Maximizing Uptake of Hygroscopic Hydrogels Through Extreme Swelling-Induced Salt Loading

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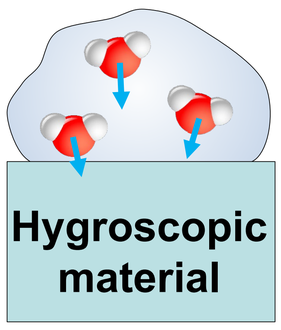
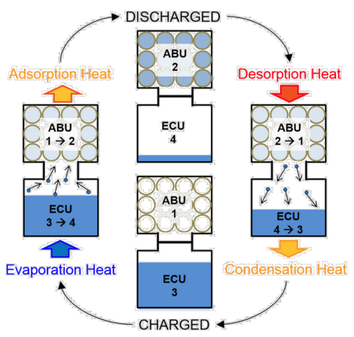
Water sorption is used in many **water-energy applications**

Moisture in ambient



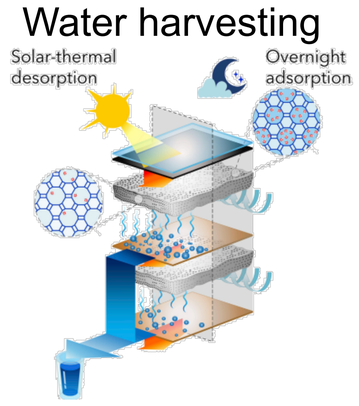
Thermal energy storage



Narayanan *et al*. *Appl. Energy*, 2017

Reuse of heat in buildings, vehicles

Water harvesting

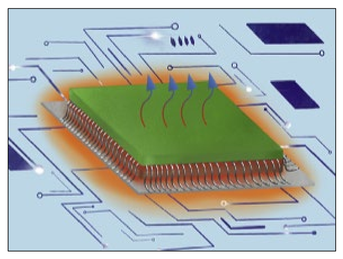


LaPotin *et al*. *Joule,* 2021

Water for a billion people*

*Lord *et al*, 2021

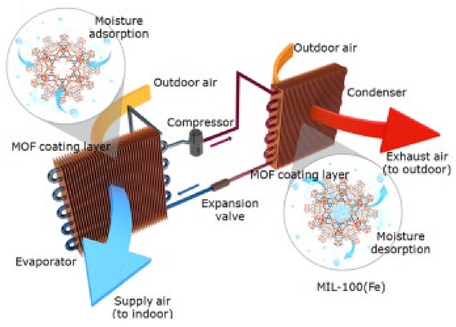
Passive cooling



Wang *et al*. *Joule,* 2020

Efficient electronics cooling

Space conditioning

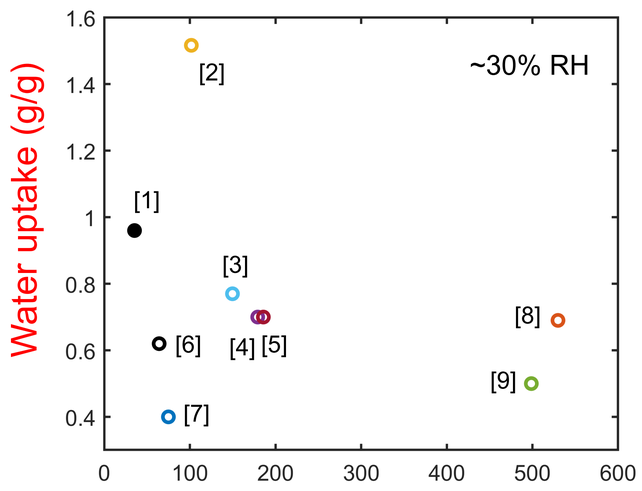


Cui *et al*, *Sci. Rep.*, 2018

Higher efficiency AC

Applications rely on hygroscopic materials

State of the art of sorbent materials



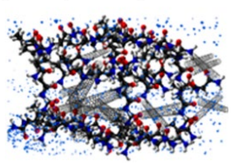
[1] Guo, Y., 2022
[2] Xu, J., 2021
[3] Xu, J., 2020
[4] Zhao, F., 2019
[5] Li, R., 2019
[6] Lei, C., 2022
[7] Hanikel, N., 2019
[8] Li, R., 2018
[9] Li, R., 2020

Adapted from Guo, Y. *et al, Nature Comms,* 2022

Hygroscopic hydrogels have best performance

- Large flexibility: combination of hydrogel + hygroscopic component
- Still insufficient performance: Low water production, low energy density

E.g. Hydrogel + Salt



Li *et al*, *Environ. Sci. Technol.*, 2018

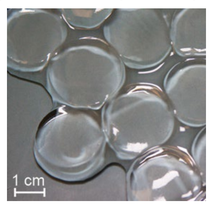
Performance improvements demand:
1) Higher water uptake
2) Shorter sorption times

Our goal: Achieve **record-high** water uptake

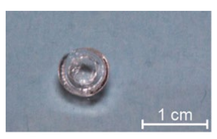
Combining ultra-hygroscopic salt (LiCl) and extreme salt loading

Step 1: Prolonged swelling of hydrogel in salt solution (LiCl)

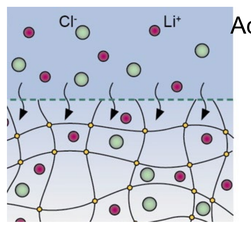
a) As-prepared poly-acrylamide (PAM) gels



b) Dried gels



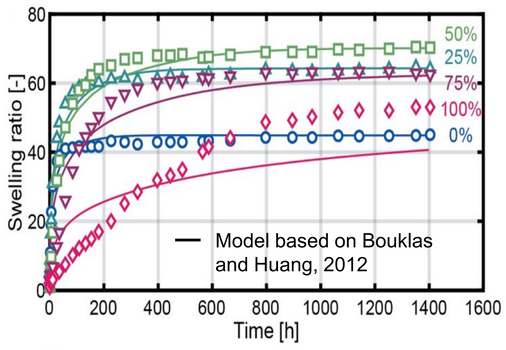
c) Swelling in aqueous LiCl for salt loading

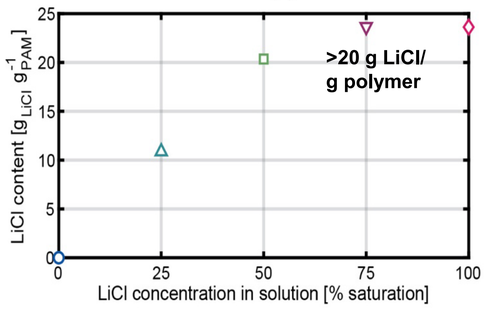


Aqueous LiCl solution (concentration = % saturation)

PAM hydrogel

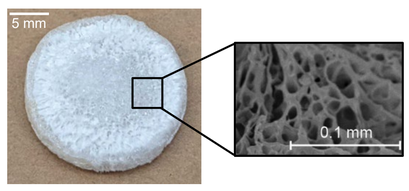
Study of PAM swelling in LiCl solutions





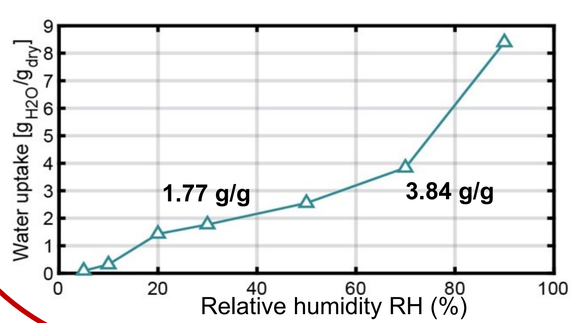
Key insights:
- Equilibrium swelling ratio (SR) and kinetics are % dependent
- Large SRs possible for high %

-Large SRs enable extreme salt loading
- Freeze-drying enhances further salt loading by ~10%

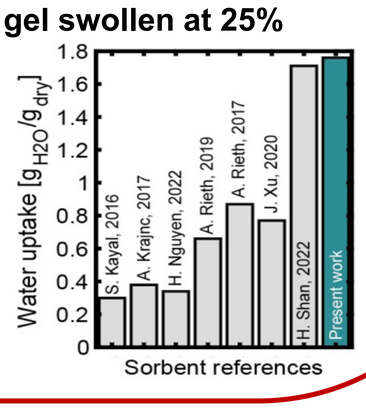


Step 2: Vapor sorption of hydrogel + LiCl composite

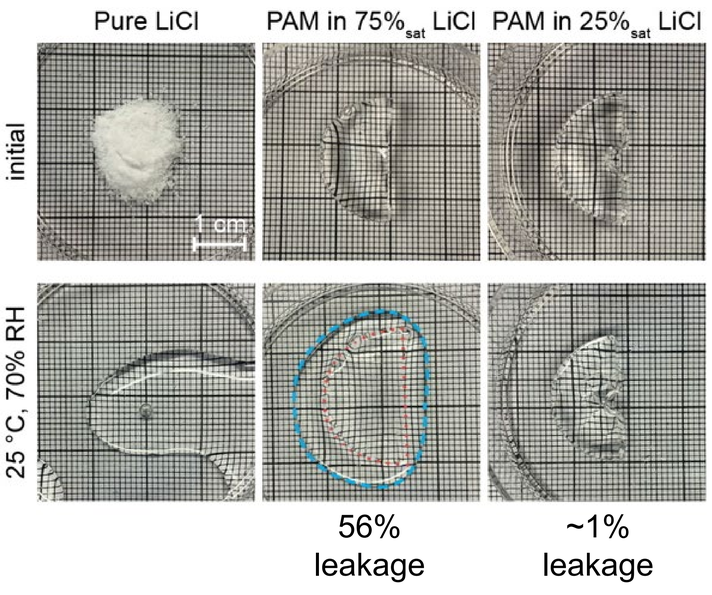
Dynamic sorption system characterization of **freeze-dried gel swollen at 25%**



Record high uptake
- 1.77 g/g, 2.55 g/g, 3.84 g/g at RH of 30%, 50%, 70%
- 4x uptake of zeolites
- 2x uptake of MOFs
- 13% higher than previous hydrogels



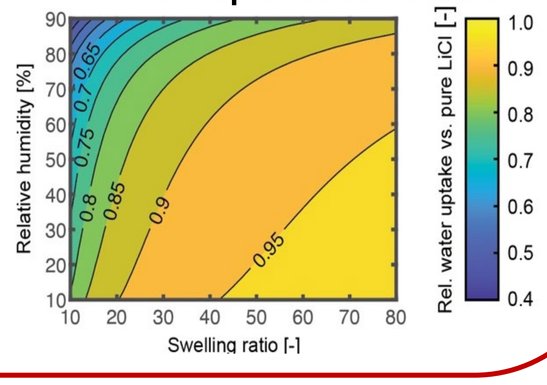
Choosing salt concentration is critical to ensure no water leakage



No leakage + maximum uptake

1) Calculate salt % in equilibrium with highest RH
2) Swell dried hydrogels in solution with calculated %
3) Let hydrogels reach equilibrium

Maximum uptakes achievable



Conclusions

- Record high water vapor uptakes of 1.77, 2.55, and 3.84 $g_{water}/g_{material}$ at RH of 30%, 50%, 70%
- 4x uptake of zeolites, 2x uptake of MOFs, 13% higher than previous hydrogels
- Achieved through study of hydrogel swelling in LiCl solutions: equilibrium, kinetics depend on concentration
- Developed guidelines for maximized water uptake with no leakage

Acknowledgements

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