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LOW EXERGY DATA CENTER HEAT STORAGE AND REUSE APPLICATIONS

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U.S. DEPARTMENT of ENERGY | NNSA National Nuclear Security Administration

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DEFINING EXERGY FROM A THERMAL STANDPOINT; QUANTITY OF USEFUL WORK POTENTIAL

$$e = (u - u_0) + p_0(v - v_0) - T_0(s - s_0) + KE + PE$$

Where:
$e = specific\ Exergy\ as\ Exergy\ per\ unit\ of\ mass$
$u = internal\ energy\ at\ T\ @\ operational\ temperatures$
$u_0 = internal\ energy\ at\ T\ @\ OSA\ temperatures$
$p_0 = final\ Pressures$
$v = initial\ mass\ velocity$
$v_0 = final\ mass\ velocity$
$T = T\ @\ operational\ temperatures$
$T_0 = T\ @\ OSA\ temperatures$
$s = initial\ entropy\ @\ operational\ temperature$
$s_0 = final\ entropy\ @\ OSA\ temperatures$
$KE = Kinetic\ Energy$
$PE = Potential\ Energy$

Where:
$(u - u_0) \propto (T - T_0)$
$p_0(v - v_0) \to 0$
$$-T_0(s - s_0) = -T(-Q)\left(\frac{1}{T_0} - \frac{1}{T}\right) = TQ\left(\frac{T - T_0}{TT_0}\right) \propto (T - T_0)$$
$KE \to 0$
$PE \to 0$
$T > T_0$

$\therefore$

$$e \propto (T - T_0)$$

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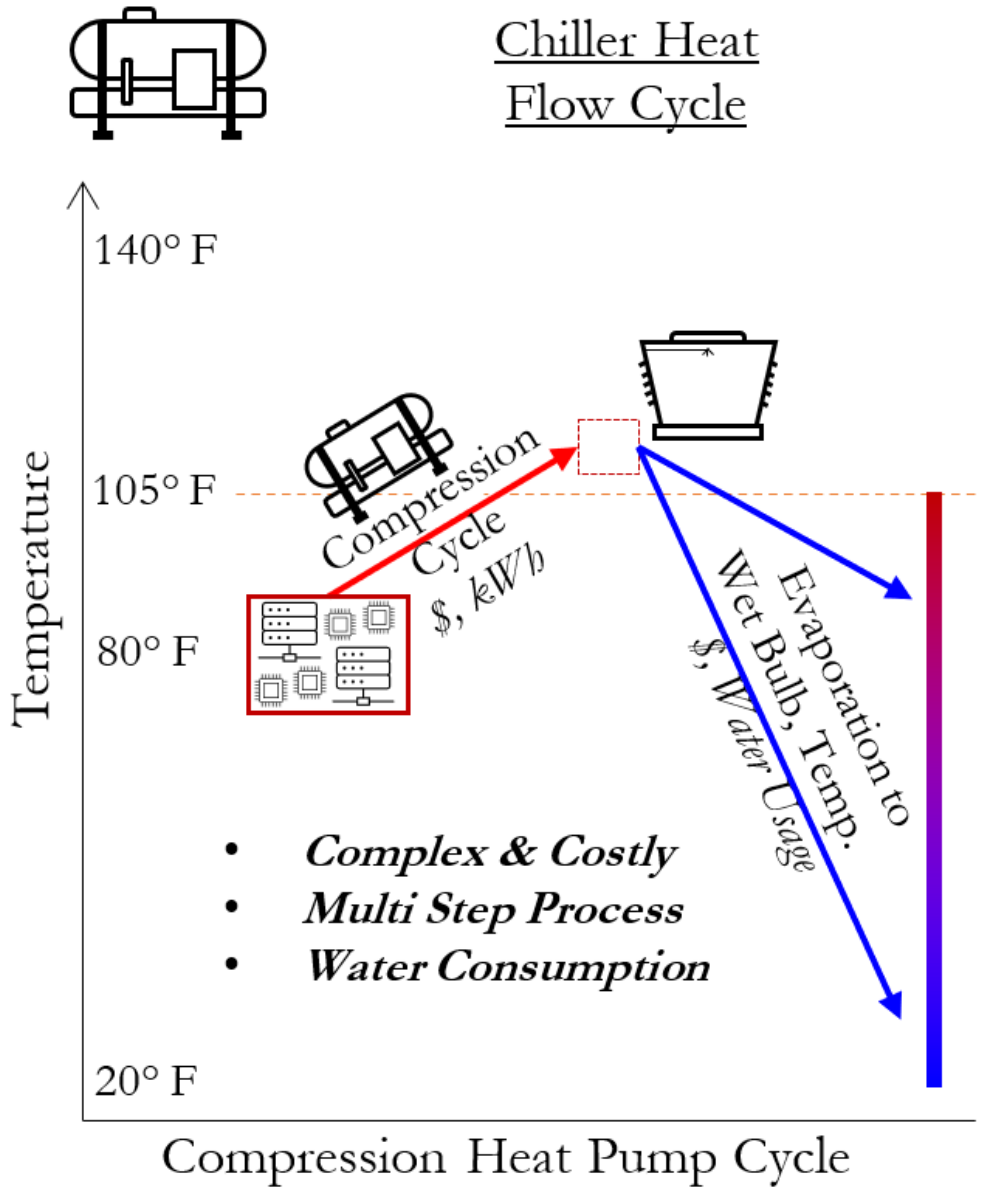
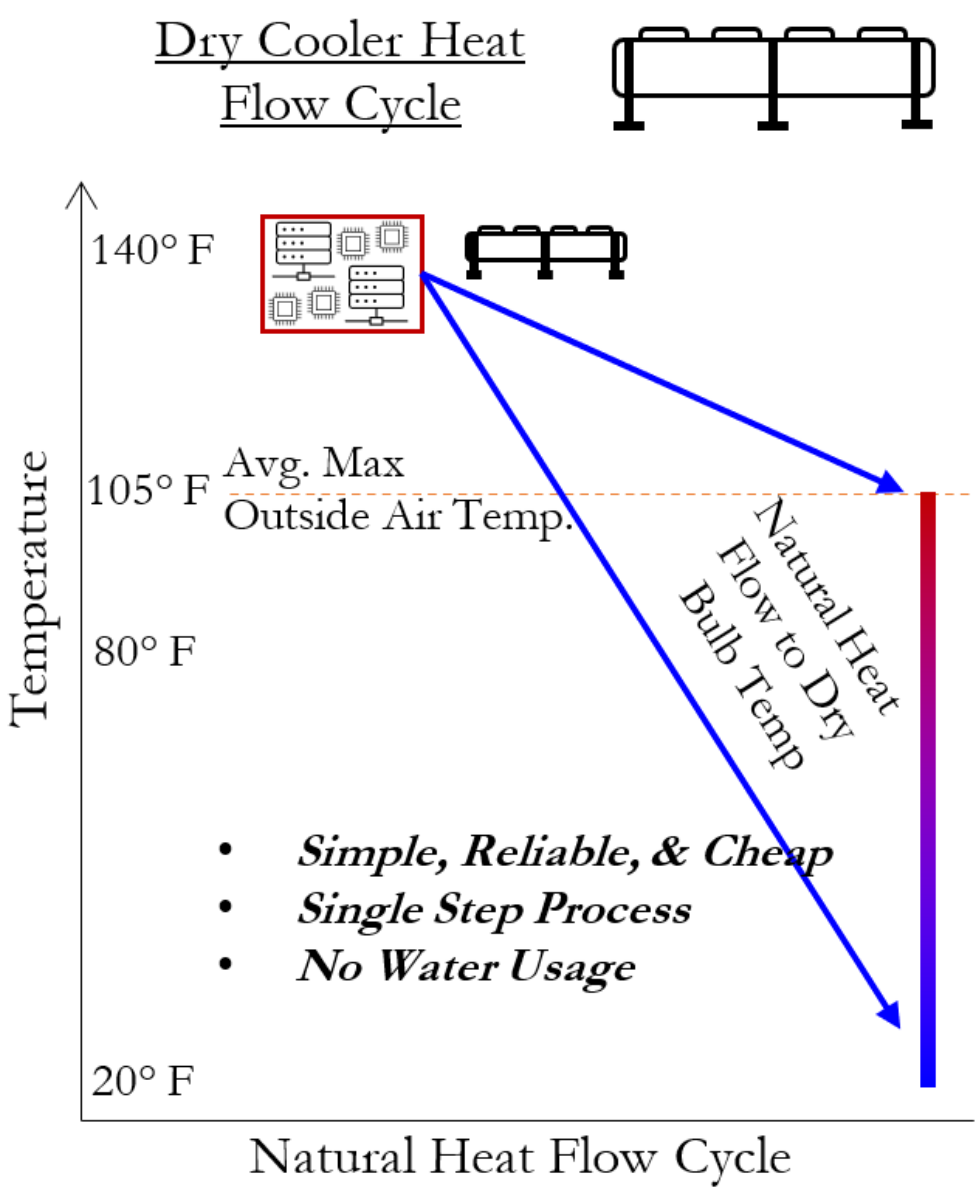
WHY MAXIMIZE EXERGY IN DATA CENTERS?





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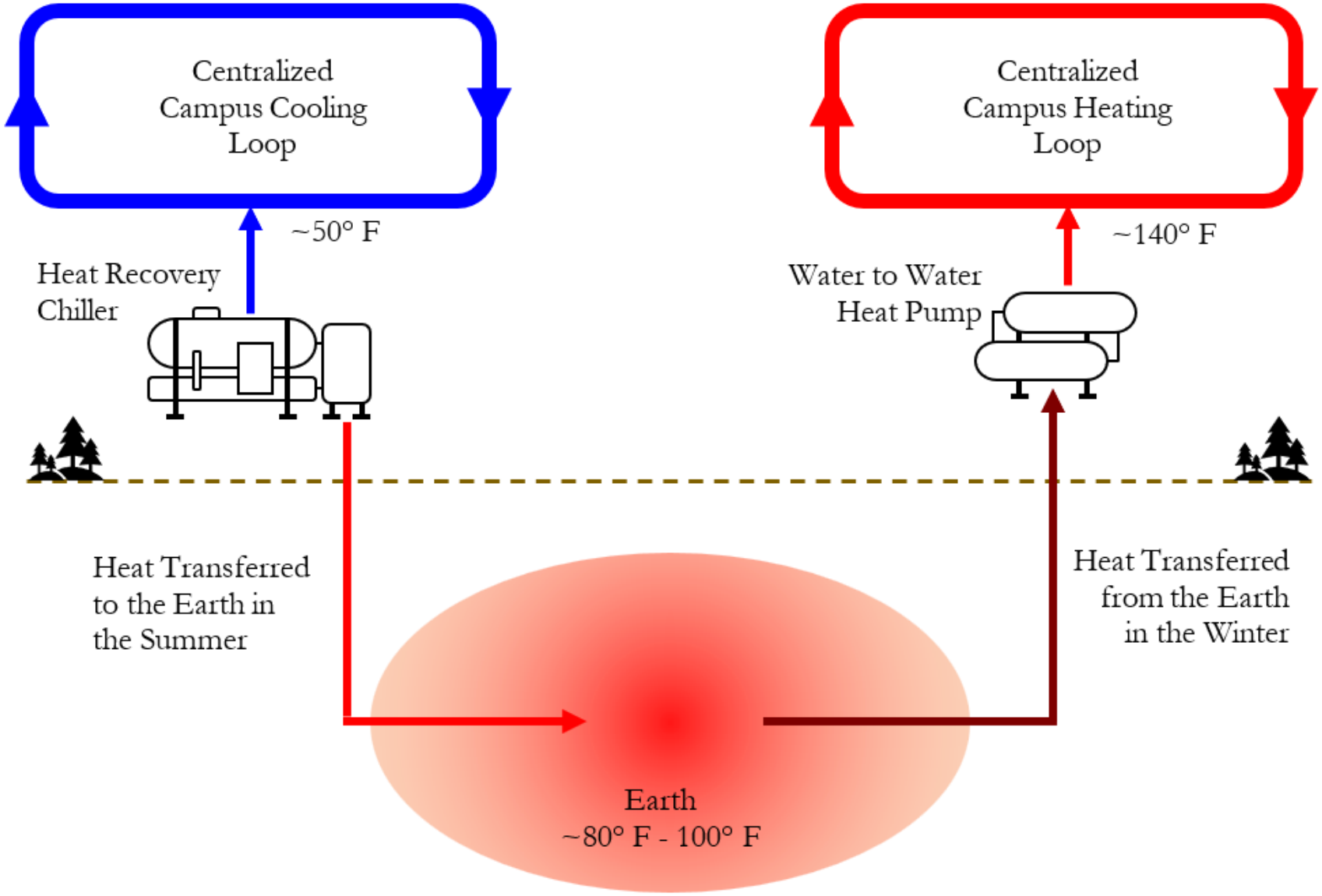
HEATING AND COOLING WITH A GEO-EXCHANGE STORAGE PROCESS

- Sandia Had a steam loop with Absorption Chillers in the ~1950 to 1990; ~350° F



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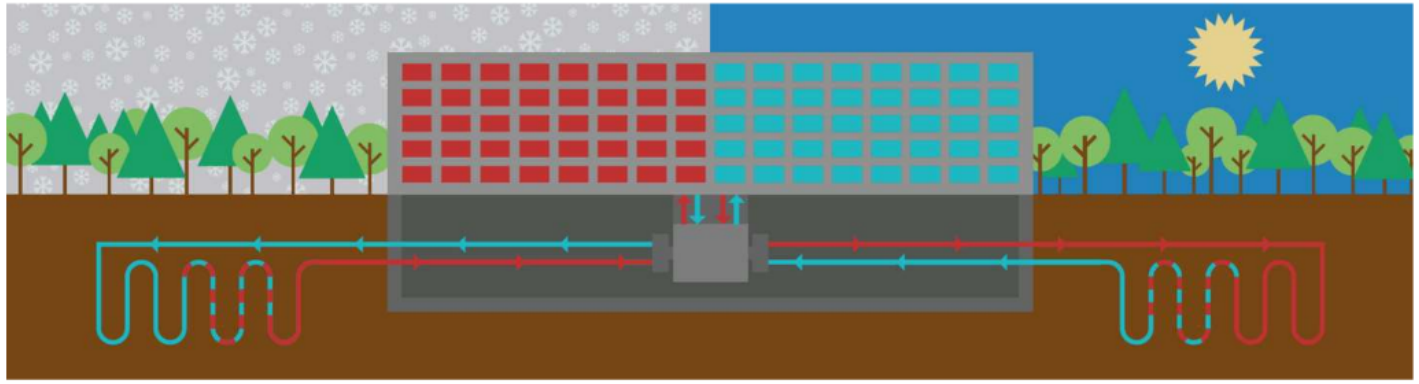
PRINCETON GEO-EXCHANGE STORAGE PROCESS

- Central heating steam pipes, operating at **~450° F**, were replaced with a water exchange central heating loop operating at **~140° F**.
- Hundreds of heat pipes were drilled to depths of 650 ft – 800 ft which was then repurposed as a parking lot. Plans to test depths of up to 3,000 ft are also being evaluated relative to **CAPEX/OPEX viability**.
- **Heat pumps** replaced gas fired steam generators. Heat recovery cooling equipment had to be utilized to recover waste heat from chillers.
- Their delivered heating COP went from **~0.75 to 4**.

Princeton University, "Geo-Exchange," Princeton University, 2026. [Online]. Available: https://sustain.princeton.edu/posts/2024/geo-exchange. [Accessed 25 7 2026].

SUSTAINABILITY at Princeton

Geo-Exchange



March 1, 2024

As part of Princeton University's goal to achieve climate neutrality by 2046, we are advancing our use of geo-exchange technology. Investing in geo-exchange projects, with enough capacity to serve the entire campus, will enable Princeton to phase out nonrenewable energy sources, including natural gas burned today to produce steam heat. flyer to understand how geo-exchange works and how we are not installing geothermal wells.

Converting the campus to a district-scale hot water system maximizes energy efficiency and supports the University's sustainability action plan. Princeton's campus conversion is achieved by drilling over 2,000 geo-exchange bores, installed 600 – 850 feet below ground, installing over 13 miles of distribution piping and upgrading our central plants and building systems. The geo-exchange bores form a closed-loop system which acts as a thermal "piggybank" below the ground. Heat-pumps are used to retrieve this thermal energy, heat or cool it and pump it out to our campus. Check out our new geo-exchange flyer to better understand how geo-exchange systems work and that we are not installing geothermal wells.

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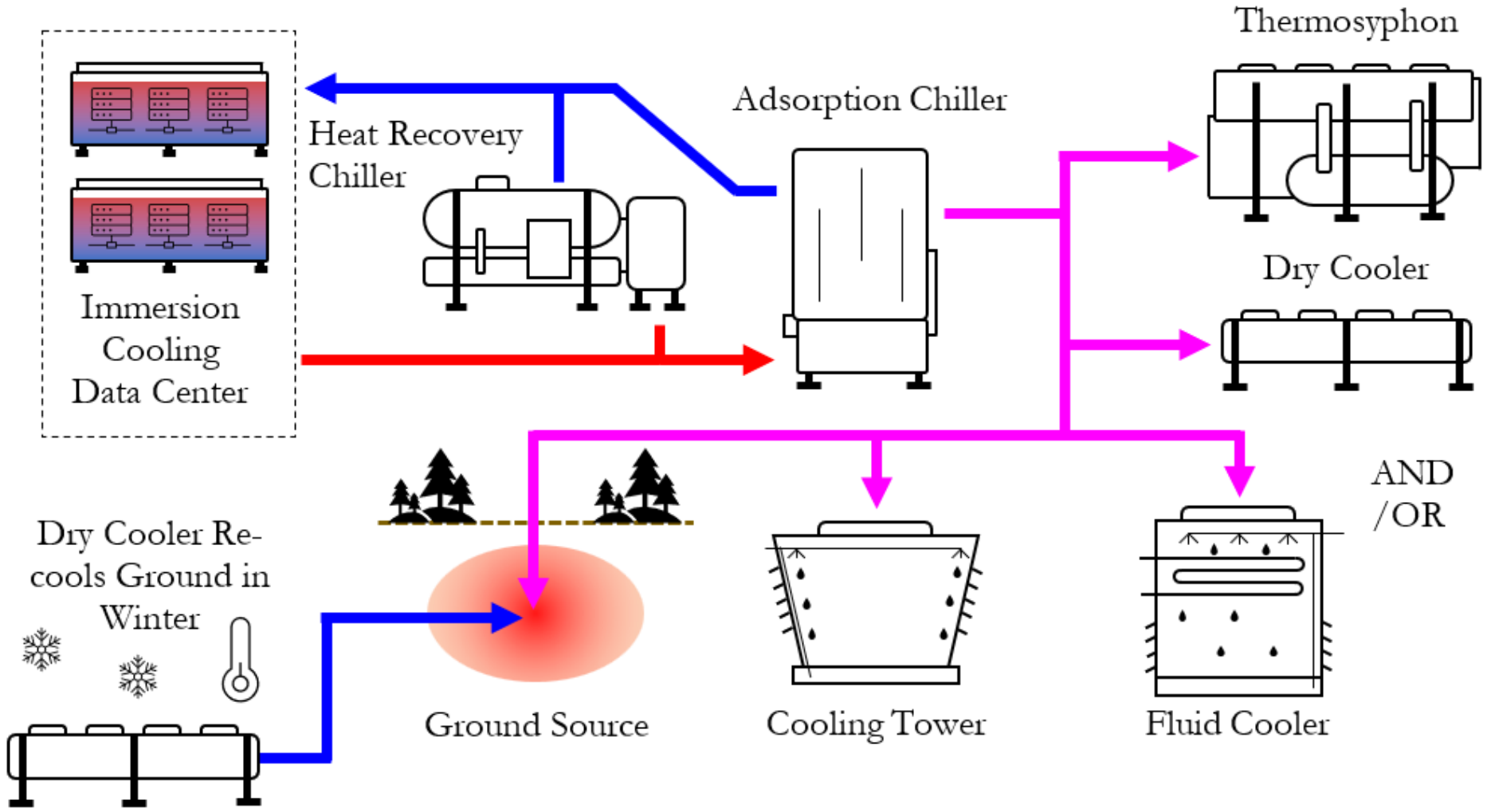
GEO-EXCHANGE WITH DATA CENTERS

- Parts of the London Tube (subway) ~95° F +
- Re-cool the Earth Battery in the Winter.
- Or Utilize the Earth Battery Heat.



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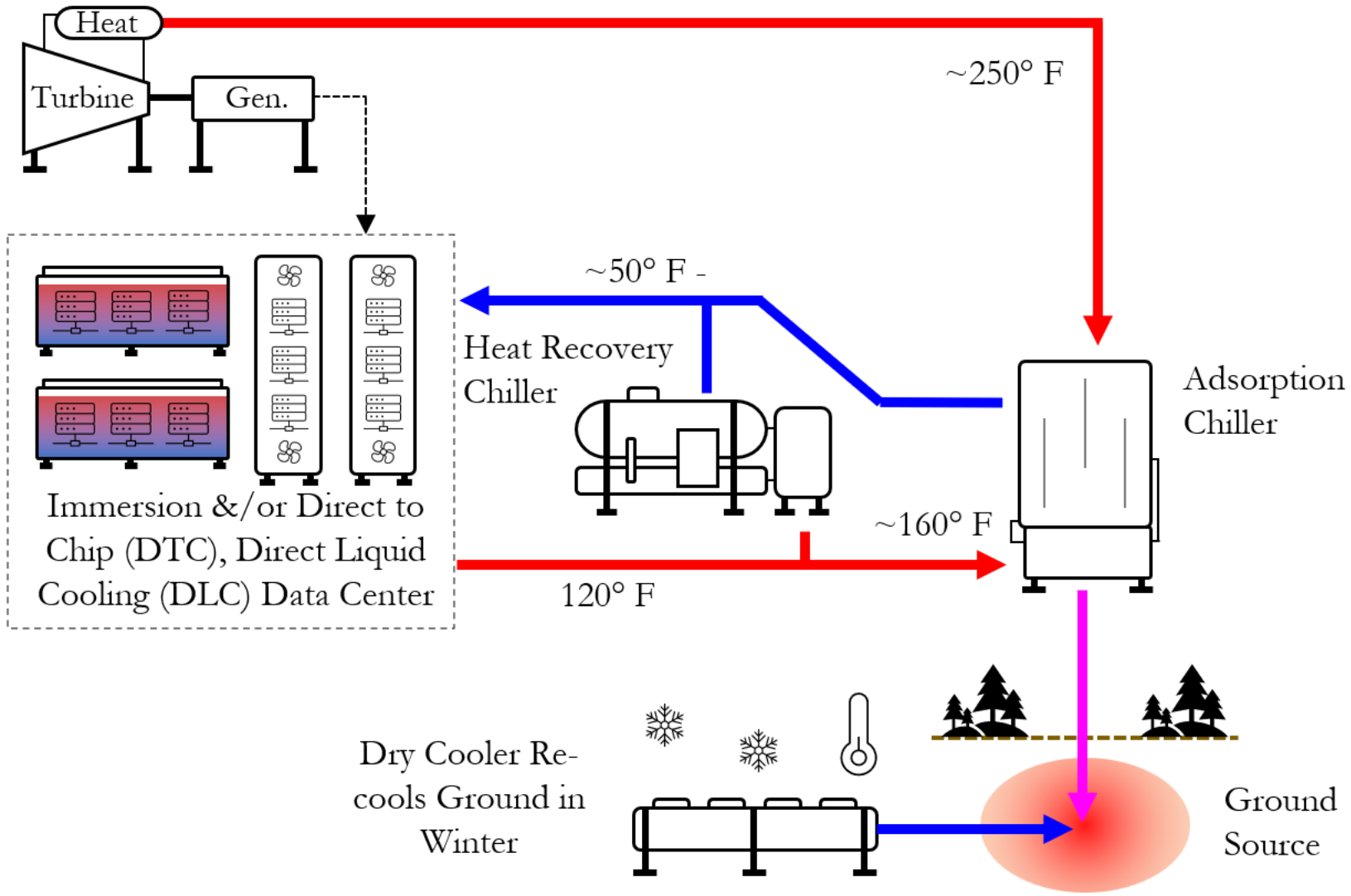
GEO-EXCHANGE WITH DATA CENTERS WATERLESS SOLUTION

- We must use a chiller due to Air to Air loads



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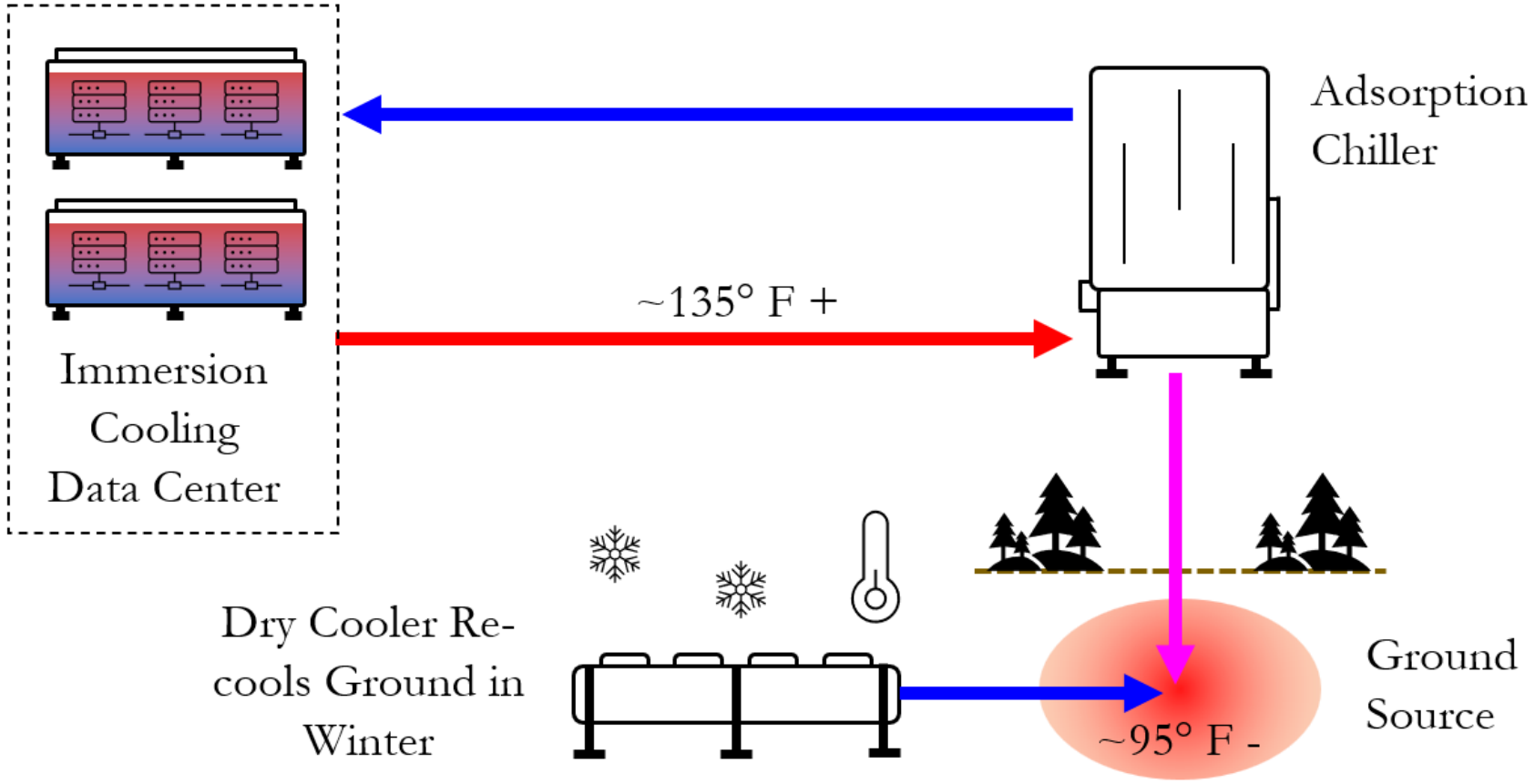
GEO-EXCHANGE WITH DATA CENTERS WATERLESS + MAXIMUM EXERGY



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HOT WATER DRIVEN ABSORPTION CHILLER SPECIFICATIONS

- Driving heat source as low as 131° F (Data Center)
- Cooling Water Temperature as hot as 99° F (Ground)

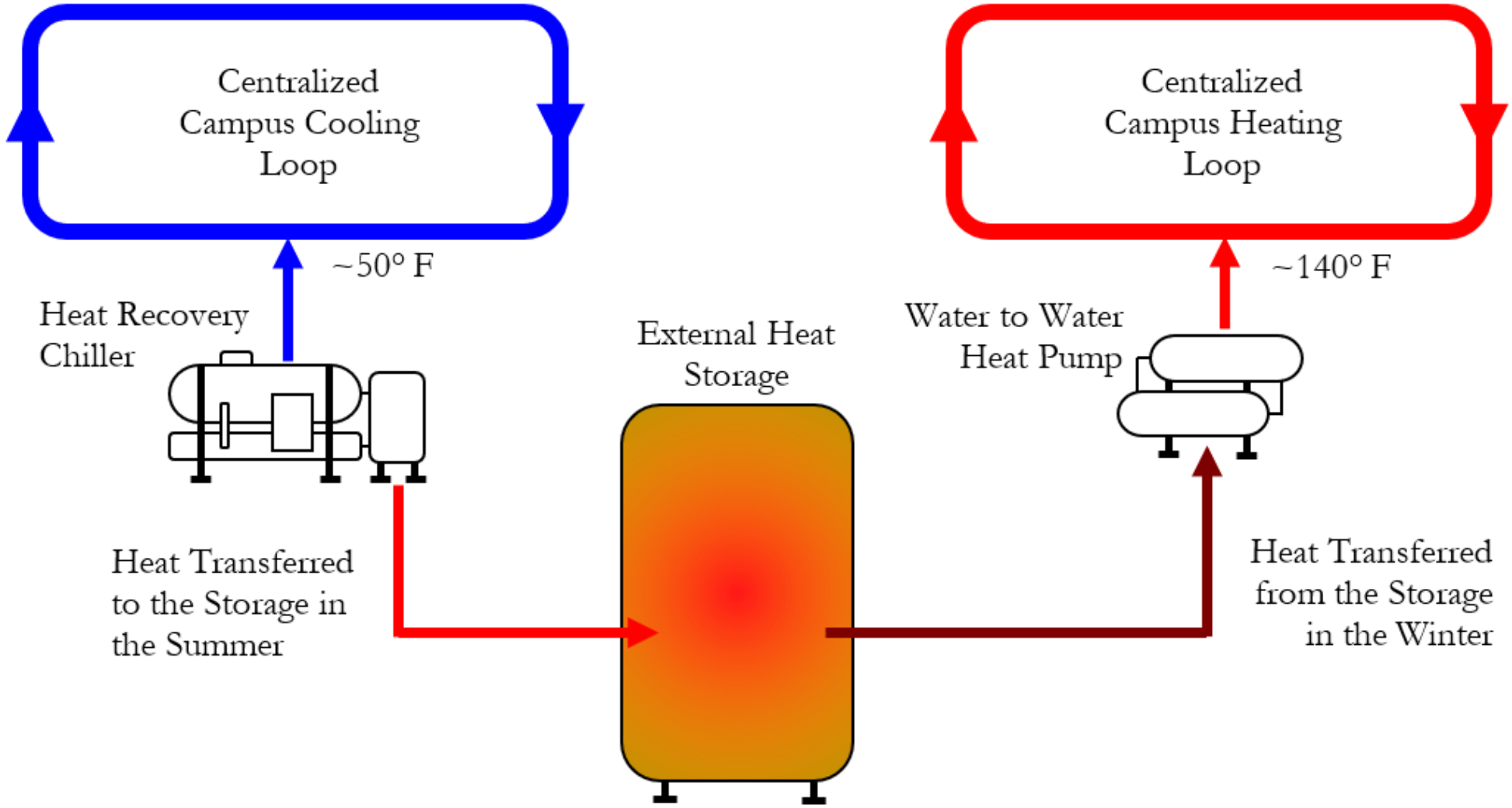
YHAU-CL/CH-DXS
Single Effect Double Lift
Hot Water Driven Absorption Chiller

Cooling capacities from 176 kW to 2813 kW

Johnson Controls International plc, YORK Single Effect Double Lift Hot Water Driven Absorption Chiller.pdf, YORK, 2026.

EXTERNAL THERMAL STORAGE

- Much Shorter Duration Than Earth's Long-term Storage Capacity.



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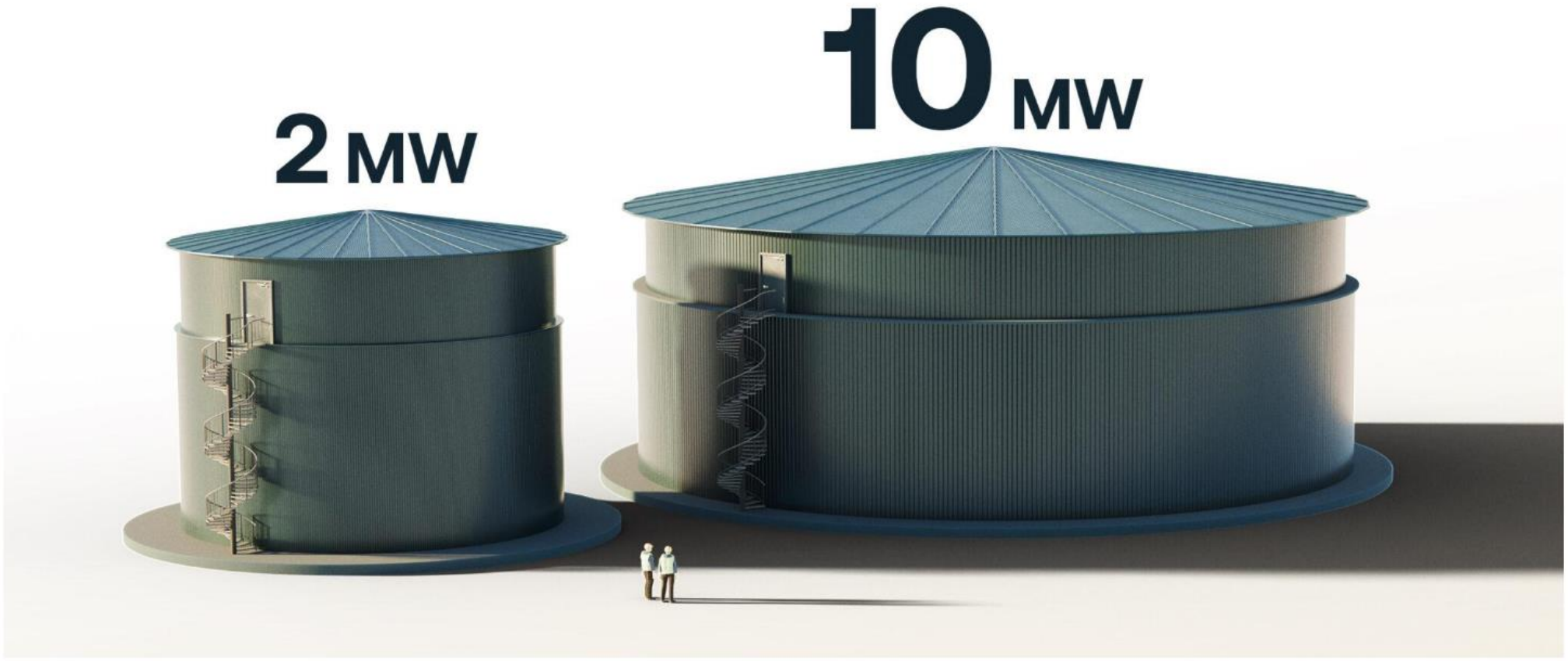
EXTERNAL THERMAL STORAGE, POLAR NIGHT OY

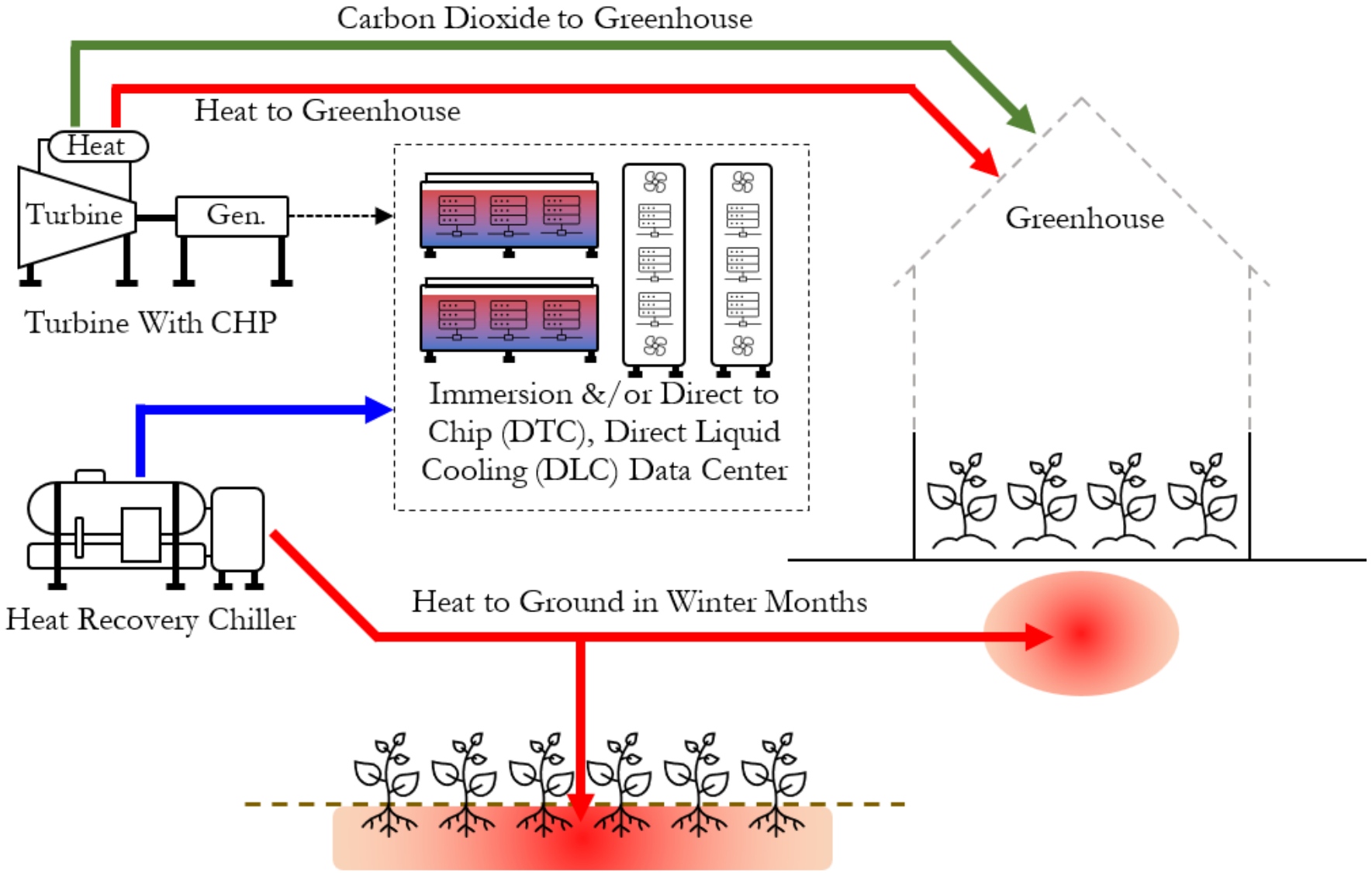
- Temperatures up to **1,100° F**
- **200 & 1,000** MWh
- Lower Exergy Lowers Capacity



Polar Night Energy Oy, "Sand Battery," Polar Night Energy Oy, 2026. [Online]. Available: https://polarnightenergy.com/sand-battery/. [Accessed 16 06 2026].

HEAT REUSE; BLOCK HEATING FOR GROWING APPLICATIONS

- 30% increase in CO_2 Concentration Generally Increases Plant Growth by Approximately 30%.



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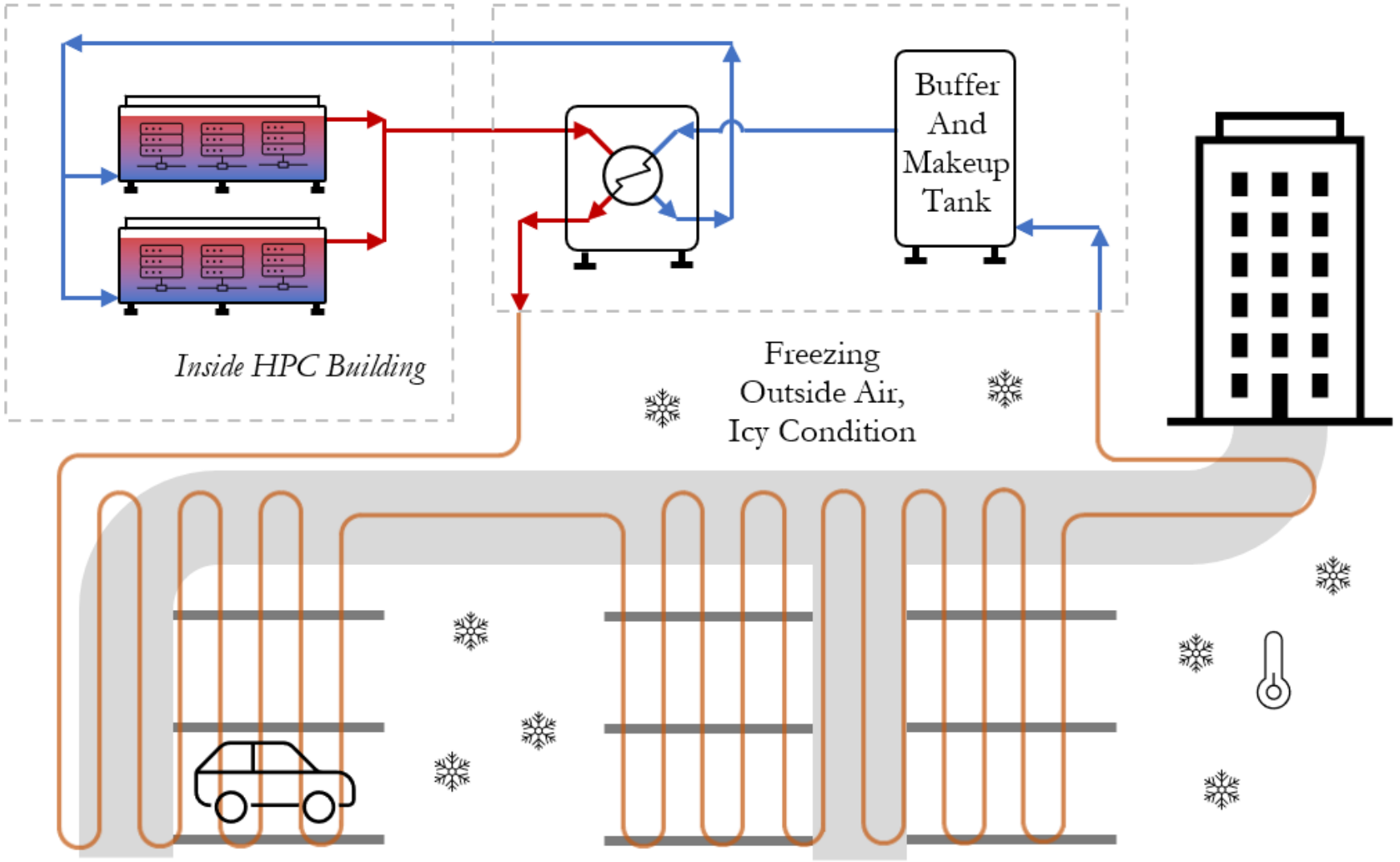
DATA CENTER COOLING HEAT REUSE ICE MELT APPLICATIONS



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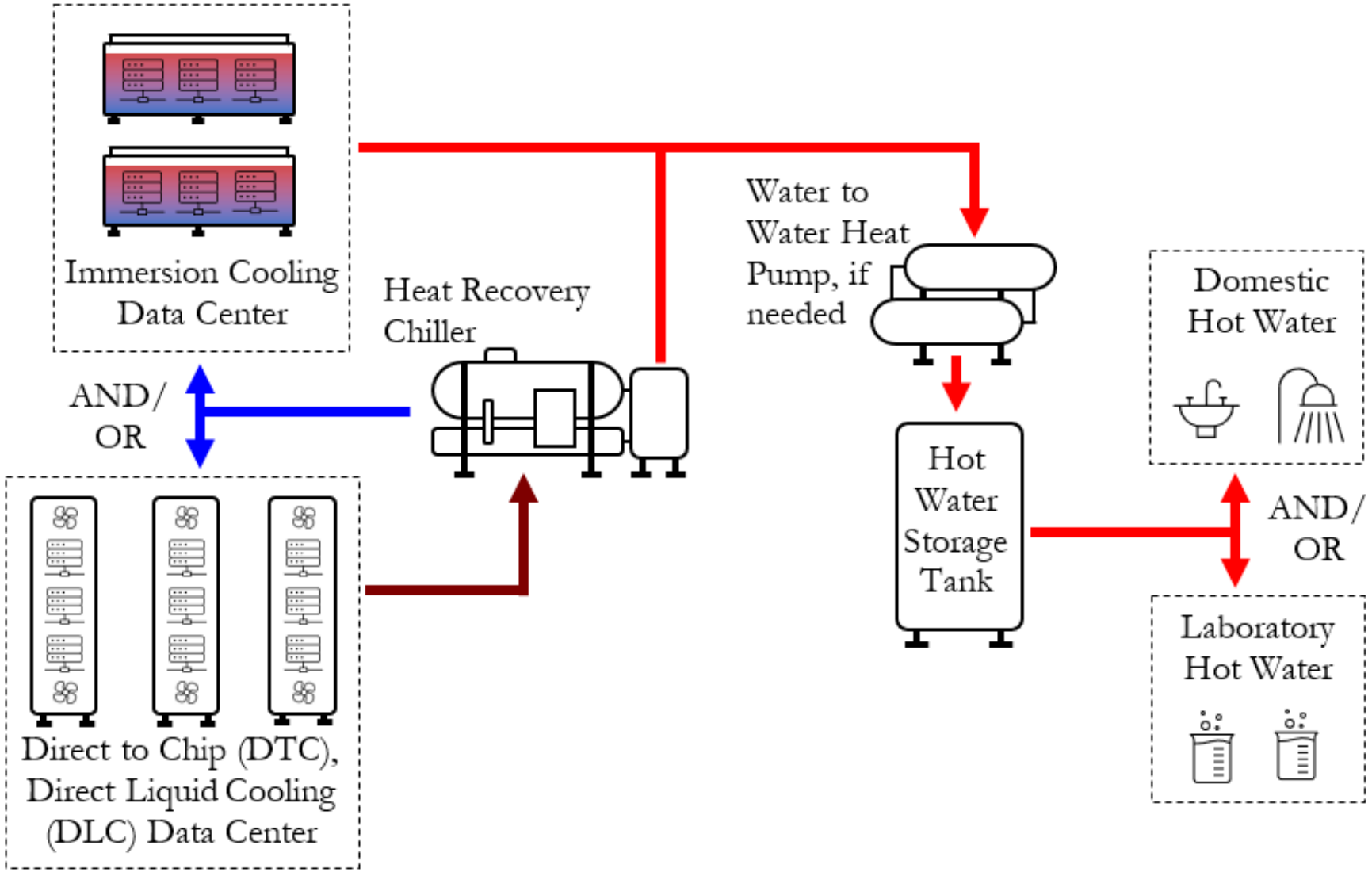
HEAT REUSE; LAB AND/OR DOMESTIC HOT WATER USAGE



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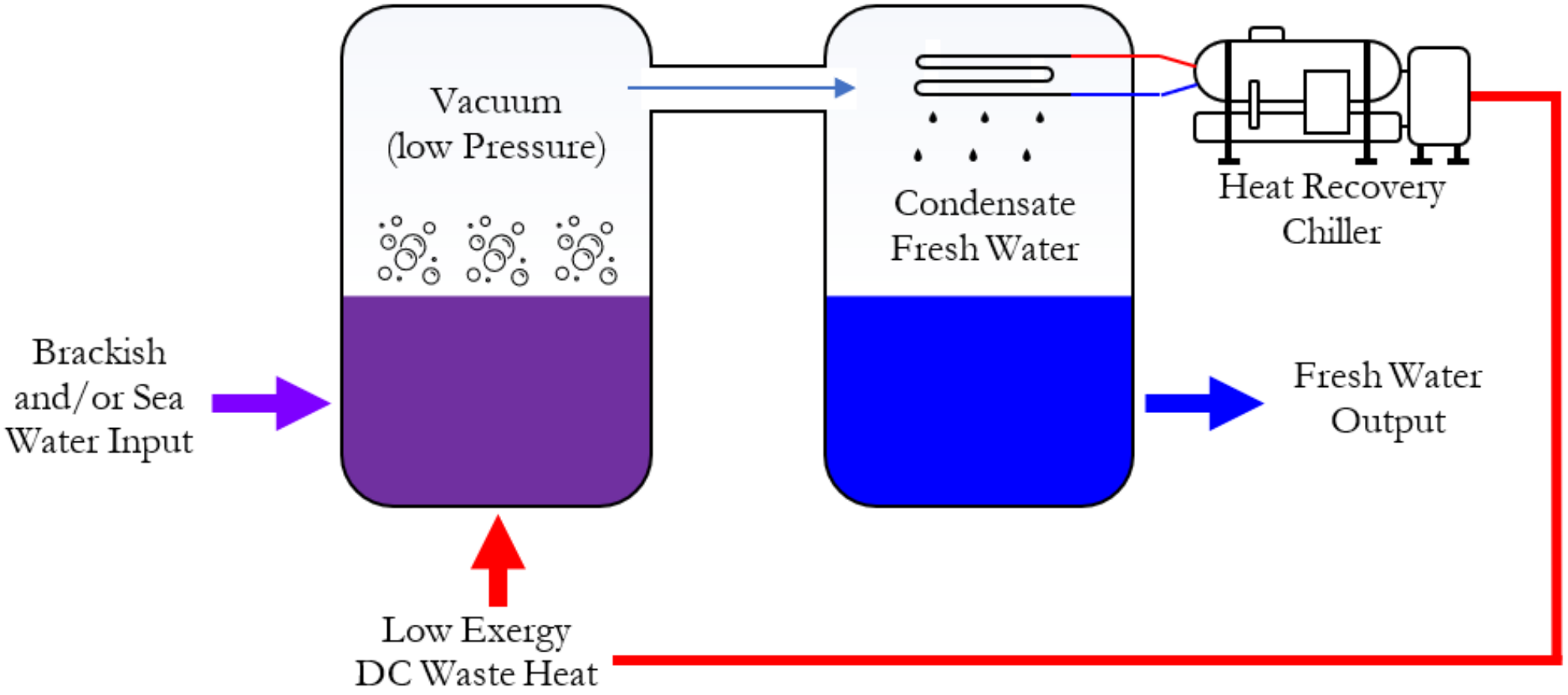
HEAT REUSE; VACUUM DISTILLATION EVAPORATION



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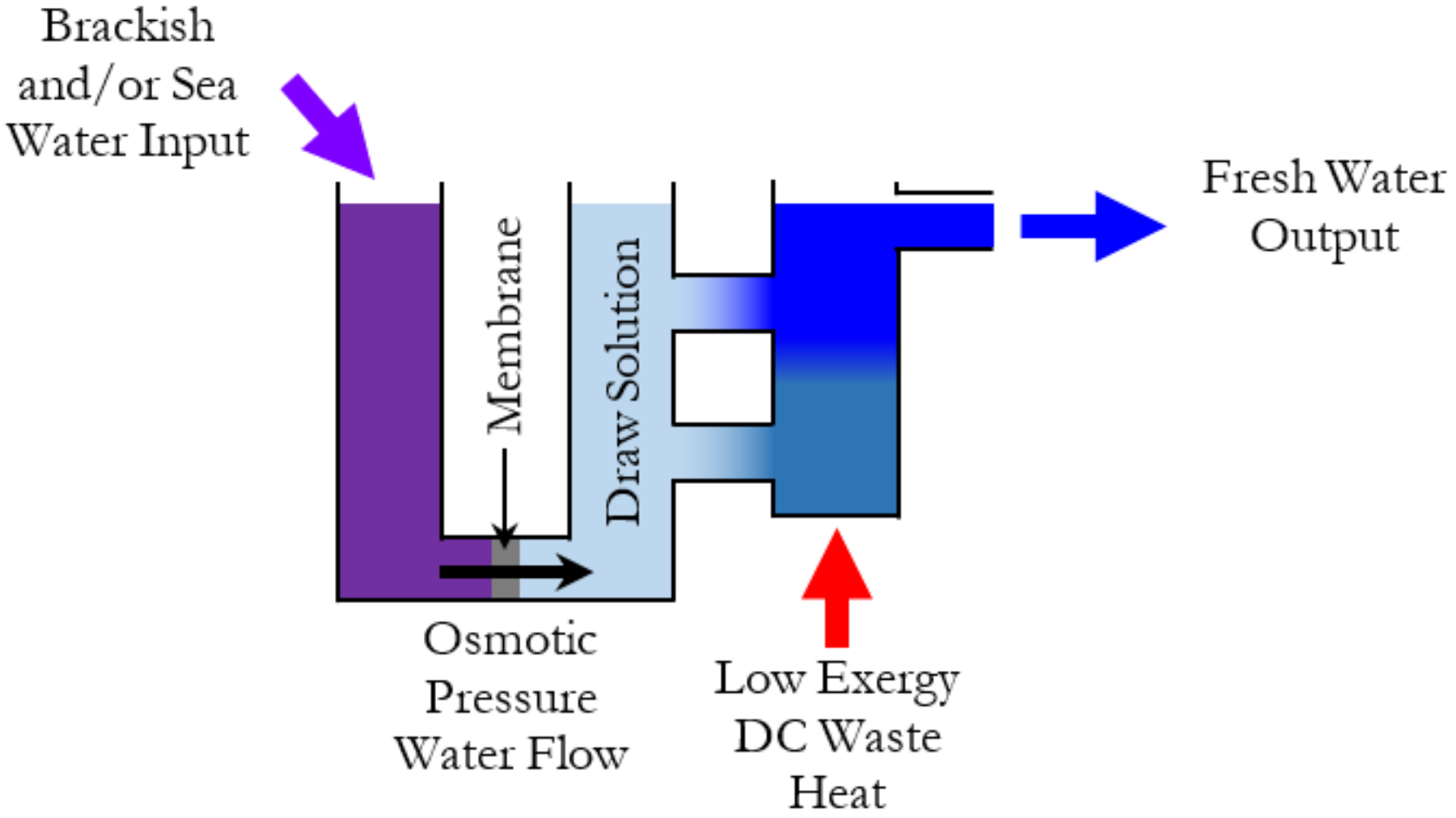
HEAT REUSE; FORWARD OSMOSIS PROCESS UTILIZING DATA CENTER WASTE HEAT



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THANK YOU & REFERENCES

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