New age adsorption cooling & recuperative power

Enwave District Energy – Pacific Northwest National Laboratory

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Objectives

- Basic adsorption chilling process overview
- Discuss the materials science advances that have lead to this *change* in this technology
- Describe metal organic framework (MOF)
- Identify the differences in MOF and silica
- Describe the benefits of MOF
- Show the effect of technology change on a district energy system
- Calculate the potential $CO2_e$ reductions from electric chillers
- Next steps

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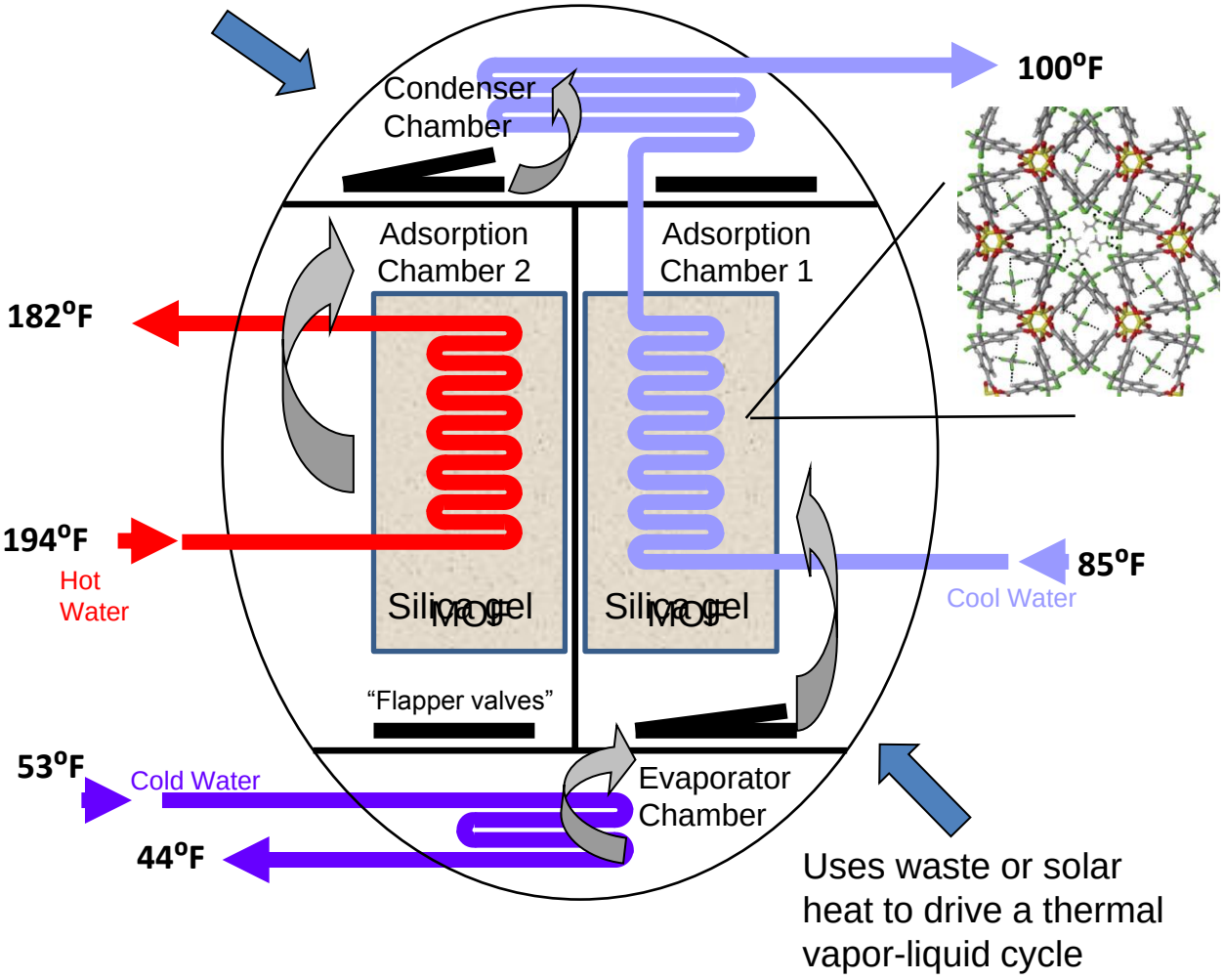
Adsorption Chiller Technology: The Basics

Few moving parts



Uses waste or solar heat to drive a thermal vapor-liquid cycle

Technical Solutions

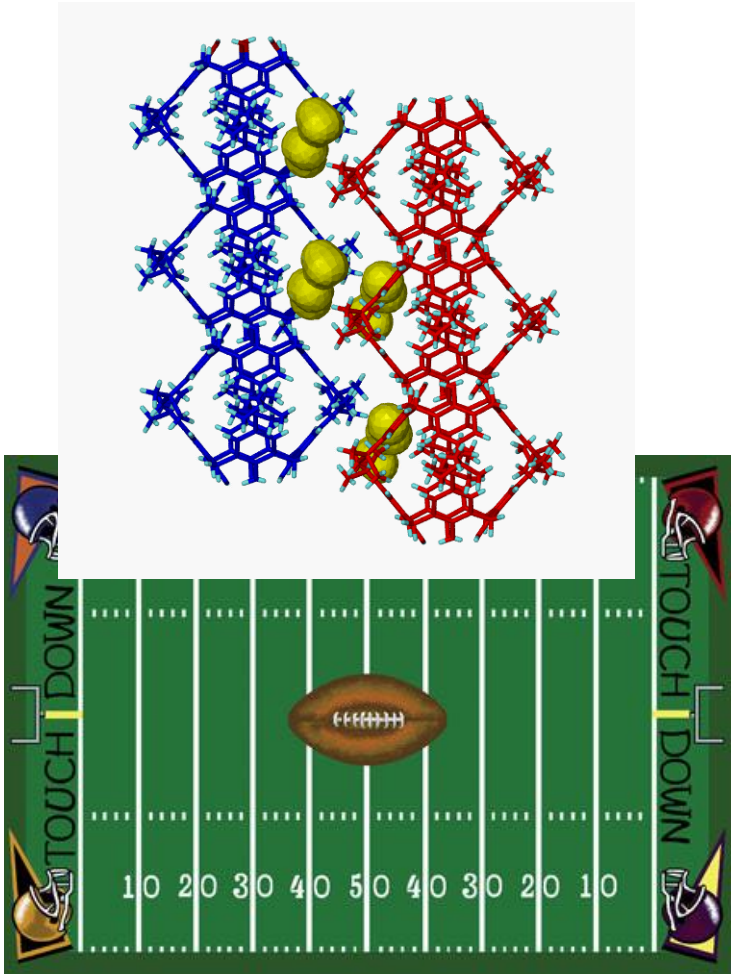
Technical Challenges

- Replace silica gel with high performance MOF sorbents
- Enable operation with more refrigerants
- But - new architecture for adsorption modules required

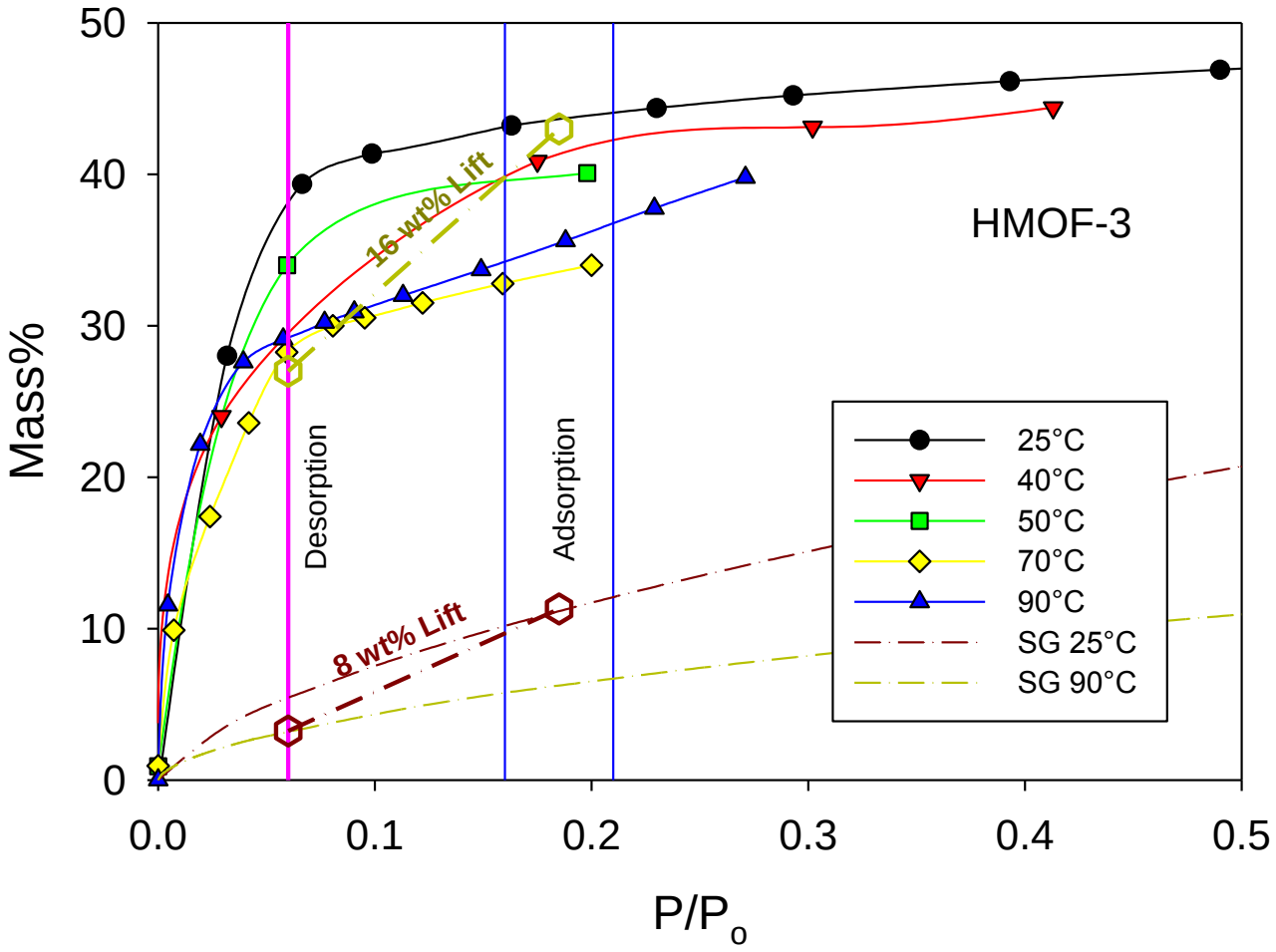
- Machines are big and heavy
  - 5000 lbs silica gel
  - 300,000 fins
  - 33,000 lbs total weight
  - ~4.5 miles of copper tubing
- Low COP ≈0.5

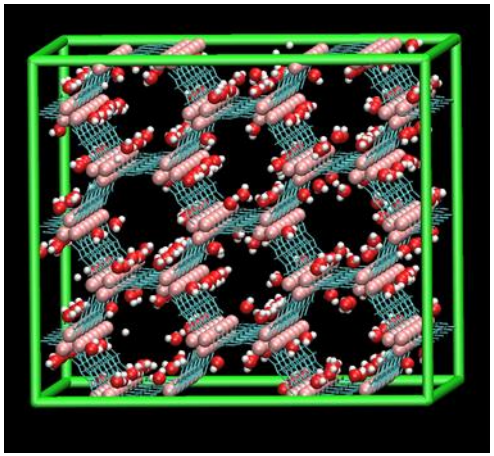
New Materials Offer New Opportunities

- Metal Organic Framework (MOF) materials are a new type of hybrid organic-inorganic porous crystalline solid
- The properties of MOFs are easier to tune synthetically than those of analogous materials (zeolites)
- MOF structures are controllable by the choice of molecular building blocks
- Thermally stable up to 300°C and sometimes higher
- **Highest surface area material known to date (>8,000 m^2/g)**
- Can we exploit these properties for heat transfer applications? Yes!



Superhydrophilic MOF for Water Refrigerant Chiller





Outperforms silica gel by 2 to 3X depending upon deployment environment. Enables air-cooled chiller operation under high ambient temperatures where silica gel chiller output goes to zero.

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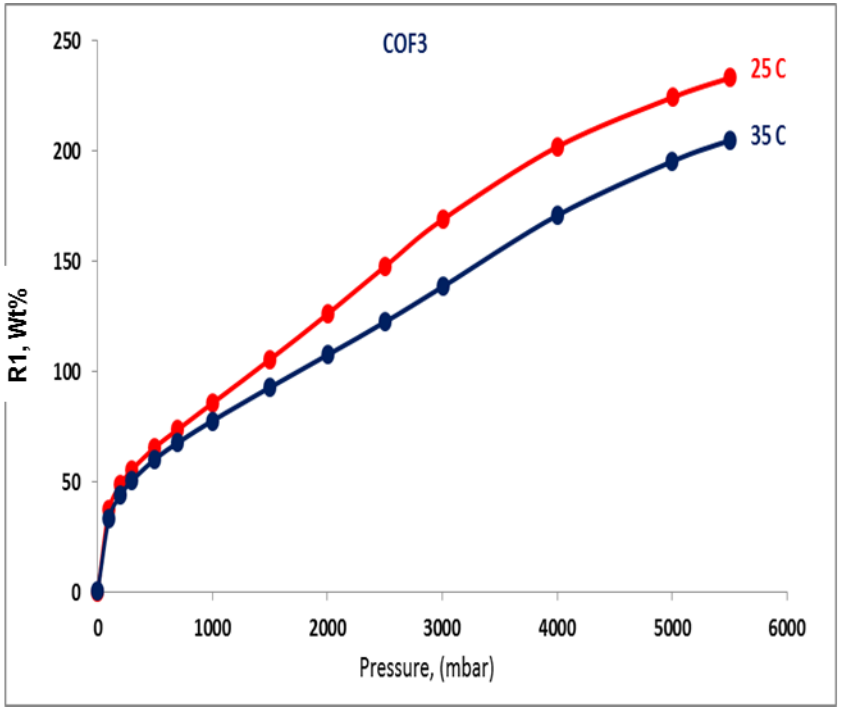
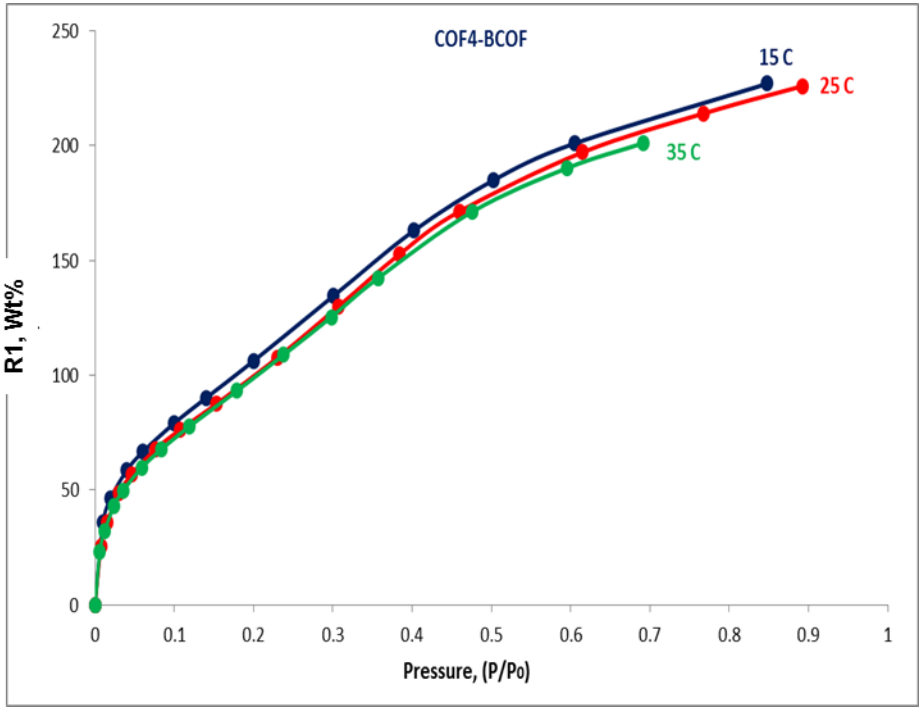
Superfluorophilic Sorbents



Crystal density = 0.84 g/cm3

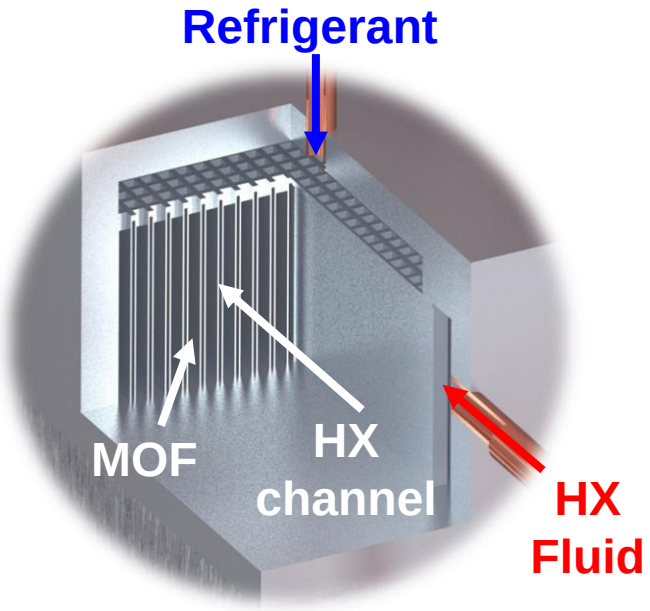


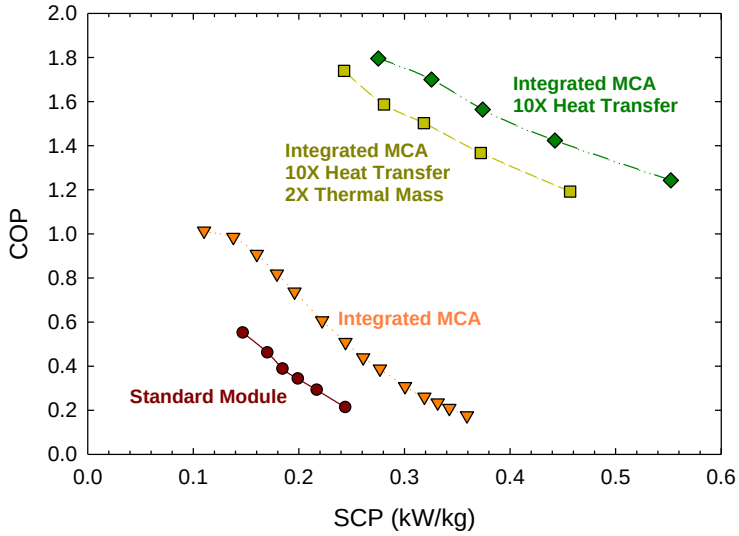
Crystal density = 0.77 g/cm3

- Ultra-high sorption capacities enable brand new chiller design running with standard refrigerants (i.e. R134a)
- Sraightforward extension to refrigeration and freezing applications difficult or impossible to do with water-based systems

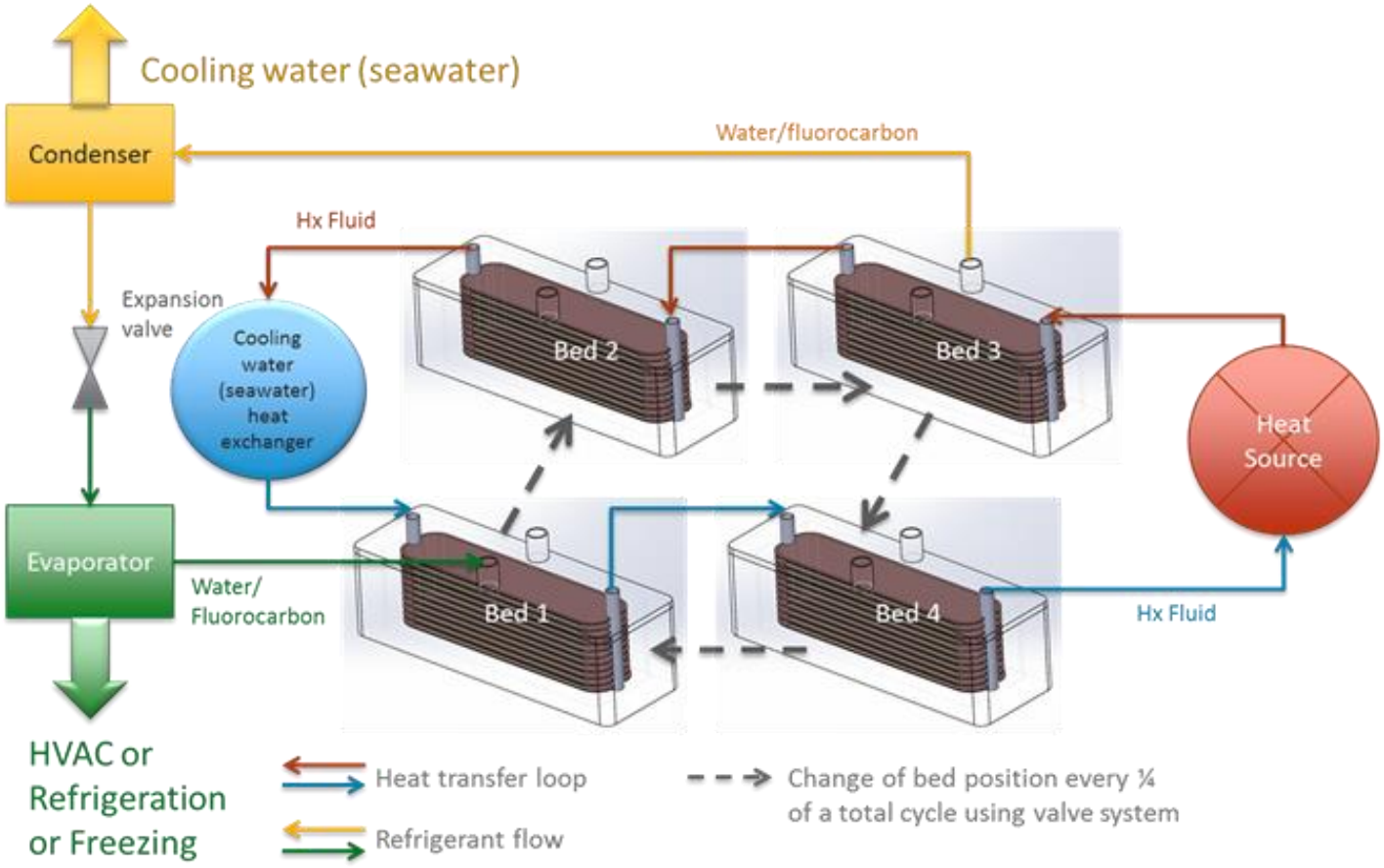
Re-inventing the Adsorption Chiller

- Using these new materials gives dramatic bed size reductions that result in heat transfer limitations with standard tube-fin heat exchanger designs
- New HX architectures are also needed to take maximum advantage of MOF sorbent properties
  - Maximize heat exchange area per unit volume of sorbent
  - Enable operation at higher regeneration temperature
  - More efficient heat recuperation between adsorption beds
  - Obtain COP>1 for first time in solid state cooling device
- Unified design for both water and fluorocarbon chillers





Re-Inventing the Adsorption Chiller



- *No rotating parts – valve actuators do the bed switching*
- *Integral heat recuperation coupled with microchannel architecture boosts COP*

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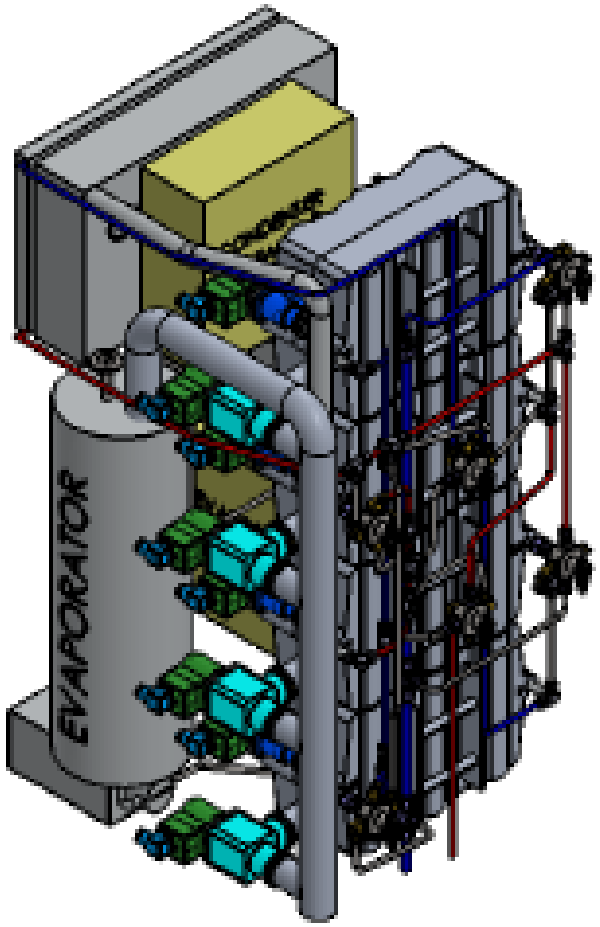
Demonstration Systems

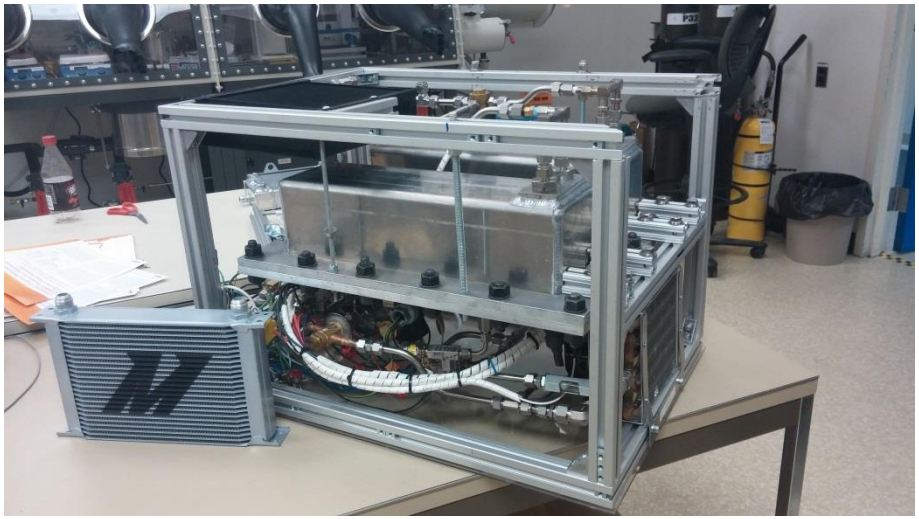


¾ RT Capacity Unit for U.S. Navy

Water refrigerant system provides opportunity to cut fuel use at forward operations bases by 30 to 40%

PNNL 2 kW Demonstration System

Runs on R134a and designed for transport to conferences, trade shows, etc.



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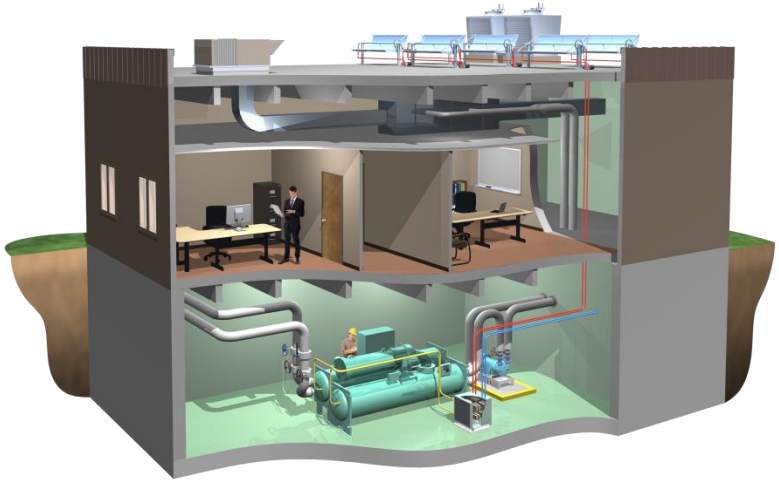
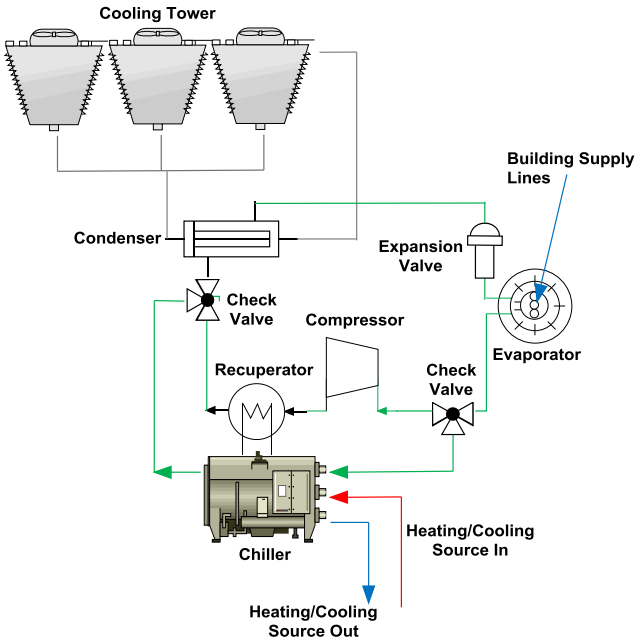
Hybrid Adsorption Vapor Compression (HAVAC) System for Buildings





- Drop-in retrofit for mechanical vapor compression system used today
- Adaptable to heat source characteristics including natural gas, low-cost solar, and low grade steam
- Reduces peak electrical demand
- Compatible with future low GWP refrigerant replacements

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Integration into district energy

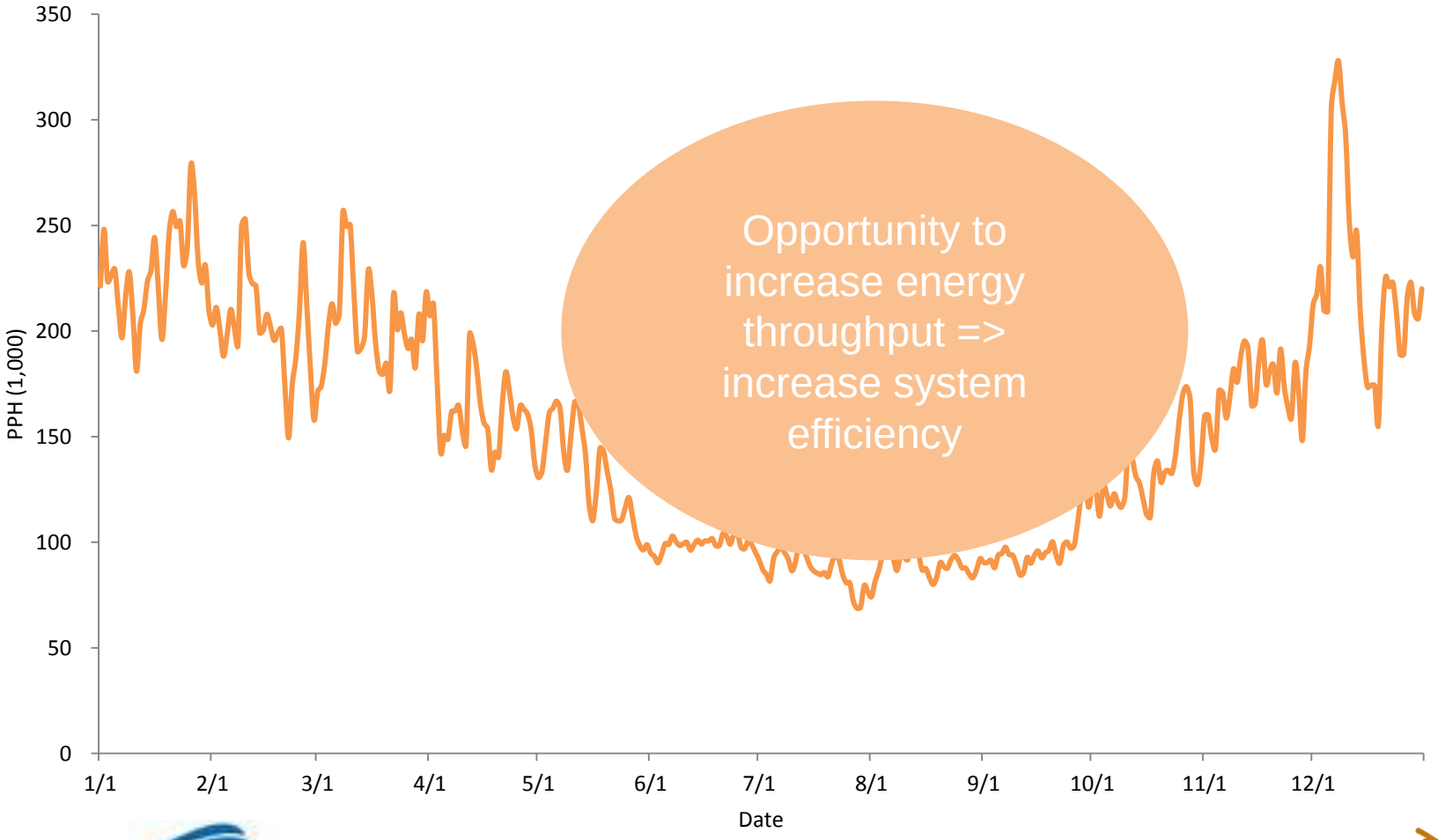
- Allows the opportunity to *more efficiently* leverage waste heat for cooling
- Due to the immense surface area of the sorbent, combined with the advanced heat exchange technology, the size and weight of these machines will be closer to that of electric driven chillers
- Can leverage existing steam and hot water systems, to turn district heating systems into district cooling. Avoiding redundant distribution piping systems.
  - Increasing the energy throughput of an existing system, without adding distribution piping will increase the overall efficiency and lower is carbon intensity
- Reduces peak electrical demand and diversifies the fuel portfolio of an existing system

Energy cost and carbon???

- Assumptions:
  - Base case electric chiller plant operating at .6kW/ton
  - Cost of electricity $.08/kWh, eGrid $CO2_e$ intensity (national average) 1,238 lbm/MWh
  - Unitized cost of energy $5.50/MMBTU and 117 lbm $CO2_e$ /MMBTU
  - Dual acting system COP 2

- Results in a:
  - 64% reduction in cooling energy costs
  - Most conservative approach would be 6% reduction in CO2 if fired from natural gas, but the ability to utilize into existing district systems with renewable components will dive this number down.

Integration into existing system



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Next Steps

- Enwave Seattle has applied for a research and development grant, through the Washington State Department of commerce.
  - Grant is intended to bridge the initial capital gap for scaling up unit
- Determine commercial market and capital costs to implement

Conclusion

- Materials science has advanced, resulting in an efficient adsorption chiller that has historically been inefficient (both in space and energy usage)
- Even with fossil fuel carbon intensity, there is a reduction in $CO2_e$ emissions
- Utilizing renewable thermal energy or waste heat recovery will drive $CO2_e$ emissions lower than possible with electric chiller
- Cooling energy costs should easily be reduced
- More work left to determine the scalability and capital cost

Thank you!

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