SUSTAINABLE DATA CENTERS ROADMAP

CHAPTER 2.4

Heat Reuse

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2.4 Heat Reuse

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Almost all the electricity used at a data center turns into heat. Very few data centers use this heat, but there is considerable interest in doing so, both to offset energy costs and to reduce environmental impacts. The rise of liquid-cooling systems (see Chapter 2.3 of this Roadmap) and higher rack densities are creating new opportunities for beneficial use of heat from data centers. This chapter explores these topics—discussing challenges, analyzing opportunities, describing current and planned projects, and concluding with recommendations.

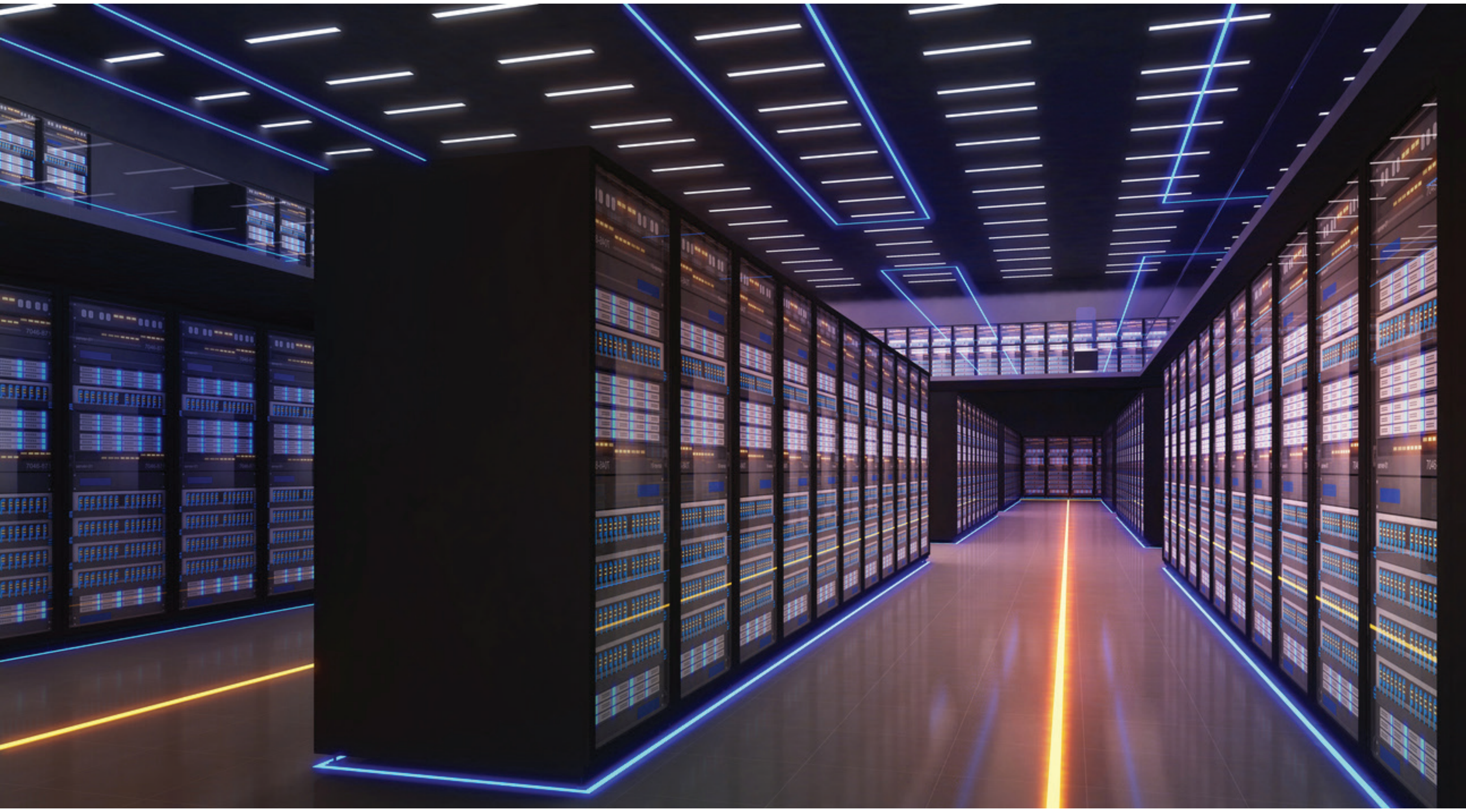
A. Challenges

Today's data centers are dominantly air-cooled. The low exit temperature (close to ambient) and low heat capacity of the air in these data centers makes any reuse of heat difficult and often impossible. (The National Renewable Energy Lab (NREL) in Colorado has a functioning example of heat reuse at an air-cooled data center,[1] but this model is not replicable on a commercial scale.)

Heat reuse projects at data centers face additional challenges. Most fundamentally, heat is difficult to transport over long distances, so data centers must be close to facilities that need heat ("heat hosts") for projects to be successful. In addition, coordination between data centers and potential heat hosts can be complicated, requiring alignment on a range of topics, including technologies, schedules and business goals.

The Open Compute Project lists six issues limiting deployment of data center heat reuse projects:

1. Data centers and heat hosts are not always located in close proximity. The cost of new infrastructure to connect them can be significant.
2. Many locations have climates in which heat is not required for human comfort for much of the year.
3. Local and national legislation does not always facilitate these projects.
4. Governments rarely offer subsidies for heat reuse projects.
5. Collaboration between data centers and heat hosts can be difficult.
6. Heat reuse projects require significant investment, often including underground pipes, pumping stations, heat pumps, controls and similar equipment.[2]



B. Opportunities

Liquid Cooling systems can enable reuse of heat that would otherwise be wasted. These systems have exit temperatures as high as 70 °C, limited only by the safe operating range of the chips. In liquid cooling systems, heat can be recycled at 45-70 °C, aligning with the thermal cycles in many district heating systems.

Liquid Cooling systems are rapidly growing in number, driven in part by the rise of graphics processing unit (GPU)-based computing for artificial intelligence (AI). The higher rack densities typical of GPUs result in greater waste heat and, in turn, the need for liquid cooling. This, in turn, creates new opportunities for heat reuse since the systems operate with higher exit temperatures.

Liquid Cooling systems with ultra-high rack densities (>100 kW/cabinet) also lower power usage effectiveness (PUE)[1] significantly (while capturing more than 99% of waste heat at ~55-70 °C).[3] With two-phase immersion cooling technology, data center PUE can reach 1.03-1.05.[4] Although capital costs for such systems are high, return on investment (ROI) can be relatively quick. One study reports ROI ranges of 1-3 years for single-phase immersion cooling systems.[3]

Table 2.4-1. Types of cooling with estimated market share and heat reuse capability.

Exit Temps	Air Cooling* 15–30 °C	Rear Door Cooling* 30–40 °C	Liquid Coolng – Direct to Chip or Immersion* 40–70 °C
Current Usage (2023)	95% Market Share[5,6]	2-3%[7]	2-5%[8]
Future Builds Usage (estimate for 2028) [9-11]	60–70% (remaining after rear door and liquid cooling estimates)	10-15%	20-25%
Comments	Dominant in legacy and smaller systems	Easiest to retrofit—maintains existing cooling methods	Can achieve PUE of 1.02; direct to chip dominant in new builds today
Heat Reuse Capability	None	Minimal—local heating	Significant, particularly at higher exit temperatures

*See Chapter 2.3 of this Roadmap for background on air cooling, rear door cooling and Liquid Cooling.

Examples of data centers with liquid cooling that reuse waste heat include the following.

- Intel + Submer (Barcelona): Deploying SmartPod XL immersion units operating at 55-70 °C, with reported >99% heat capture, feeding local district heating.[12]

- Aquasar (ETH Zurich): Hot-water cooling recovers ~80% of heat, utilized in campus heating, saving ~$1.25 million annually.[13]

- iDataCool (Germany): Custom hot-water cooling for HPC, drives an adsorption chiller; target ~65 °C for useful heat.[14]

- QTS, Digital Realty, Equinix (Nordics): Air-cooled centers use heat to warm homes; immersion cooling pilots in Finland and Sweden are underway.[15]

Combining liquid cooling systems with heat pumps can open opportunities for heat reuse at data centers. Heat pumps take a source of low-temperature heat and raise the temperature, making the heat suitable for a wider range of applications.[16]

Two types of facilities offer the best opportunities for data center heat reuse: district heating and direct air capture. Other possibilities include electricity generation, agriculture and aquaculture. These are discussed below.

i. District heating

In colder regions, the most impactful use of waste heat is often through district heating networks—centralized systems that distribute hot water or steam to buildings for space conditioning and water heating. District heating systems in Nordic countries use moderate-temperature water—typically input at 60-70 °C and returned in the vicinity of 50 °C. These are excellent matches to modern liquid-cooling systems, but in order to optimize district heating, data centers need to be carefully planned to integrate with district heating options.

District heating systems have many benefits.[17] They reduce greenhouse gas emissions and energy use, increase energy efficiency, lower building costs (no separate boilers, chillers or other related hardware) and improve reliability (industrial-grade district energy equipment is more robust than commercial equipment installed at the building level). Cities and communities often support district heating systems due to reduced cost for new housing development and the capacity to provide baseload power and heat for microgrids. Local grid infrastructure can benefit through reduced peak demand enabled by aggregating loads and shifting peak demand with thermal energy storage.[18]

The main challenge in using data center heat for district heating is seasonality. In warmer months when district heating is not needed, the data center must have an alternative method of rejecting its waste heat. This requirement raises the overall capital cost of the data center's cooling infrastructure. As a result, the benefits of linking to a district heating system must be substantial in terms of cost reductions, carbon emission reductions, improved social acceptance or otherwise.

However, several data centers have successfully supplied waste heat use for district heating systems. For example, in 2020, Meta began routing low-grade heat from its Odense data center to the local district heating utility (Fjernvarme Fyn).[19] Through heat pumps, the temperature is raised to meet residential needs. The Odense system provides essentially "free" heat to over 7000 homes (and growing), offsetting fossil fuel use and supporting Denmark's national climate targets.

Following Meta's lead, Microsoft is launching a heat recovery system at its new Danish data centers to supply thermal energy to the local district heating network. Scheduled for full operation by 2026, the system will deliver surplus heat equivalent to thousands of households' annual demand.[20] It forms part of Microsoft's broader strategy to align with Denmark's clean energy and circular economy goals.[21]

Matching data centers with district heating systems in the United States is more challenging than in northern Europe. US district heating systems—including the largest in New York and Boston/Cambridge—tend to be based on steam rather than hot water.[22] These systems cannot easily be converted to hot water because the radiators in buildings are much less efficient than those in northern Europe. To create the necessary steam, heat pumps would need to be used to raise the temperature of liquid-cooling systems. These heat pumps are becoming available but need electricity to operate, undercutting the energy reduction goal of heat reuse programs.

Chinese authorities and data center operators are exploring use of data center waste heat for district heating, though projects are at an early stage. A study by Tsinghua University and the United Nations Environment Programme (UNEP)-Copenhagen estimates that northern Chinese data centers generate about 70 petajoules of recoverable winter waste heat annually, with potential to quadruple by 2060 if coupled with heat pumps and storage.[23] In Tianjin, Tencent captures waste heat from servers at its data center and, with heat pumps, provides hot water for municipal heating.[24]

ii. Direct air capture

Since carbon emissions are one of the key issues associated with data center expansion, it is interesting to examine whether direct air capture (DAC) systems could be operated with waste heat from liquid-cooling systems. DAC facilities have the ability to operate year-round—a major advantage for data center heat reuse when compared to the seasonal nature of district heating systems. Further, while costs for DAC systems are still quite high, there are many commercial contracts to purchase carbon dioxide (CO_2) removals from the initial suppliers, suggesting that the high cost is not necessarily a barrier to deployment.[25]

The primary energy demand in a DAC facility is for heat to regenerate sorbents and solvents (the material that captures CO_2 from the air). One challenge in using data center waste heat for DAC is that the sorbents and solvents typically require temperatures in the vicinity of 90-120 °C to desorb the CO_2 in a pure state. At exit temperatures from data center liquid-cooling systems, producing the steam for desorption requires either a heat pump or very substantial vacuum. Both need significant electricity input, as does converting the captured CO_2 to liquid form for transportation.

Under these conditions the value of the captured CO_2 must be very high to justify the additional energy. The data center is acting to subsidize the DAC system, rather than the DAC system subsidizing the data center. This may be a perfectly acceptable outcome given the apparent high value of CO_2 removed from the air today ($500-$1000/ton).[25]

Microsoft—the world's largest purchaser of CO_2 from DAC—is conducting a test of DAC using data center heat.[26,27] Meta and Alphabet are exploring options in this area as well.[28,29]

iii. Organic Rankin Cycle Power (ORC) electricity generation

Using waste heat to generate electricity would have significant benefits. Such a system would be usable 24/7 and reduce the overall electricity demand of the data center. Organic Rankin Cycle Power (ORC) systems use a heat exchanger to transfer the cooling heat from a liquid system to an organic fluid that can be expanded to vapor to pass through a turbine. The fluid is then condensed again, typically by a cooling tower or air cooler. These systems are in routine use for low-temperature geothermal power and are being developed for engine heat recovery. In both cases the heat sources are higher temperature (typically 80-100 °C) than exit heat from data center liquid-cooling systems.[30]

This approach has received significant academic attention but is not currently in use for data centers. One analysis suggests a payback period of 4-7 years.[31] However, a manufacturer of these systems for engine heat reuse, Vertiv, has sponsored a detailed experimental study of its application to data center heat at 58 °C with an atmospheric heat sink between 14 and 35 °C.[32]

The company found that:

> "When operating at TH [hot-side temperature] ~58 °C, TL (low-side temperature) ~14 °C, and near full load, the ORC can convert ~2% of the waste heat into mechanical energy. Although this may appear negligible, the best data centers consume ~20% of the IT load to transport the waste heat to the outdoors. The ORC provides this cooling with a net output of mechanical energy creating a significant improvement in data center PUE. The regenerative turbine liquid pump consumes ~50% of the energy output of the expander. When the parasitic load to transport the residual waste heat into ambient air is considered, the ORC as a WHR [waste-heat recovery] system is an energy consumer.
>
> That being said, in a data center application the WHR system is the cooling system which must operate continuously as load varies from 0% to 100% and ambient temperature varies according to the prevailing weather conditions predicted based on a century of records. *The unstable flow limits at the expander inlet in the subject ORC system fall well within the spring, summer, and fall high temperatures expected in Ashburn, VA. Thus, use of ORC WHR as the sole data center cooling means is precluded."*

In other words, the system tested was unable to operate stably in temperatures expected of temperate zone data centers. Vertiv makes recommendations for how these fundamental problems may be overcome, but the challenge is significant when considering the relatively low amount of power generated and the anticipated high capital cost. This detailed analysis from a commercial supplier suggests why current implementations are not commercial and why the complexity of this approach is probably hindering even a demonstration system in a data center today.

iv. Other possible uses of waste heat

Other possible heat hosts for data centers include aquaculture projects, greenhouses and low temperature industrial processes (such as drying). A large number of possible applications of this kind exist at temperatures of 60-90 °C,[33] many of which do not have the seasonality constraints of district heating. However, current projects are very limited in number and are mostly in Nordic countries. The Green Mountain data center in Norway is sending waste to the world's largest land-based trout farm.[34] Luleå University of Technology in Sweden and the University of Notre Dame in the US have greenhouses that receive heat from data centers.[35] The EcoDataCenter in Falun, Sweden uses waste heat to dry wood for wood pellet production.[36] However, most applications of this kind remain academic exercises only and are probably too small to attract the attention of new large data centers (>100 MW), which will have liquid cooling systems large enough to integrate into more complex industrial applications.

C. Current and Planned Projects

The Open Compute Project (OCP) maintains a list of heat reuse projects at data centers around the world.[2,37,38] The numbers are modest. OCP lists only 12 projects with a capacity of 5 MW or more of heat reuse in operation today and 13 projects of that size in planning. Almost all the projects are in Northern Europe. Eight of the planned projects are in Germany, which has a policy requiring heat reuse in large data centers by 2026.[39] Operating and planned projects with data from OCP are shown in Table 2.4-2.

Some significant investments in heat reuse projects are underway. Google is spending $1 billion to expand its Hamina, Finland data center and will give the heat for free to the local community.[44] It expects to provide 80% of the heating needs of the community. (There are no details on the summer heat management approach at this site.) Nordic data center provider atNorth has announced a hyperscale facility in Finland, which will open with 60 MW and provide heat to the community, with plans to expand to several hundred megawatts.[40] One source suggests that data centers in Europe near existing district heating networks could be capable of supplying 75 TWh/year—enough for 10% of the EU's heating demand by 2030.[41]

Table 2.4-2. Operating and planned heat reuse at data centers (adapted from OCP database[38]).

Site Name	Company/ Operator	City	Country/ State	Nominal reuse capacity (MW)
Operating Sites, Built Stage				
NREL	NREL	Golden	Colorado	5
Westin Building	Amazon Web Services	Seattle	Washington	5
Ericsson	Ericsson	Rosersberg	Sweden	10
Green Hub	GreenHub Data	Stockholm	Sweden	40
Stockholm Data Park	Centers	Stockholm	Sweden	10
LUMI Supercomputer	Stockholm Exergi	Kajaani	Finland	10
Ficolo	CSC	Vantaa	Finland	10
Green Computing	Ficolo Oy	Paris	France	20
Algae Farm	Green IT Solutions	Enge-Sande	Germany	15
nLighten	WindCloud	Hannover	Germany	5
Equinix AM3	NorthC Datacenters	Amsterdam	Netherlands	14
DC2-Telemark	Equinix	Rjukan	Norway	20
Planned Sites, Planning Stage				
DC Val d Europe	OVHCloud	Val d'Europe	France	7.8
DC Heated Night Club	Mainova Webhouse	Frankfurt Seckbach	Germany	30
Equinix FR4, FR6 & FR8	Equinix	Frankfurt Griesheim	Germany	56
Franky	Telehouse	Frankfurt Gallus	Germany	14
Stack 80 MW data Center	Stack Infrastructure	Taunus	Germany	80
Data Center at ICE Train Station	Stack Infrastructure	Limburg	Germany	35
Digital Park	Digital Realty	Frankfurt Fechenheim	Germany	20
heiCOMACS	heiCOMACS Forschungszentrum	Heidelberg	Germany	54
Jupiter Project	Jülich	Jülich	Germany	15
Elementica	Elementica	Stockholm	Sweden	21
EcoDataCenter2	EcoDataCenter	Östersund	Sweden	20
Qscale Q01 Campus	Qscale	Quebec	Canada	96
Wyoming Hyperscale	Wyoming Hyperscale	Evanston	Wyoming	120

In contrast, Meta's Richland Parish (Holly Ridge), Louisiana data center announcement makes no mention of including any heat reuse approaches.[42] While the project is significant (it is projected to be a 4 million ft^2, $10 billion campus with up to 2 GW compute capacity), it is not near a district heating opportunity. The benefits of other heat reuse options are apparently not sufficient to warrant investment.

As of 2024, NREL was developing the Urban Renewable Building and Neighborhood Optimization (URBANopt) platform to analyze the use of waste heat sources within geographically cohesive building districts. This tool will facilitate integration of waste heat into district energy systems, enhancing overall energy efficiency.[43]

Table 2.4-3 summarizes key factors in considering heat reuse projects in countries around the world.

Table 2.4-3. *Heat reuse economic factors by country.*

Region	Low-Hanging Fruit	Net Cost Insights	Future Centers' Economics
USA	Close-coupled retrofits, hybrid cooling	Hybrid cooling yields positive ROI; immersion retrofits costly[43]	New liquid-designed data centers could deliver lower capex/opex
EU	Free cooling, district heat export	12.2% cost savings via heat reuse; 70% chiller reduction via free cooling	Immersion includes long-term gains; retrofit less viable
UK	Free cooling retrofits	Similar cost benefits to EU; policy incentives still needed	Future builds will favor hybrid and immersion systems
Japan/APAC	Hybrid cooling; free cooling in cooler regions	Fewer studies, but expect similar savings when applied	Fastest-growing immersion adoption; cost benefits likely
China	Hybrid cooling pilots	Retrofitting remains expensive without pipeline incentives	Large new high-performance computing builds suitable for immersion from start
India	Hybrid during cooler seasons	Limited data; cooling efficiency still key	Immersion adoption early; local costs variable
South Korea	District cooling pairing	Waste heat flexible in district networks; economies rising	Immersion viable in new developments
Singapore	Free cooling	Tropical climate limits reuse; focus on cooling energy savings	High-density future data centers may offset higher initial cost
Russia	Close-coupled retrofits, free cooling	Subsidized energy reduces ROI action	New builds likely stick with efficient air; liquid niche
Finland	Free cooling, district heat export	Heat export drives clear ROI; colder climate favorable	New builds with immersion + heat export are highly cost-effective

D. Recommendations

1. *Data center operators should* ***adopt high-temperature liquid-cooling systems****—such as direct-chip or immersion cooling—that achieve exit temperatures of 45-70 °C, enabling effective heat reuse in applications, such as district heating.*

2. *National and subnational governments* ***should require feasibility studies for heat reuse in permitting large new data-center projects and offer incentives, such as fast-track permitting and subsidies, to deploy such systems****. National and subnational governments should consider requiring 10-20% heat reuse mandates for new data centers (such as in Germany).*

3. *District heating utilities and municipal planners should* ***proactively partner with data-center developers to map potential synergies and create or extend thermal infrastructure*** *that connects data centers to buildings, industrial users and aquaculture facilities.*

4. *Heat host industries (e.g., hospitals, laundries, greenhouses and industrial processes) should* ***actively engage with data-center operators to explore using waste heat for 24/7 applications,*** *including agriculture, drying, aquaculture and wastewater treatment.*

5. *Technology developers and standards organizations should* ***produce guidelines, matchmaking tools and technoeconomic frameworks that facilitate collaboration between data-center operators and prospective heat hosts****, building on the work of the Open Compute Project (OCP) and others.*

6. *Research institutions, utilities and innovative companies should* ***pilot alternative uses and technologies—such as data-center-powered DAC systems****—evaluating performance and return on investment to increase reuse pathways.*

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