Utilizing Data Center Waste Heat to Generate High-Temperature Steam via an Adsorption Heat Pump

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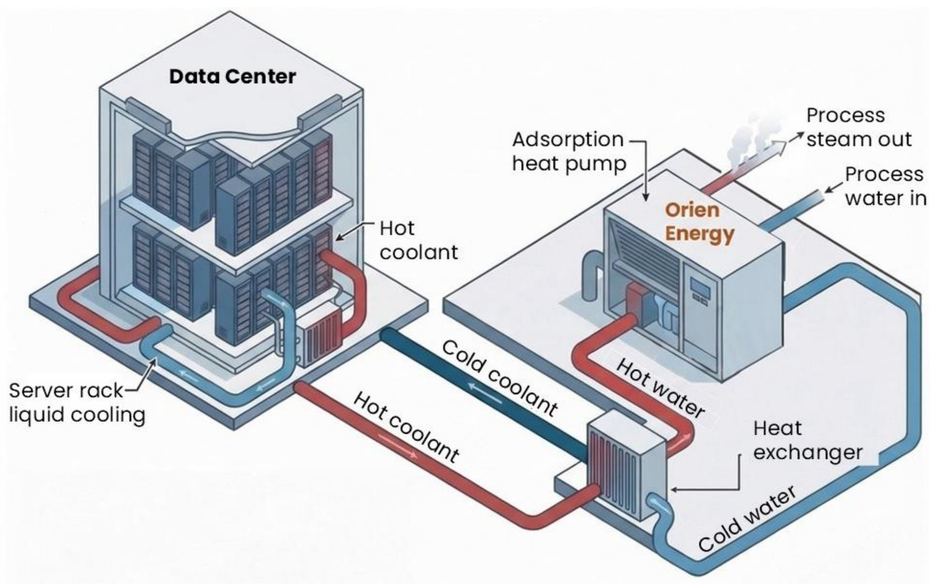
1. INTRODUCTION

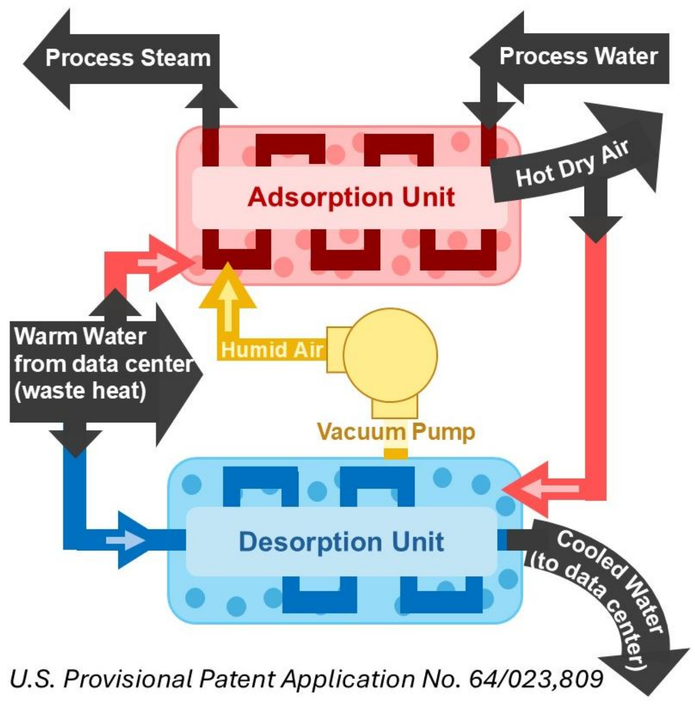
- Data center electricity usage 415TWh in 2024, expected to double by 2030
- Nearly 100% of this electricity turns into low-grade waste heat
- Existing waste heat recovery solutions (e.g., district heating, greenhouses, swimming pools) remain limited
- Challenges: large magnitude of heat dissipation, low-grade heat constrained by chip thermal limits
- Thermally-driven adsorption heat pump enables large-scale reuse of data center waste heat while also providing cooling



2. CONCEPT

Thermally-driven adsorption heat pump with water as adsorbate

- Adsorption (exothermic): warm water carrying waste heat from the data center flows through the adsorbent bed, releasing adsorption heat that is transferred to a closed water–steam loop for steam generation



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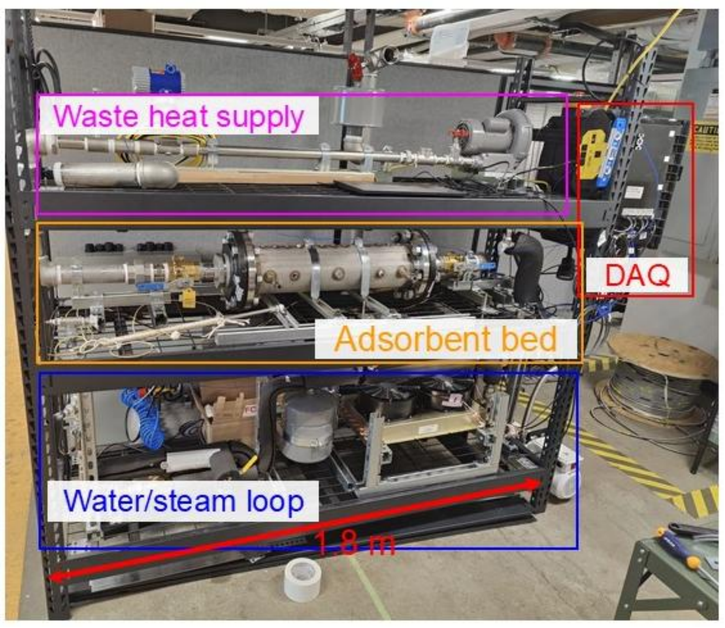
Once system is saturated:

- Desorption (endothermic): combined temperature and pressure swings regenerate the adsorbents using the same low-grade waste heat from the data center, with no additional heat input; simultaneously provide cooling for the data center

3. EXPERIMENTAL SETUP

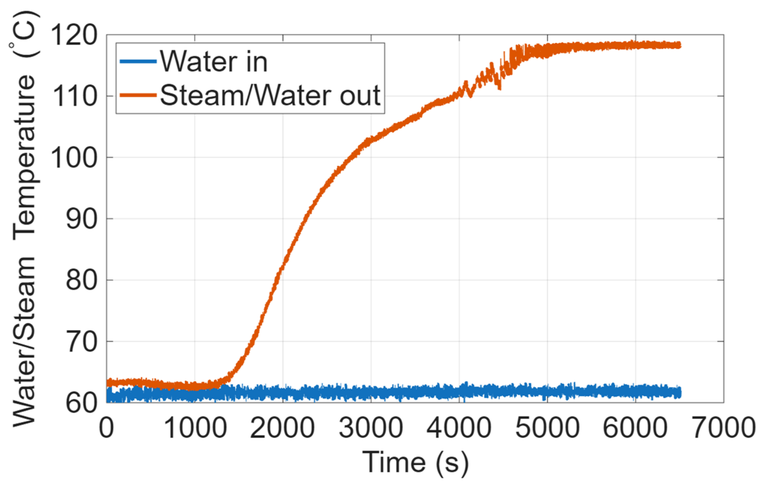
1 kW adsorption heat pump prototype designed to utilize warm water in the temperature range of 60–80°C, representative of waste heat from next-generation liquid-cooled data centers, to generate high-temperature steam (120°C and above)



- Waste-heat supply delivers 100% relative humidity (RH) air to adsorbent bed
  - Humidified air utilized instead of warm water for simplicity
- Adsorbent bed functions alternately as adsorption and desorption unit
- Closed-loop water circuit to extract heat from the adsorbent bed for steam generation

4. RESULTS

Adsorption: 2-bar (120°C) steam generated from 60°C, 90% RH humid air, representative of waste heat from next-generation liquid-cooled data centers



Suitable temperature and pressure level of steam for several MW-scale industrial applications:

- Paper manufacturing
- Food processing
- Chemical production
- Integration in existing thermal networks for district heating

Desorption: Preliminary results show temperature reductions exceeding 40°C within the adsorbent, with an average coefficient of performance (COP) > 6, demonstrating a strong cooling effect and highlighting significant potential for data center cooling

5. CONCLUSION

1. Conceptualized an adsorption heat pump to upgrade low-grade data center waste heat into high-temperature steam while providing “free” cooling
2. Demonstrated 120 °C steam generation from a 60 °C heat source, validating technical feasibility for next-gen liquid cooled data center heat reuse
3. Ongoing work to demonstrate desorption process driven by low-temperature waste heat and to achieve a system-level COP > 8

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