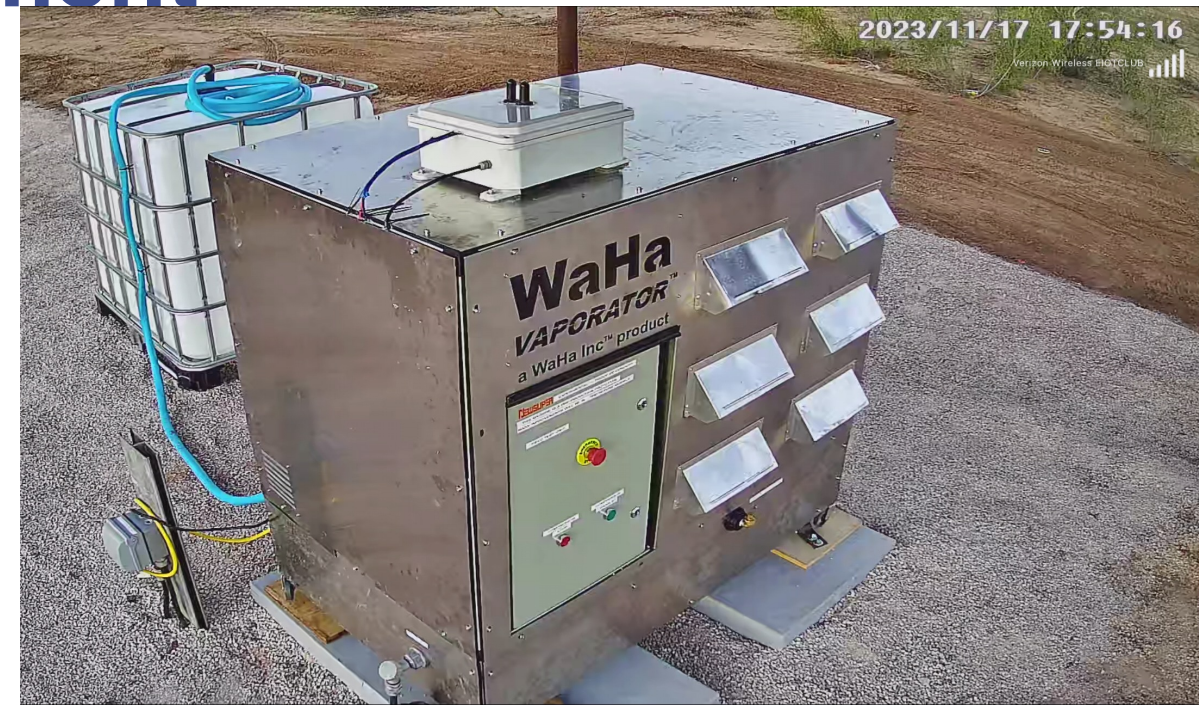
WaHa

Energy-Efficient System for Water Generation



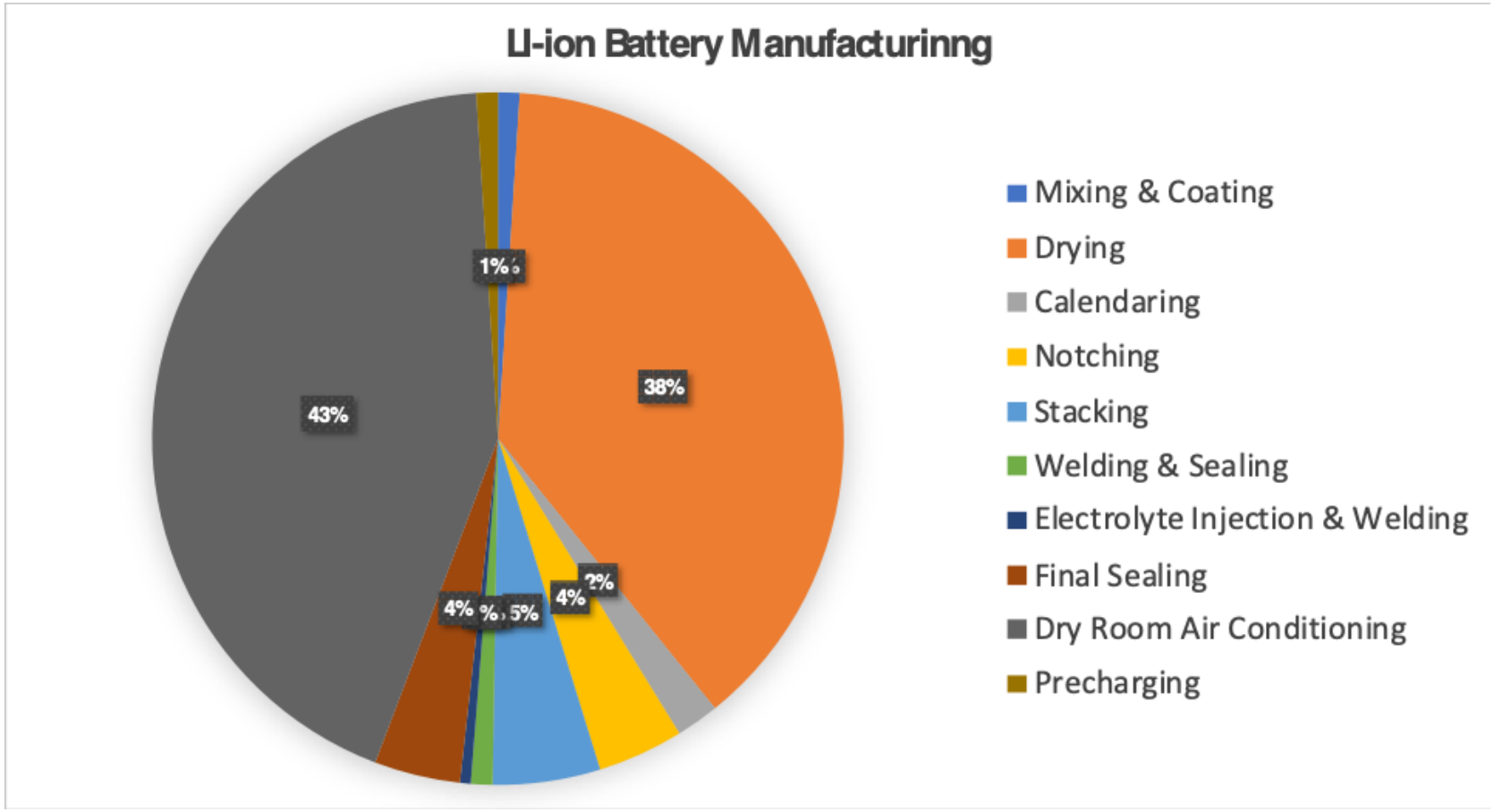


Energy Efficient AWG System in Harsh Environment

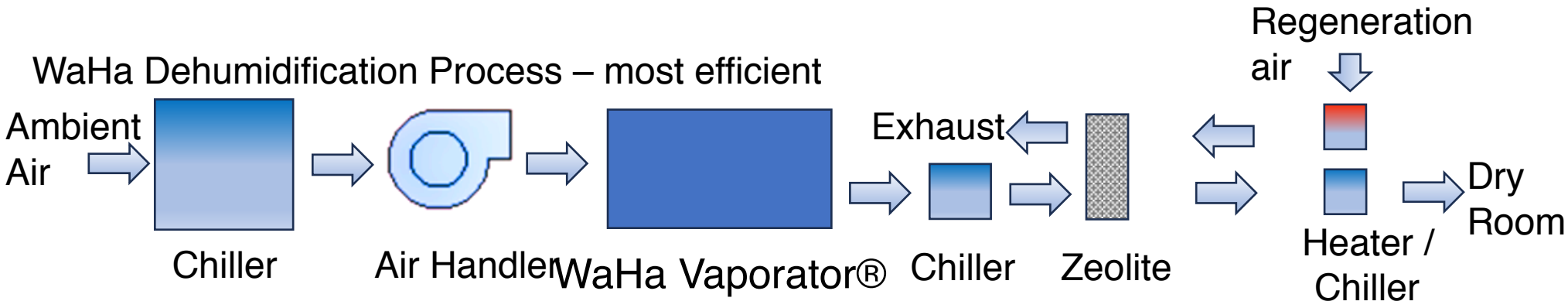


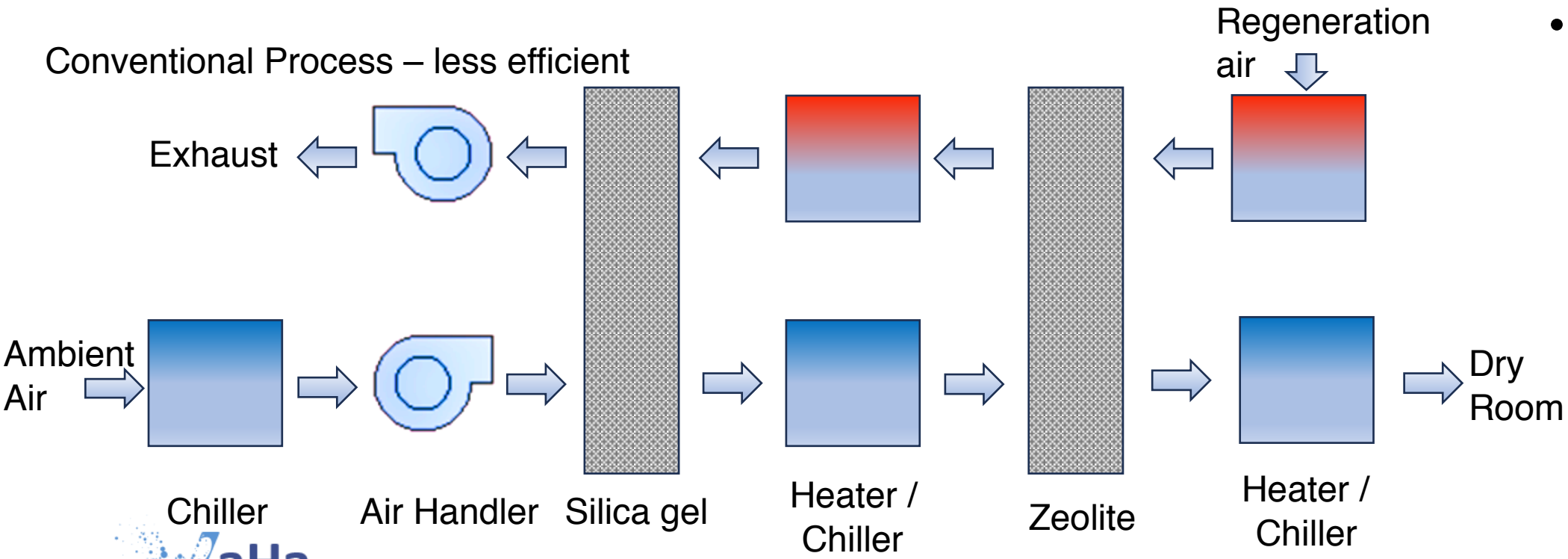
- Install in the desert of West Texas
- 20-24 liters / day
- 0.45 – 0.69 kWh/kg (based on AH)

Dry Room Air Conditioning is the #1 Source of Energy Consumption in Li-ion Battery Manufacturing



Our Process Reduces Dry Room Air Conditioning Energy Consumption by 40-60%





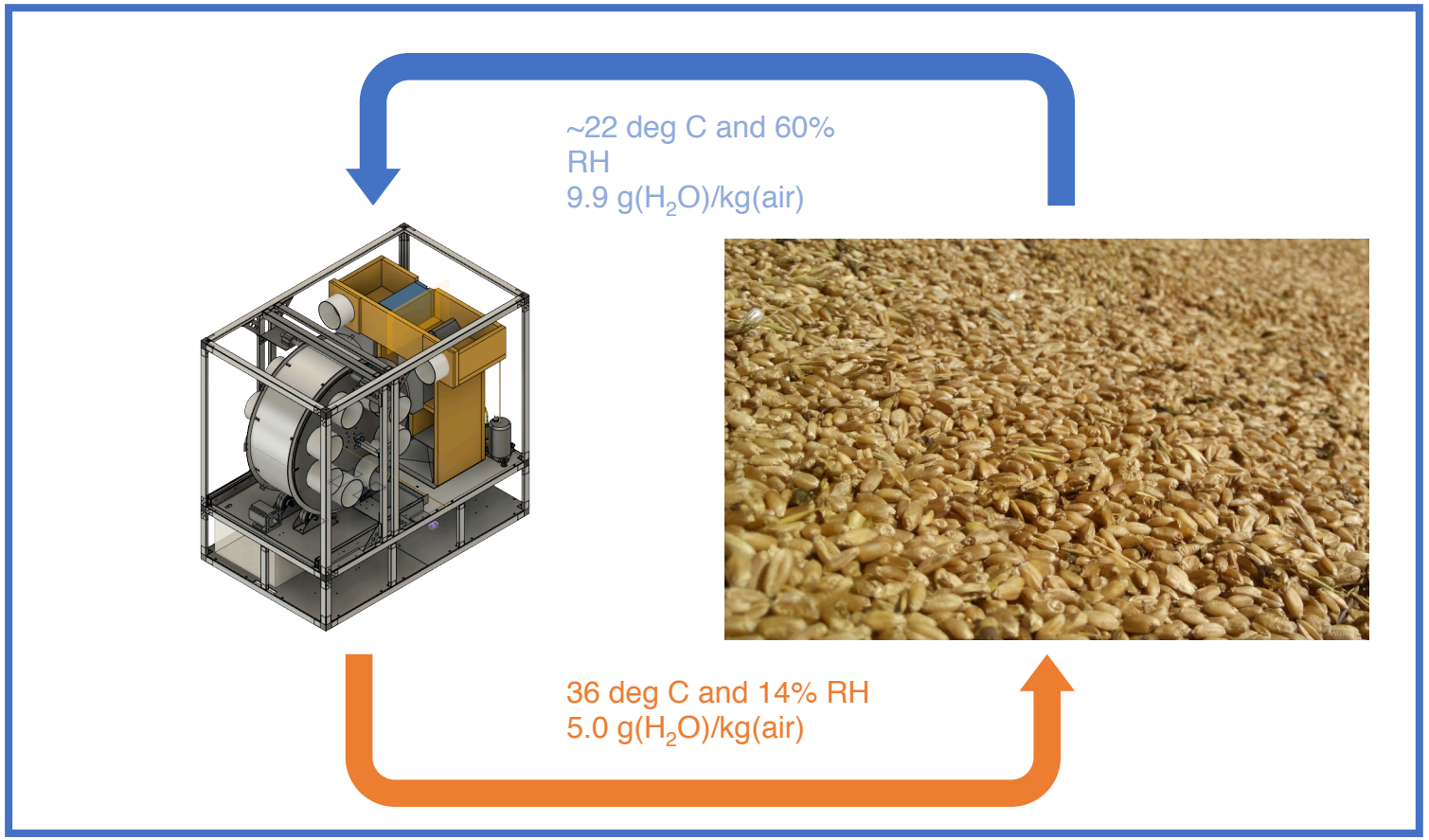
- Replacing traditional silica gel regeneration with WaHa Vaporator®
- Reducing water being sent to zeolite

Johnson Controls

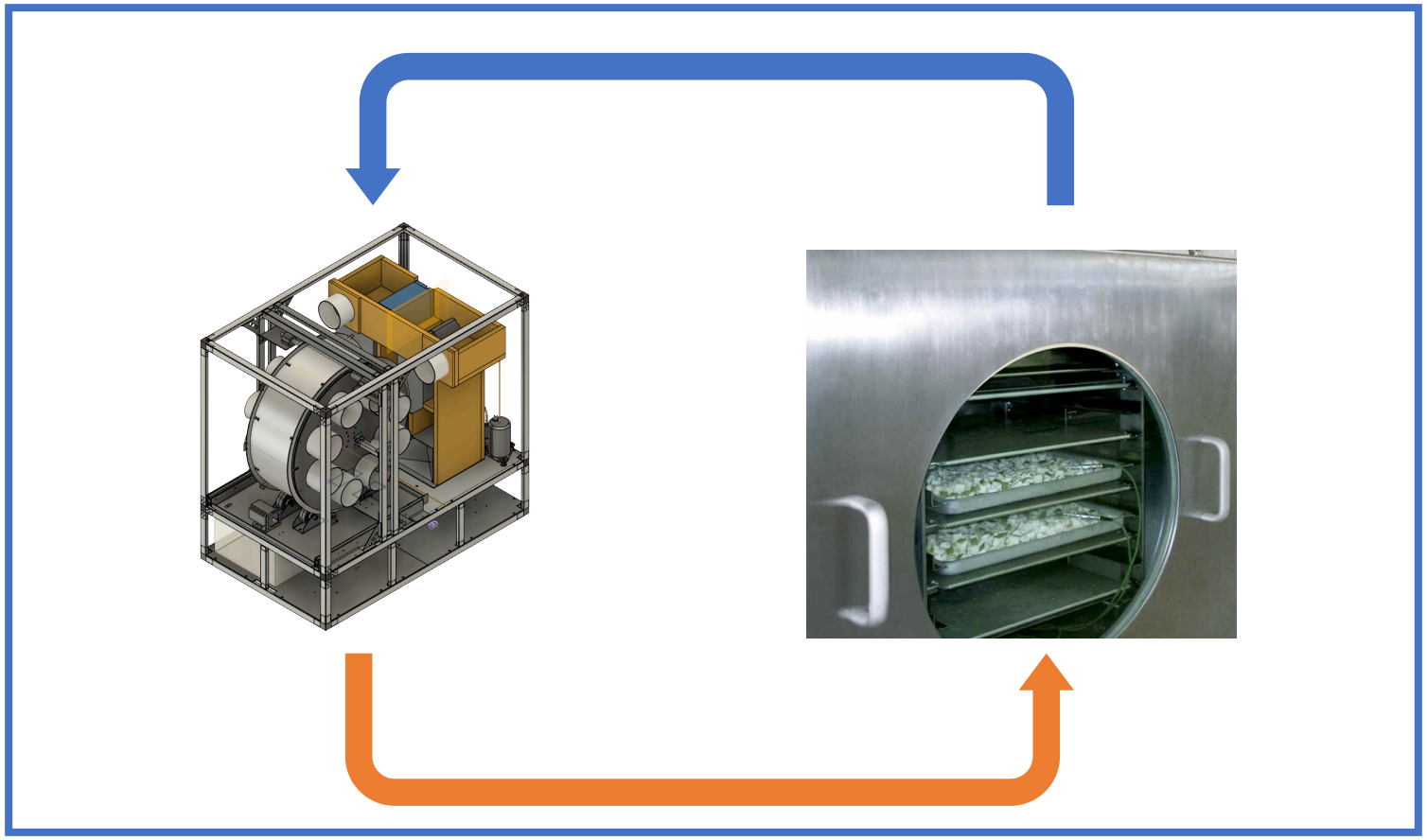
Munters

WaHa

Grain Drying



Freeze Drying @-20C



Water Purity Analyzed – Torrent Laboratory

	PQL	Value	MCL	Unit	Comments
Nickel	0.005	ND		mg/L	
Selenium	0.01	ND		mg/L	
Aluminum	0.1	ND		mg/L	
Iron	0.3	ND		mg/L	
Calcium	0.2	ND		mg/L	
Magnesium	20	ND		mg/L	
Potassium	0.02	ND		mg/L	
Sodium	20	ND		mg/L	
Manganese	2	ND		mg/L	
Arsenic	0.0005	0.00073	0.01	mg/L	Trace level near detection limit
Chromium	0.0005	ND		mg/L	
Lead	0.0005	ND		mg/L	
Copper	0.02	0.59	1.3	mg/L	Likely from Copper tubing

	PQL	Value	MCL	Unit	Comments
Calcium Hardness	1	ND		mg/L	
Total Hardness	1	ND		mg/L	
Nitrate	0.1	ND		mg/L	
Nitrite	0.1	0.15	1	mg/L	Trace level near detection limit
Total Dissolved Solids	10	12		mg/L	Range for tap water is 50-1000
Residual Chlorine	0.2	ND		ug/L	
Chloroform	0.5	ND		ug/L	
Bromoform	0.5	ND		ug/L	
BDCMethane	0.5	ND		ug/L	
DBCMethane	0.5	ND		ug/L	
pH	0.1	5.27		SU	Same as distilled water
Turbidity	0.2	0.33	5	NTU	Near detection limit
Total Coliforms		Absent		CFU/mL	
E. Coli		Absent		CFU/mL	

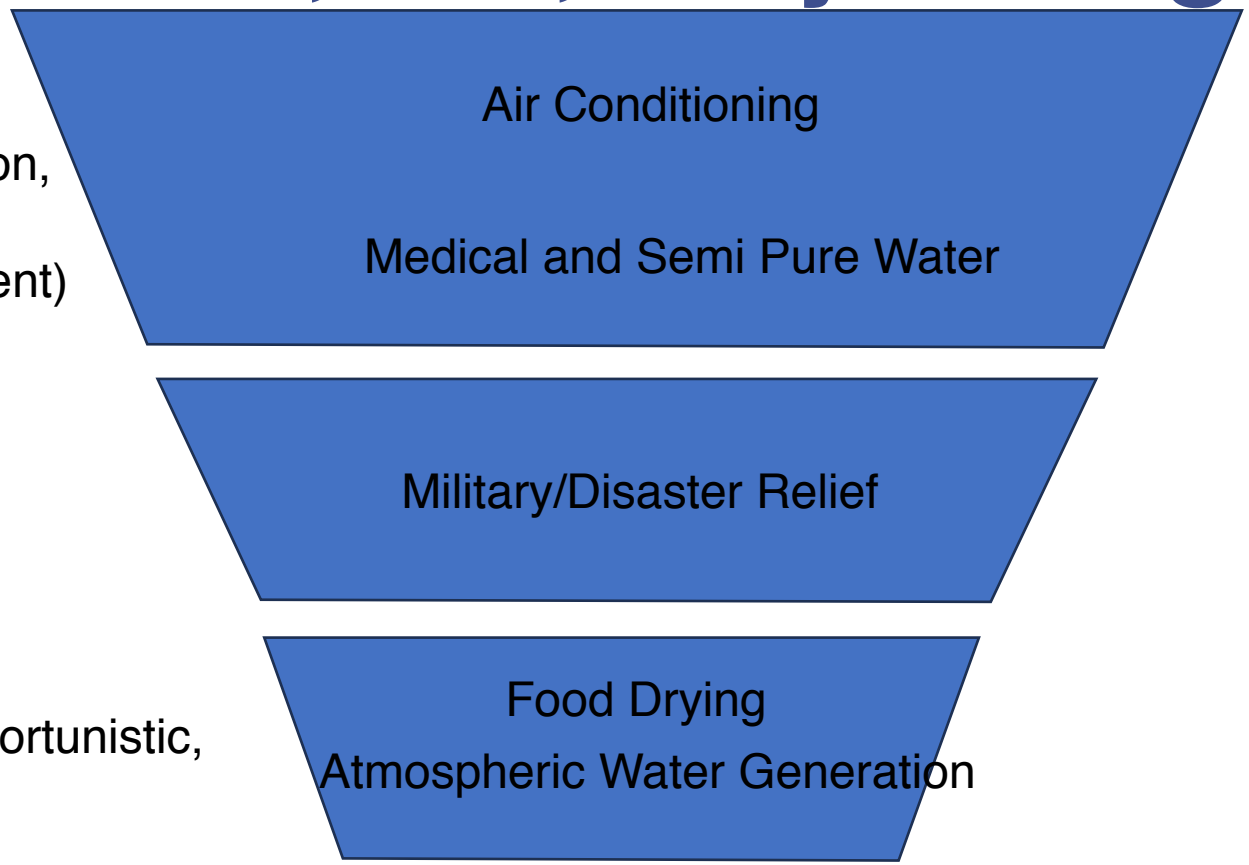
- Analysis by Torrent, EPA and NSF Certified
- Results better than guidelines
- pH level consistent with distilled water (dissolved CO_2). Can be raised (7.11) with mineralization
- This water gathered during a time of poor air quality in CA due to extensive fires
- Cu due to copper cooling coil – easy to fix

Traction – Lots, *but*, only 1 Target Market

Long-term
(regulatory, qualification, customer build cycle, technology development)

Medium-term
(focus, partnerships)

Short-term
(strong market fit, opportunistic, low technical risk)



Low dew point dehumidification: Li-ion battery production

WaHa

Markets – essentially same device for all markets

Market	TAM	Target Markets	Notes	Differentiators
Controlled Environment Agriculture (CEA)	$1.4B $.8B $.5B	Dehumidification ~~Supplemental Water~~ CO2 Injection (later)	4 LOIs signed, 4 more in negotiations 1 offer to fund all development	Yield, Opex, Capex Opex, Sustainability Farm siting flexibility, Sustainability
Desiccant (where vapor-compression dehumidifiers do not work well)	$2B	Low temperature (cold storage, ice rinks) Low dewpoint (Li-ion battery production) ~~Storage rooms (pharma, silos)~~ Coolers	Energy analysis verified by a large US HVAC company. 9x-64x improvement over their systems.	Opex Capex
Humidity management	TBD	Semiconductor fabs Data centers	Solution reviews w/2 largest fabs	Opex Humidity variance Sustainability
HVAC dehumidification / Humidity management / Indoor air quality	$127-19 1B	Commercial Industrial Residential Automotive	Energy analysis verified by a large US HVAC company. 5.5 – 7x improvement over their systems.	Opex & Capex Sustainability Comfort Maintenance
Solar Panel Cleaning	$1.3B	Generate water directly at solar farms for panel cleaning	Letter of support from robotic solar panel cleaning company	Panel productivity Opex & Capex
Ultrapure	$5B	Semiconductor manufacturing Pharmaceutical manufacturing Energy production (green H2) Cosmetics	LOI from biotech company	Quality Capex & Opex Reliability Sustainability

WaHa Technology Addresses

- Water Scarcity
- Energy Savings for Dehumidification
- Low Energy Pure Water Generation

Q & A