INTEGRATING AI-DRIVEN LABS INTO CAMPUS INFRASTRUCTURE: A HOLISTIC APPROACH

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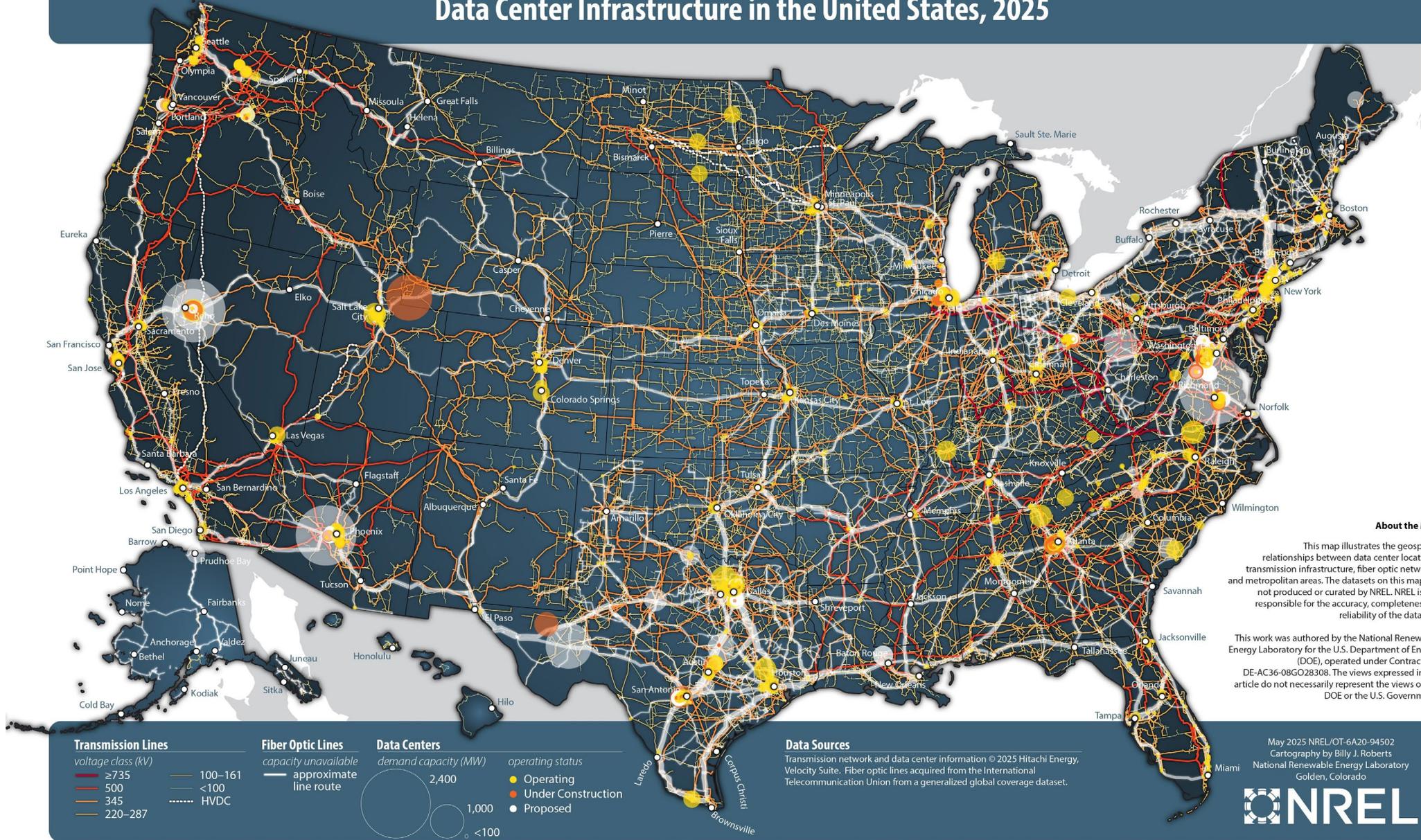
Director Of Science And Technology

LEARNING OBJECTIVES

- **Understand the Impact of AI on Laboratory Environments**

- **Assess the Infrastructure Demands of AI-Driven Research**

- **Explore 5th-Generation District Systems**

- **Develop Strategies for Resilient and Sustainable AI Infrastructure**

THE GROWTH OF AI

I²SL

Data Center Infrastructure in the United States, 2025

Transmission Lines
voltage class (kV)

- ≥735
- 500
- 345
- 220–287
- 100–161
- <100
- HVDC

Fiber Optic Lines
capacity unavailable
— approximate line route

Data Centers
demand capacity (MW)
- 2,400
- 1,000
- <100

operating status
- Operating
- Under Construction
- Proposed

About the Map

This map illustrates the geospatial relationships between data center locations, transmission infrastructure, fiber optic networks, and metropolitan areas. The datasets on this map are not produced or curated by NREL. NREL is not responsible for the accuracy, completeness, or reliability of the datasets.

This work was authored by the National Renewable Energy Laboratory for the U.S. Department of Energy (DOE), operated under Contract No. DE-AC36-08GO28308. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government.

Data Sources

Transmission network and data center information © 2025 Hitachi Energy, Velocity Suite. Fiber optic lines acquired from the International Telecommunication Union from a generalized global coverage dataset.

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Cartography by Billy J. Roberts
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NREL

AI & LABORATORY ENVIRONMENTS

Biomedical & Life Sciences

Drug discovery and protein modeling
Genomics

Physical & Climate Sciences

Materials discovery
Climate modeling

Engineering & Automation

Robotic laboratories
Digital twins

Education & Collaboration

Personalized learning
Data democratization

Traditional Labs

- Bench science, limited computing needs, conventional HVAC

AI-Enhanced Labs

- Robotics, simulation, digital twins, growing compute density

HPC / Data Centers

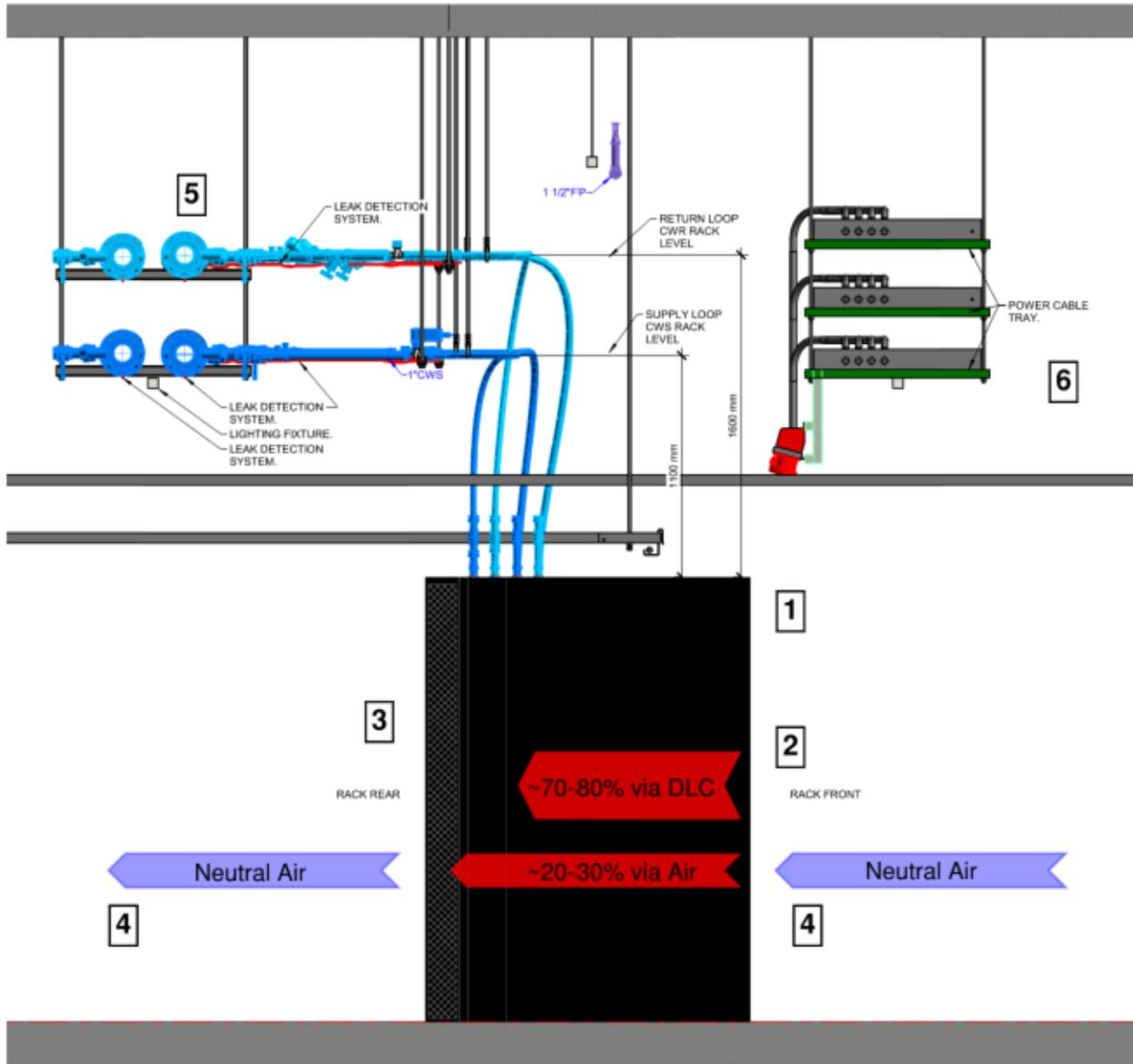- High-density racks, liquid cooling, 24/7 compute demand

Campus Utilities

- Integrated energy loops, renewable sources, heat reuse

HIGH DENSITY DATA CENTERS

1. High density rack with A.I. GPUs, rack densities commonly 50-100 kW rack, projected to exceed 200 kW in a few years.

2. Direct liquid cooling (DLC) applies cooling direct-to-chips via rack mounted CDU, covers ~70-80% of the rack load.

3. Remaining 20-30% of rack load is addressed by air based systems such as rear-door coolers.

4. The rack load is removed with rack based cooling, surrounding room is neutral temperature air.

5. Direct-to-chip cooling allows for the use of warmer chiller water, which can even be campus chilled water return. Economizer operation is extended.

6. Power distribution, from local PDUs, through to racks can be MC feeder cables, busway or other methods.

Anticipated increase in A.I. rack densities:

	2024	2025	2026	2027	2028	2029+
AI GPU Roadmap	36x to 576x GPUs per rack					
AI GPU Rack Density	~130 - 250 kW		~250 - 900 kW		~900 - 1,000 + kW	

THE SUSTAINABILITY CHALLENGE

ENERGY INTENSITY DILEMMA

COOLING AND WATER DEMANDS
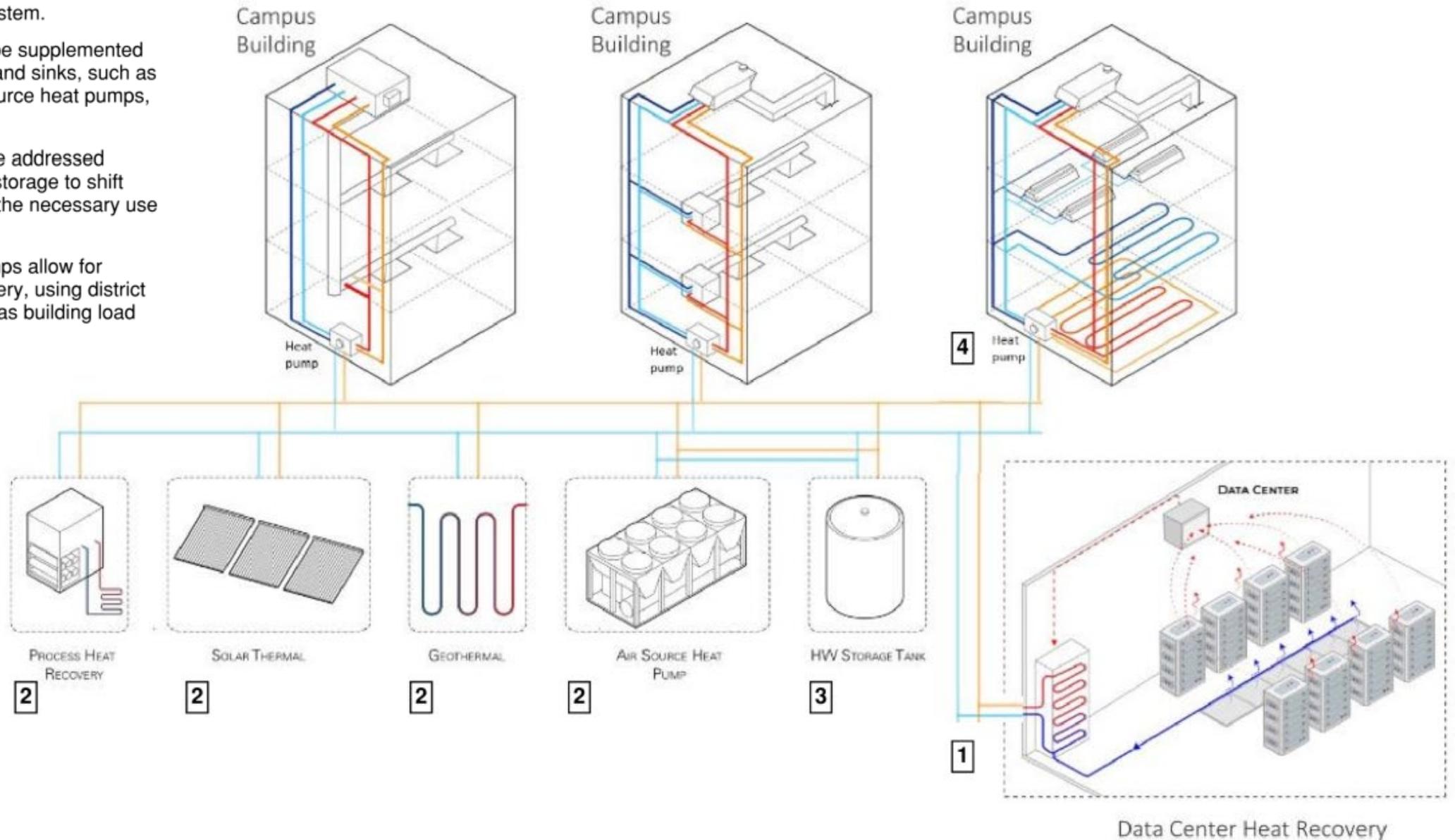
CARBON COMMITMENTS
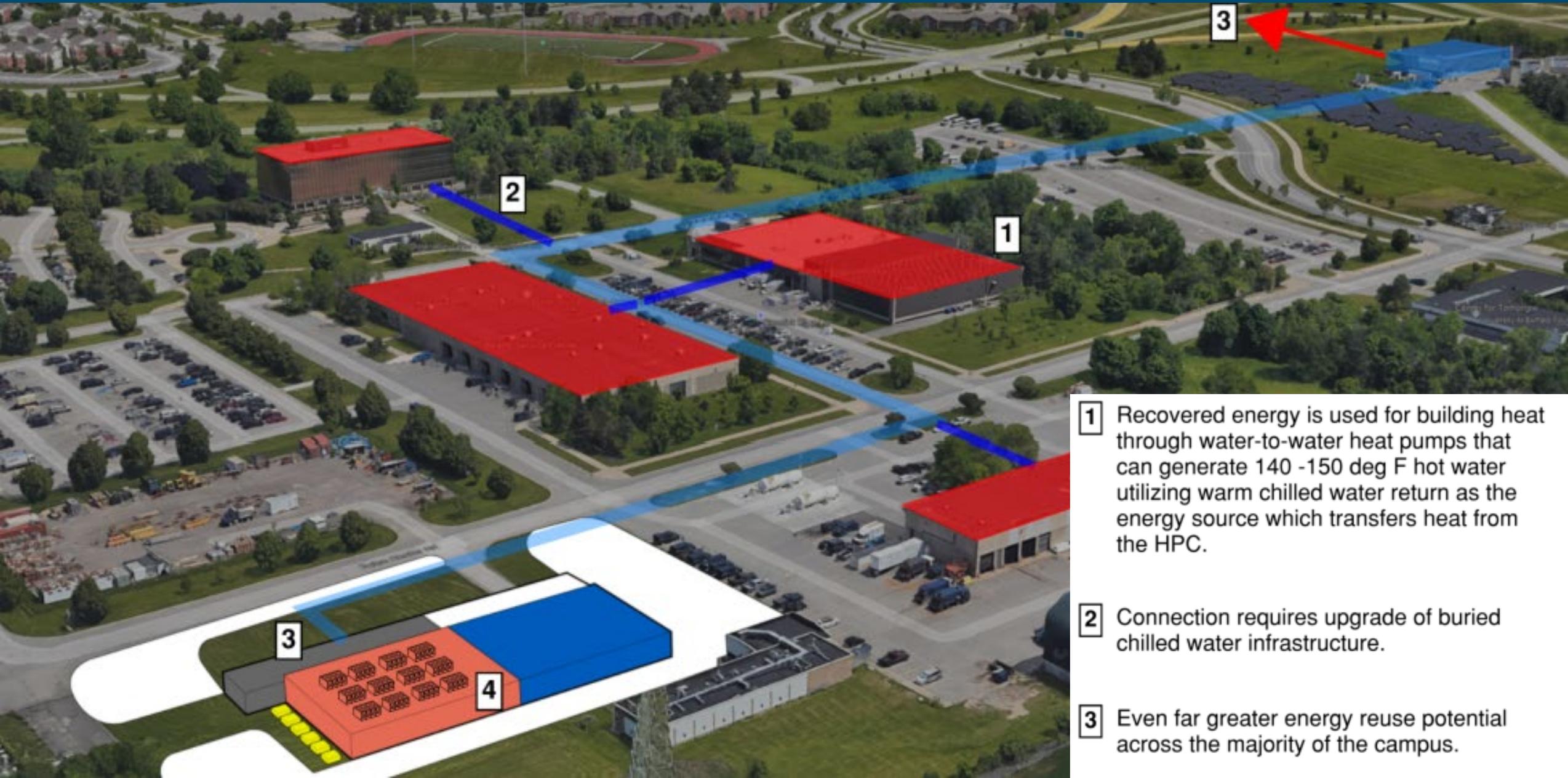
1. Data center becomes a heat source for the 5th generation district system.

2. The district system can be supplemented with other heat sources and sinks, such as geothermal, solar, air-source heat pumps, and more.

3. Unbalanced loads can be addressed through thermal energy storage to shift energy sources/sinks to the necessary use period.

4. Water-to-water heat pumps allow for campus wide heat recovery, using district loop as a source or sink as building load requires.

Campus Building — Heat pump

Campus Building — Heat pump

Campus Building — Heat pump

PROCESS HEAT RECOVERY

SOLAR THERMAL

GEOTHERMAL

AIR SOURCE HEAT PUMP

HW STORAGE TANK

DATA CENTER

Data Center Heat Recovery

INTEGRATING AI INTO CAMPUS INFRASTRUCTURE

1 Recovered energy is used for building heat through water-to-water heat pumps that can generate 140 -150 deg F hot water utilizing warm chilled water return as the energy source which transfers heat from the HPC.

2 Connection requires upgrade of buried chilled water infrastructure.

3 Even far greater energy reuse potential across the majority of the campus.

RESILIENCY AND OPERATIONAL FLEXIBILITY

Redundancy Definition Has Shifted

Distributed Energy = Distributed Risk

Compute Intensity is Doubling Every 18-24 months

Climate and Regulatory Change

Data + Automation = Operational Intelligence

THE PATH FORWARD

Audit and Assess

Know your baseline

Map existing thermal and electrical loads

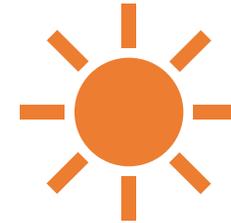Identify recoverable energy and thermal demands

Integrate

Move away from standalone designs

Campus master planning

Go modular with heat pumps, substations and distribution loops

Electrify and Decarbonize

Heat pumps instead of fossil fuel

Heat recovery and reuse before new generation

Integrate renewables and thermal storage

QUESTIONS?

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