

# Bits, Bytes, and BTUs



OFFICE

DATA CENTER

HIGH BAY  
LABORATORIES





# Motivation

Data centers are highly energy-intensive facilities

- 10-100x more energy intensive than an office.
- Server racks well in excess of 30kW.
- Power and cooling constrain existing facilities.
- EPA estimate: 3% of U.S. electricity
- Surging demand for data storage, cloud/web services, extreme scale ...



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# Computing Integration Trends

- More cores, die-stacking: memory close to xPU.
- Fabric Integration, greater package connectivity
- Advanced Switches with higher radix and higher speeds
  - Closer integration of compute and switch
- Silicon Photonics
  - Low cost, outstanding performance but thermal issues do exist
- All this drives continued increases in power density (heat).
  - Power – 400 Vac 3ph, 480 Vac 3ph
  - Density – raised floor structural challenges
  - Cooling – liquid cooling for 50-100 kW racks!

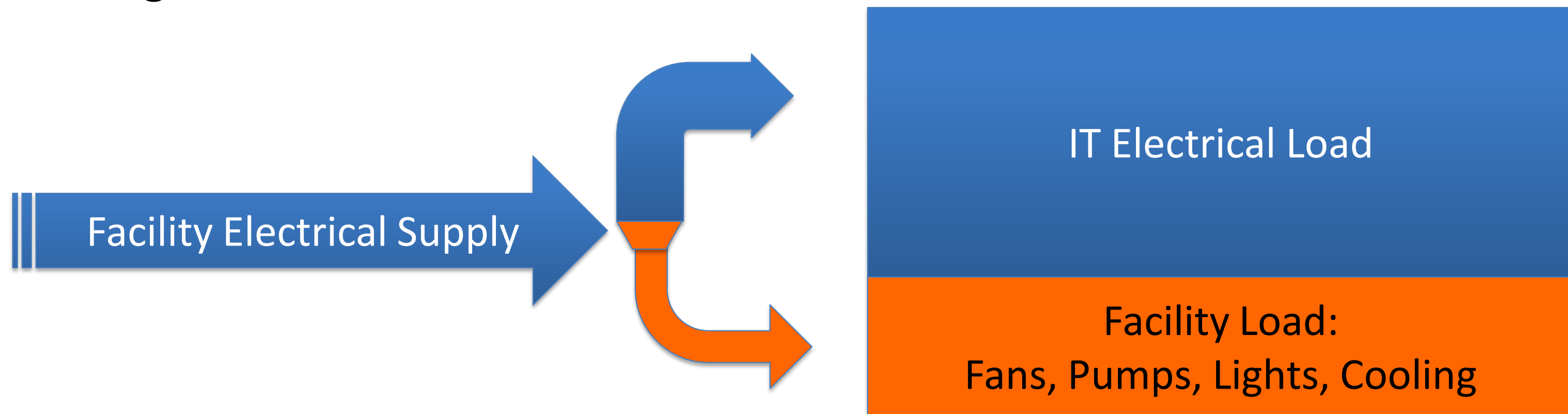
# Energy Efficient Data Centers

- Choices regarding power, packaging, cooling, and energy recovery in data centers drive TCO.
- Why should we care?
  - Carbon footprint.
  - Water usage.
  - Limited utility power.
  - Mega\$ per MW year.
  - Cost: OpEx ~ IT CapEx!
- **Space Premium:** Ten 100KW racks take much, much less space than the equivalent fifty 20KW air cooled racks.



# Facilities and Utilities

- Most sites have a relatively fixed electrical supply, ~\$1M/MW year.
- Expensive and nontrivial to increase facility electrical supply to meet growing demand.



- A less efficient data center steals power and dollars that could otherwise be used for compute capability.
- Minimize investment in facility and operating expense, maximize investment in compute and staffing.

# Holistic View of Compute, Space, Power, Cooling

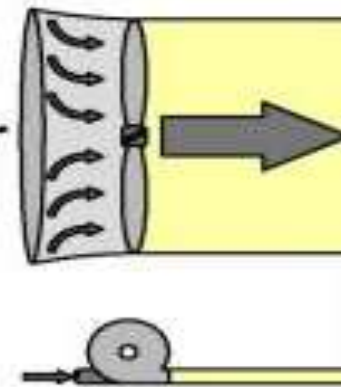
- **Electrical** distribution:
  - 208v or 480v?
- What is your “ambient” **Temperature**?
  - 13C, 18C, 24C, 30C, 35C, 40.5C ...
  - (55F, 65F, 75F, 85F, 95F, 105F ...)
- Approach to **Cooling**: Air vs Liquid and where?
  - Components, Liquid Doors or CRACs, ...
- “Waste” **Heat**:
  - How hot? Liquid or Air? Throw it away or can you use it?



# Cooling Efficiency

- Heat exchange: liquids are ~1000x more efficient than air.
- Transport energy: liquids require ~10x less energy.  
(14.36 Air to Water Horsepower ratio, see below).
- Liquid-to-liquid heat exchangers have closer approach temps than Liquid-to-air (coils), yielding increased economizer hours.

Heat Transfer		Resultant Energy Requirements			
Rate	$\Delta T$	Heat Transfer Medium	Fluid Flow Rate	Conduit Size	Theoretical Horsepower
10 Tons	12°F	Forced Air	9217 cfm	34" Ø	3.63 Hp
		Water	20 gpm	2" Ø	.25 Hp



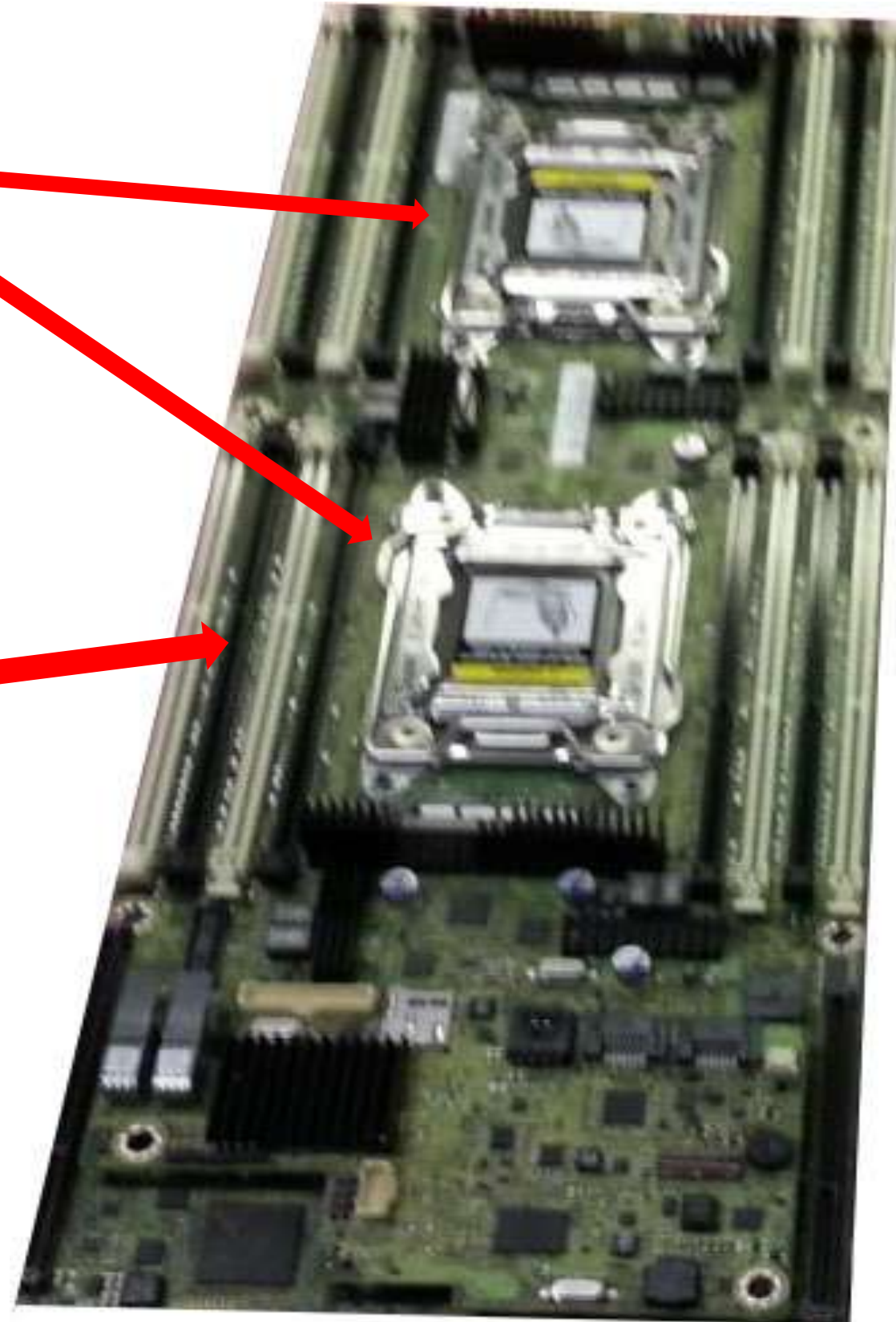
# Safe Temperature Limits

**CPUs**

**~65C**  
**(149F)**

**Memory**

**~85C**  
**(185F)**



**GPUs**

**~75C**  
**(167F)**

CPU, GPU & Memory, represent ~75-90% of heat load ...



# Move to Liquid Cooling

- Server fans are inefficient and noisy.
  - Liquid doors are an improvement but we can do better.
- Rising power densities require component-level liquid cooling.
- Liquid benefits:
  - Thermal stability, space efficiency, more turbo mode, better MTTF.
  - Warm water cooling
    - Eliminates inefficient and expensive chillers.
    - Eliminates condensation concerns.
    - Better waste heat re-use options.



- Save wasted fan energy and use it for computing.
- Unlock your cores and overclock to increase throughput!



# Liquid Cooling – New Considerations



- Air Cooling:
  - Humidity. Fan failures.
  - Cable blocks and grated floor tiles.
  - Mixing, hot spots, “top of rack” issues.
- Liquid Cooling:
  - pH & bacteria, dissolved solids.
  - Type of pipes (black pipe, copper, stainless)
  - Corrosion inhibitors, etc.
- When considering liquid cooled systems, insist that vendors adhere to the latest ASHRAE water quality spec or it could be costly.

# NREL Data Center

- Showcase Facility
  - 10MW, 10,000 s.f.
  - Leverage favorable climate
  - Use evaporative cooling, NO mechanical cooling.
  - Waste heat captured and used to heat labs & offices.
  - LEED Platinum Facility, **PUE 1.06**
- High Performance Computing
  - 20 year planning horizon
    - 5 to 6 HPC generations.
  - Insight Center
    - Scientific data visualization
    - Collaboration and interaction.



*Lower CapEx and lower OpEx.*

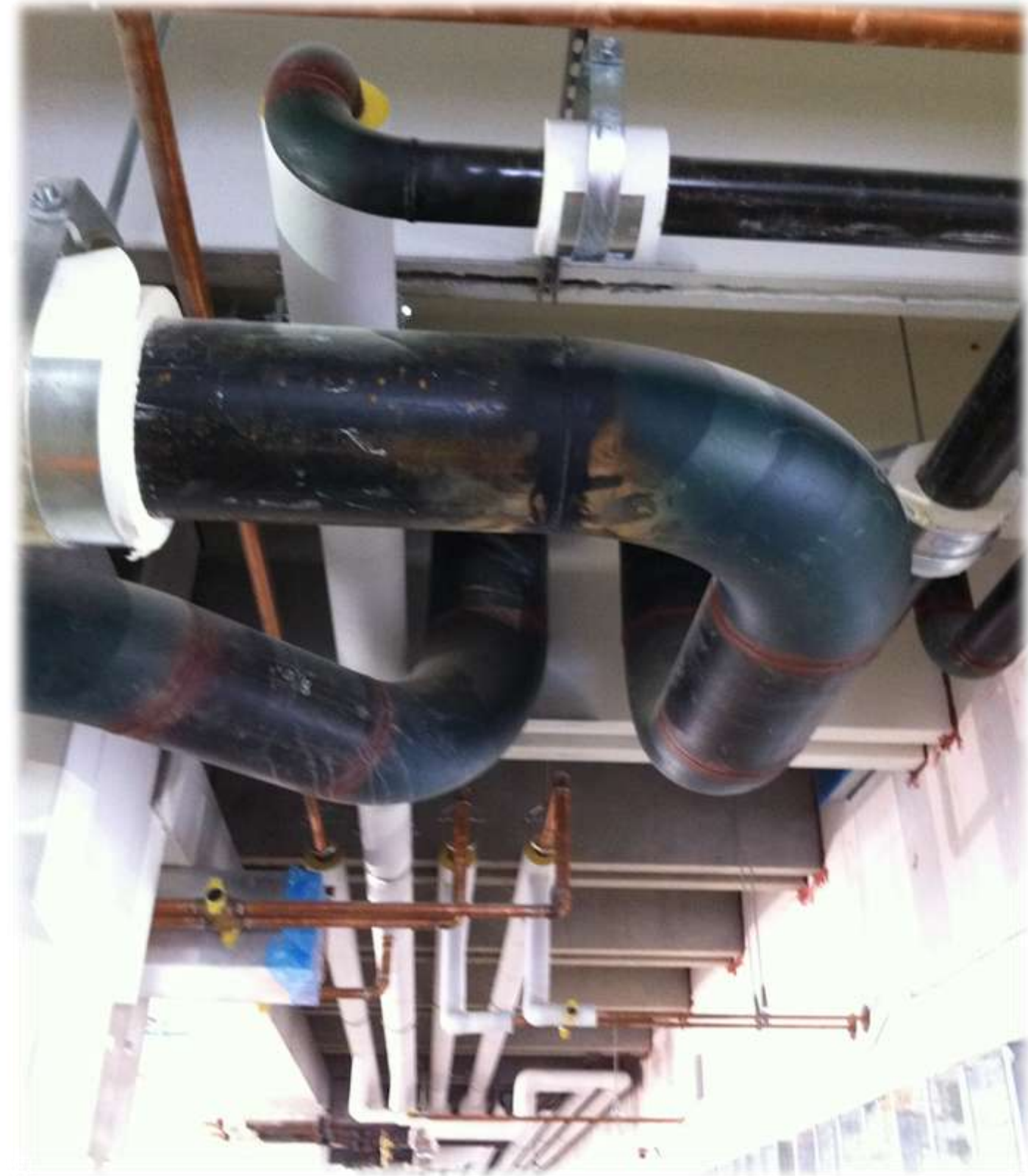
*Leveraged expertise in energy efficient buildings to focus on showcase data center.*

*Integrated chips to bricks approach.*



# Key NREL Data Center Specs

- Warm water cooling, **24C (75F)**
  - ASHRAE “W2” category
  - Water much better working fluid than air - pumps trump fans.
  - Utilize high quality waste heat, **+35C (95F)**.
  - +90% IT heat load to liquid.
- Racks of legacy equipment
  - Up to 10% IT heat load to air.
- High power distribution
  - 480VAC, Eliminate conversions.
- Think outside the box
  - Don't be satisfied with an energy efficient data center nestled on campus surrounded by inefficient laboratory and office buildings.
  - Innovate, integrate, optimize.





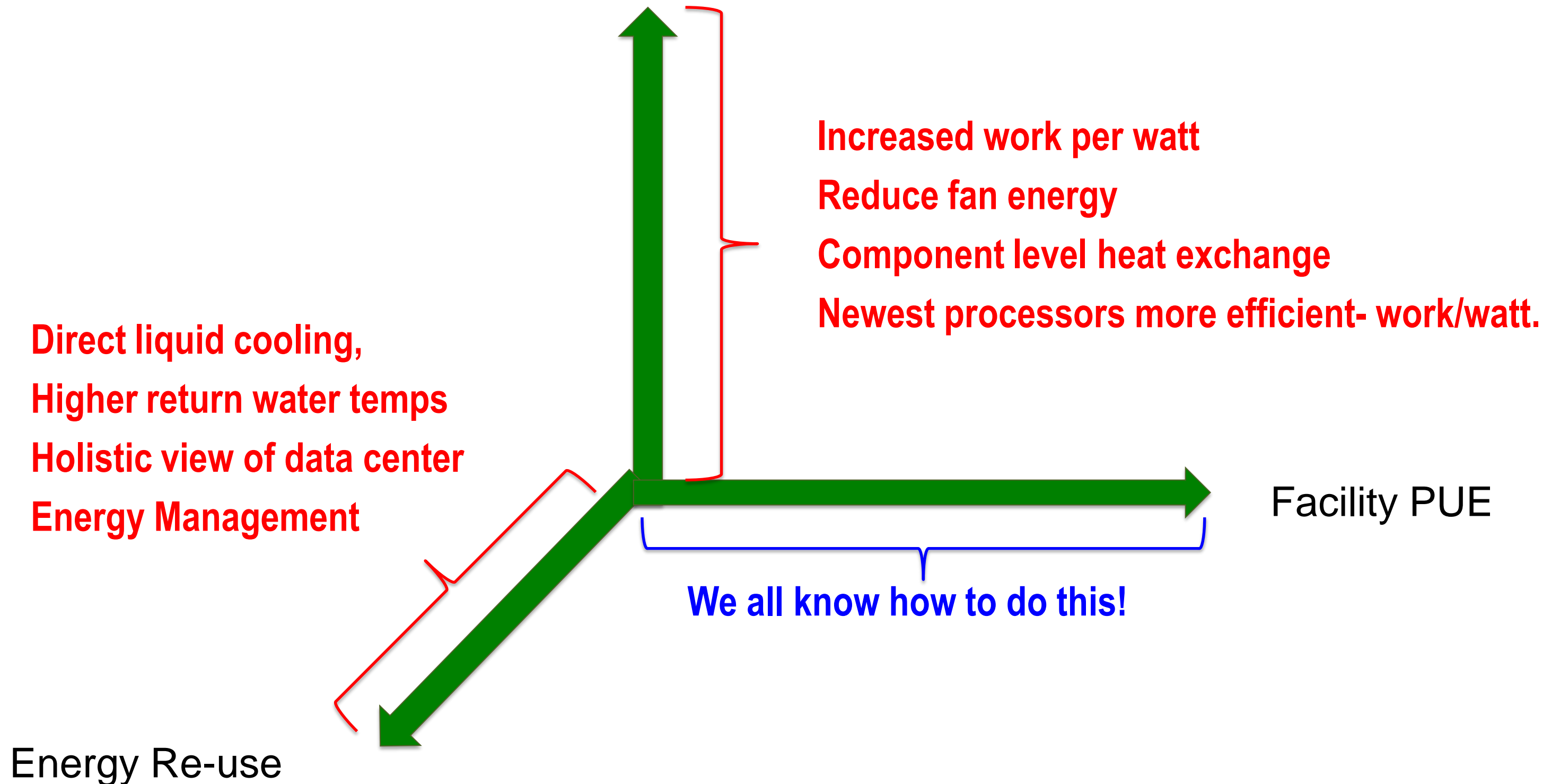
# NREL HPC Data Center Cross Section



- Data center equivalent of the “visible man”
  - Reveal and share inner workings of the building.
  - Tour views into pump room and mechanical spaces
  - Color code pipes, LCD monitors

# Efficient Data Centers: 3-D Optimization

IT Power Consumption

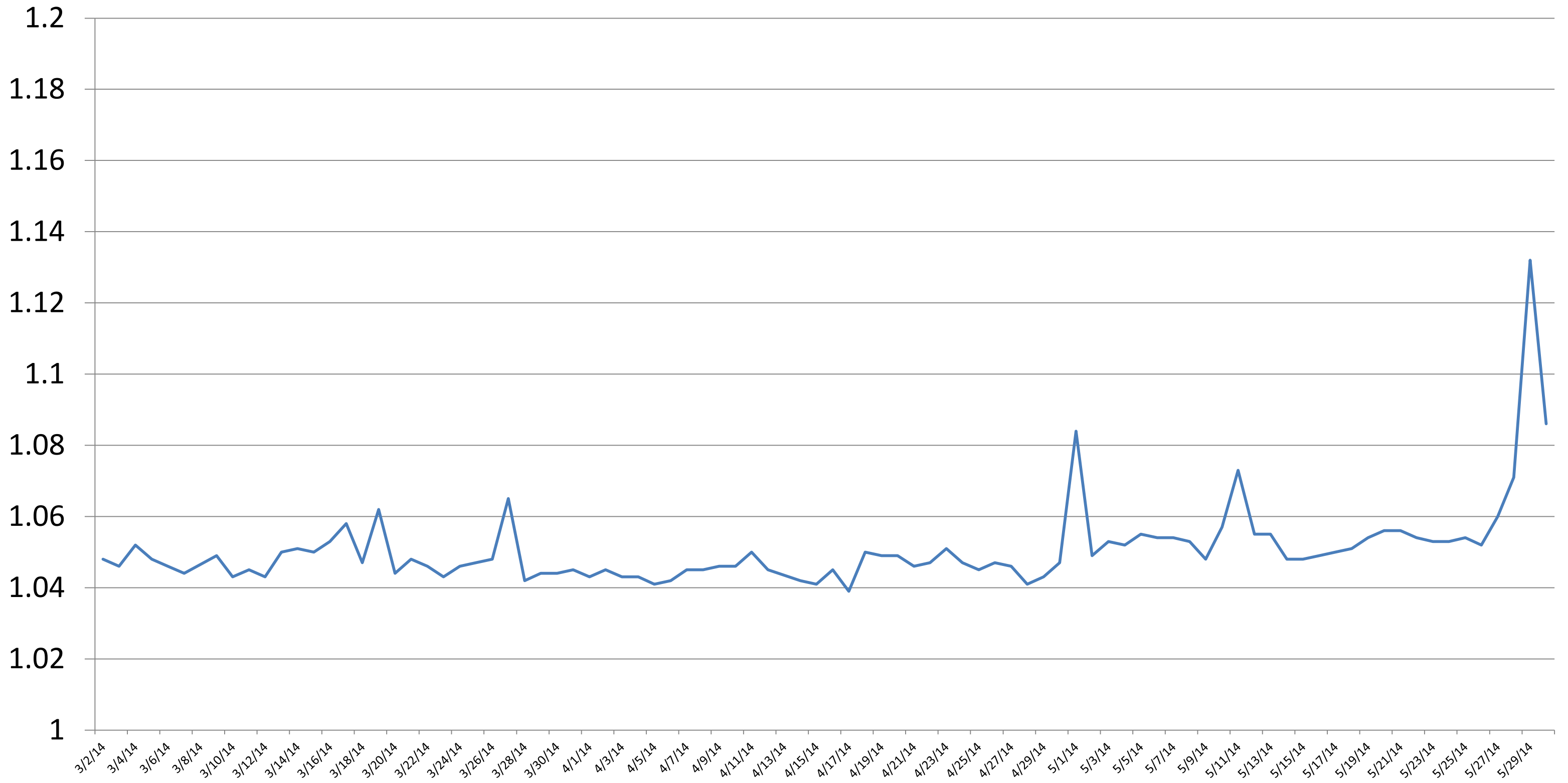




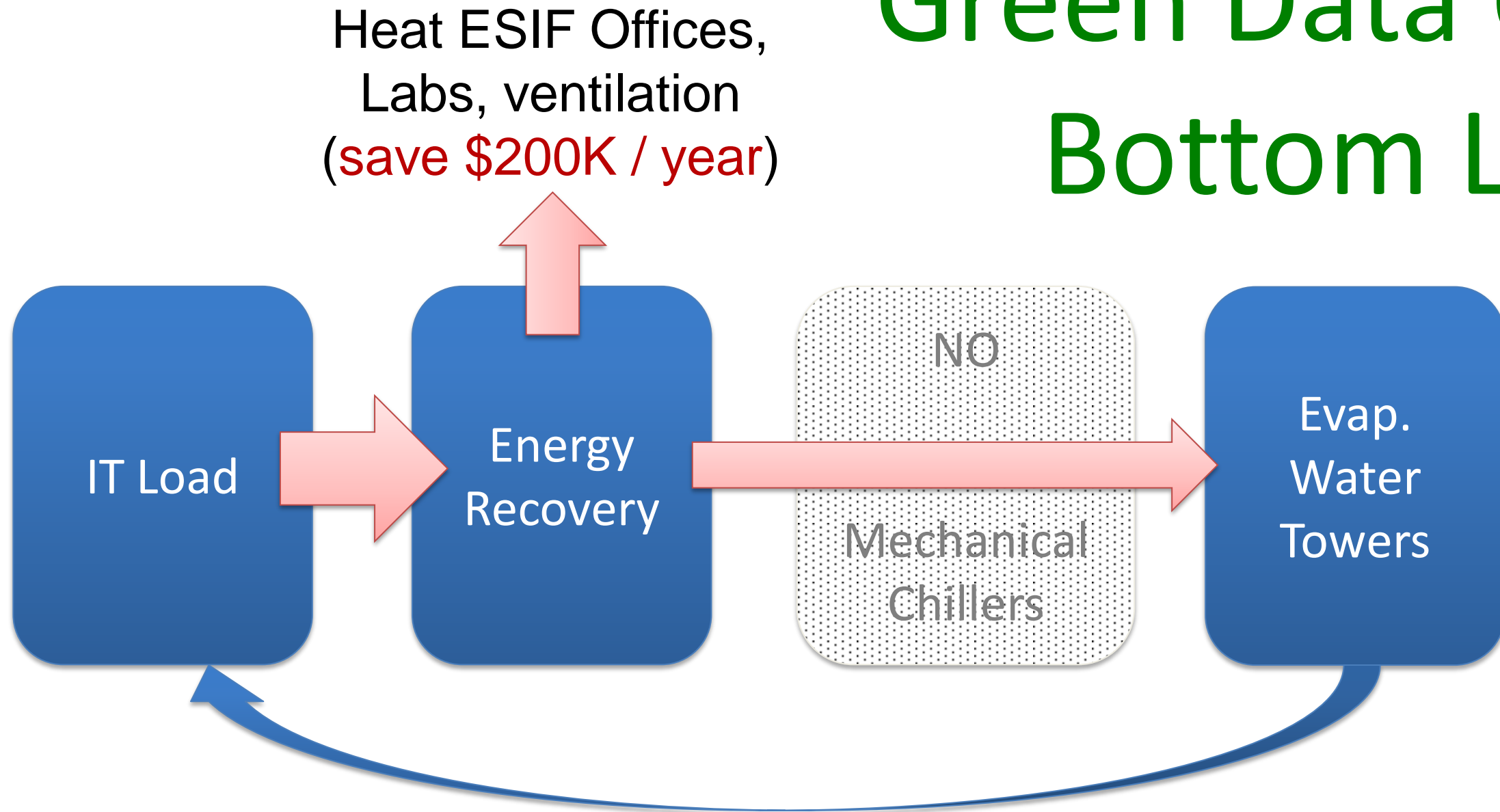
# Early Experience with Liquid Cooling

- 21 months of operation, zero incidents
  - This includes work with engineering prototypes starting in Jan 2013.
  - Liquids in the rack, no water on the floor!
- “Production” racks delivered in late August & Sept. 2013.
- Peregrine passed acceptance test in Nov 2013.
- Full production usage since Jan 2014.
  
- Early engagement with prototypes and HP engineering team was positive experience for both HP and NREL.

# NREL ESIF 3-month PUE, avg 1.05



# Green Data Center Bottom Line



Cost less to build  
Cost less to operate

Comparison of ESIF  
PUE 1.06 vs efficient  
1.3 data center.

## CapEx

No Chillers  
Initial Build: 600 tons  
10 Yr. growth: 2400 tons  
**10-year Savings:**  
(\$1.5K / ton)

## Savings

No Chillers  
\$.9M  
\$3.6M  
**\$4.5M**

## OpEx (10MW IT Load)

PUE of 1.3  
PUE of 1.06  
Annual Savings  
**10-year Savings**  
(\$1M / MW year)

## Utilities

\$13M  
\$10.6M  
\$2.4M  
**\$24M**  
(excludes heat recovery benefit)

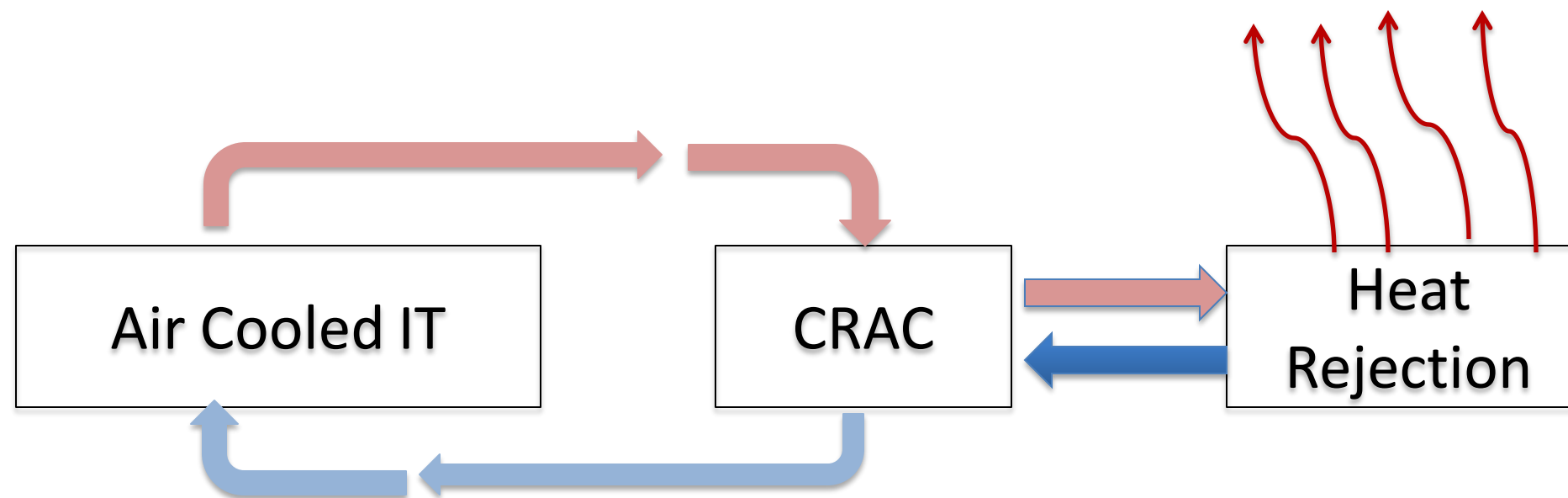


# Liquid Cooling Checklist

- ASHRAE TC9.9 liquid standards provide excellent guide.
- Cooling Distribution Units
  - Efficient heat exchangers to separate facility and server liquids
  - Flow control to manage heat return.
- System filtration (with bypass) to ensure quality.
- N+1 redundancy in hydronic system.
- Utilize warm supply, provide hot return to support re-use.
- Minimize “exposure” when servicing.
- Leak detection with Integrated EPO back to PDU.
- Heat exchange at the heat source.
- Robust, well engineered solution.
- At least 95% of rack heat load captured directly to liquid.

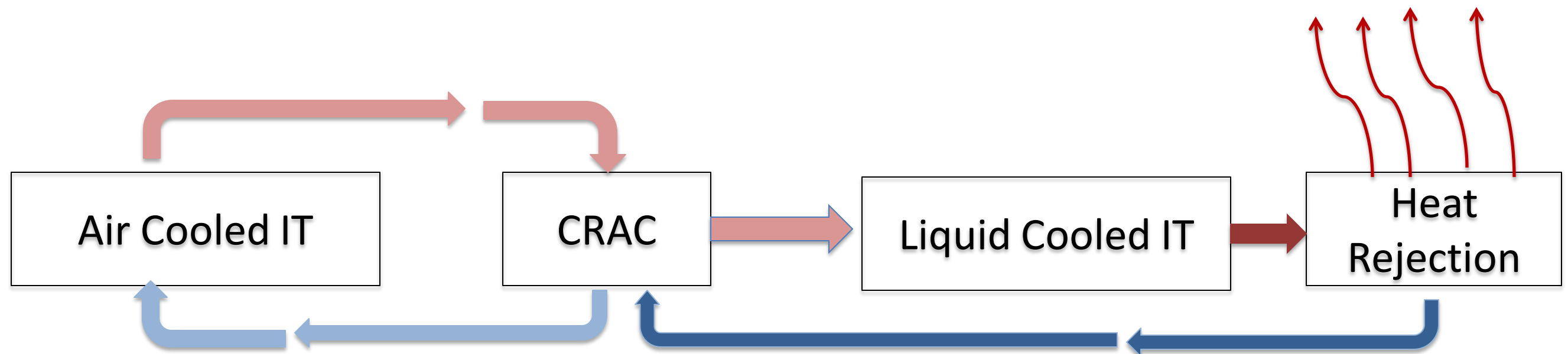
# Air to Liquid Transition Path

- **NREL started with a new data center, how do I use liquid cooling in my traditional data center?**
  - If you have traditional CRAC units, you already have liquid into your data center.
  - Intercept the CRAC return water that would go to your heat rejection (chiller?) and route it to the liquid cooled racks first and take the warmer return water to your chiller.



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# Final Thoughts

- **Energy Efficient Data Centers**

- Well documented, just apply best practices. It's not rocket science.
- Separate hot from cold, ditch your chiller.
- Don't fear H<sub>2</sub>O: Liquid cooling will be increasingly prevalent.
- PUE of 1.X, focus on the "1" and find creative waste heat re-use.

- **Metrics will lead to sustainability**

- If you don't measure/monitor it, you can't manage it.
- Accurate, 1Hz measurements necessary for effective management.

- **Holistic approaches to Work Flow and Energy Management.**

- Lots of open research questions.
- Projects may get an energy allocation rather than a node-hour allocation.
- Utility time-of-day pricing drive how/when jobs are scheduled within a quality of service agreement.

Questions?