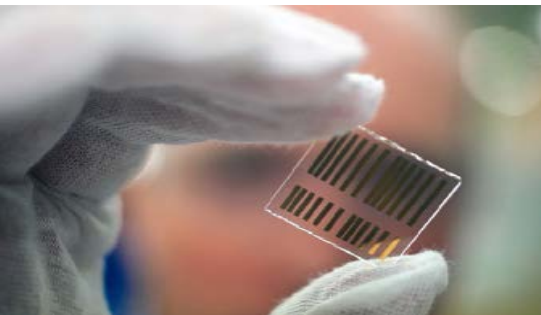# Sustainable Data Centers

Steve Hammond

November 2016

Roadmap

1. **Where did we come from?** Our holistic "chips to bricks" approach.

3. **What have we accomplished?** Peregrine, warm water cooling, PUE, waste heat re-use, and TCO. Lessons learned.

4. **What's next?** Sustainability, water usage, carbon-free data center

NREL's Dual Computing Mission

- Provide high performance computing and related systems and expertise to advance the lab mission, _and_

- Push the leading edge for data center sustainability.

- Leadership in liquid cooling, waste heat capture and re-use

  Holistic "chips to bricks" approaches to data center efficiency.

- ESIF - Showcase facility for visitors to see first hand best practices in use.

- Critical topics include

  - Water usage,

  - Liquid cooling and energy efficiency,

  - Carbon footprint,

  - Time of day utility pricing, Load shifting and demand response

Where did we come from?

August 2011

Planning for a New Data Center

- Started planning for new data center in 2006.

- Based on industry/technology trends, committed to direct liquid cooling.

- <u>Holistic</u> approach – integrate racks into the data center, data center into the facility, the facility into the NREL campus.

- Capture and use data center waste heat: office & lab space (now) and export to campus (future)

- High power density racks - 60KW+ per rack

- Liquid cooling at the rack, no mechanical chillers

- Use chilled beam for office/lab space heating. Low grade waste heat use.

- Two critical temperatures:

    - IT cooling supply – could produce 75F on hottest day of the year.

    - IT return water - required 95F to heat the facility on the coldest day of the year.

Build the World's Most Energy Efficient Data Center

Energy Efficient Data Centers

- Choices regarding power, packaging, cooling, and energy recovery in data centers <u>drive TCO</u>.
- 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.

Safe Temperature Limits

CPUs

~65C

(149F)

GPUs

~75C

(167F)

Memory

~85C
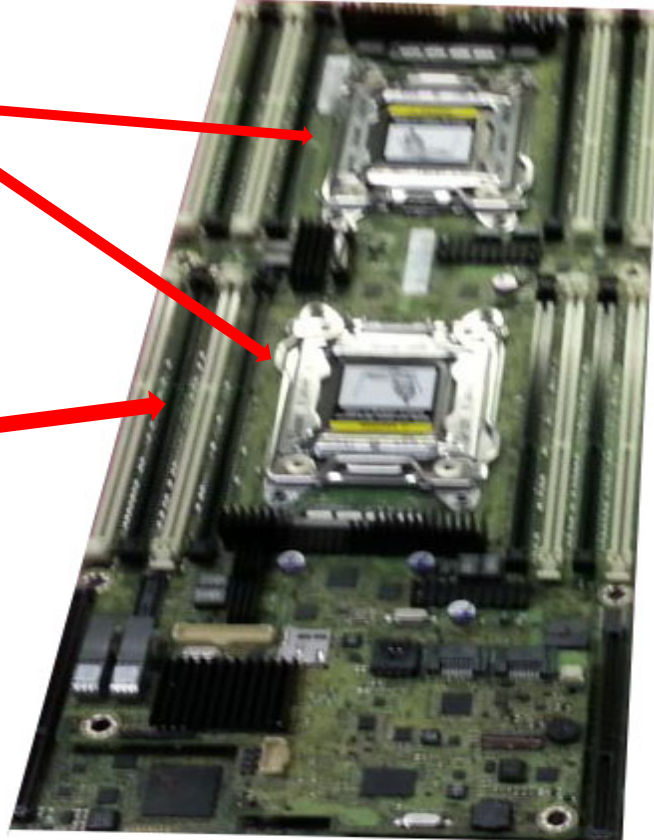
(185F)

CPU, GPU & Memory, represent ~75-90% of heat load …
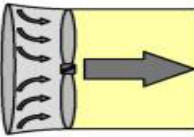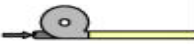
Holistic View of Compute, Space, Power, Cooling

- **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.

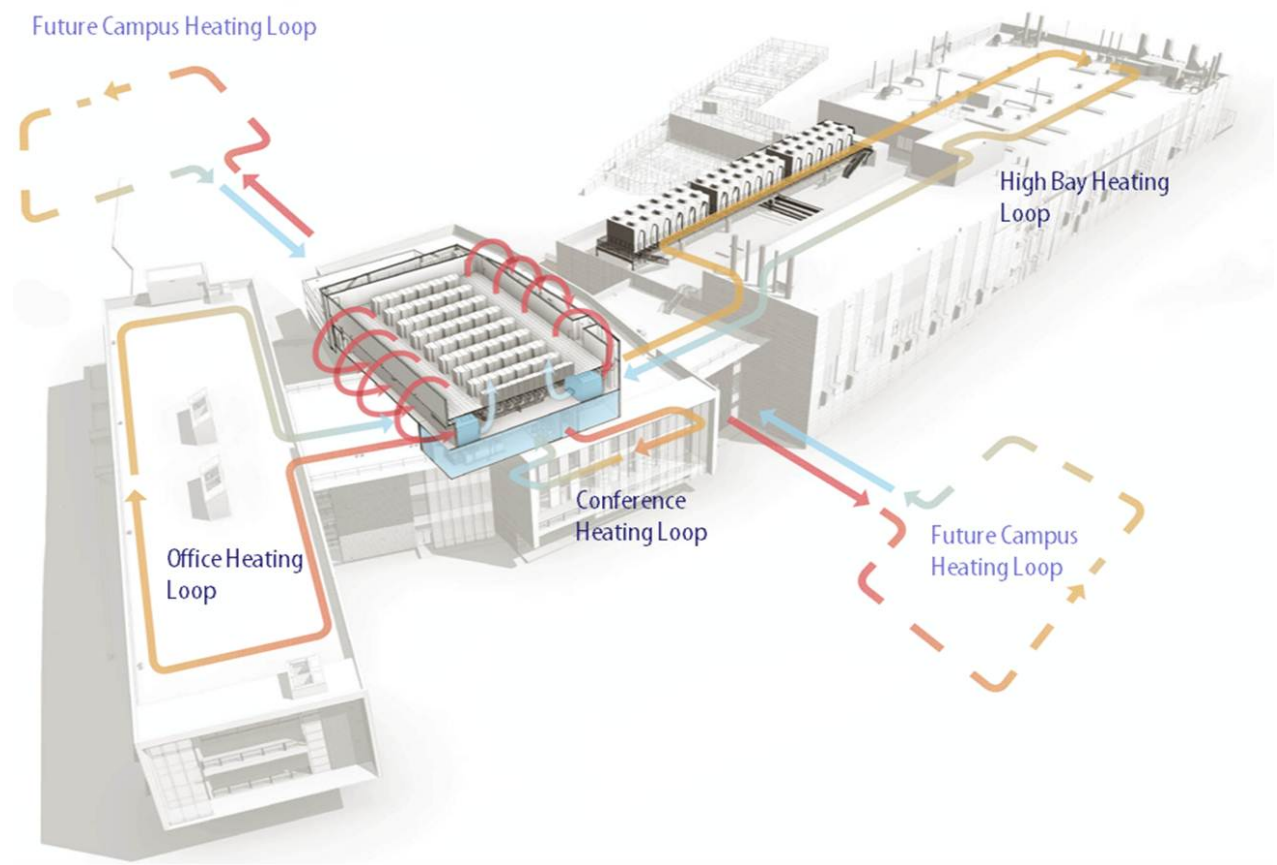| Heat Transfer		Resultant Energy Requirements			
Rate	Δ T	Heat Transfer Medium	Fluid Flow Rate	Conduit Size	Theoretical Horsepower
10 Tons	12°F	Forced Air	9217 cfm	34" Ø	3.63 Hp
		Water	20 gpm	2" Ø	.25 Hp

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!

Future Campus Heating Loop

High Bay Heating Loop

Office Heating Loop

Conference Heating Loop

Future Campus Heating Loop

Biggest challenge is <u>not</u> technical

- Data Center best practices are well documented.

- However, the total cost of ownership (TCO) rests on three legs:

  - Facilities – "owns" the building and infrastructure.

  - IT – "owns" the compute systems.

  - CFO – "owns" the capital investments and utility costs.

- Why should "Facilities" invest in efficient infrastructure if the "CFO" pays the utility bills and reaps the benefit?

- Why should "IT" buy anything different if "CFO" benefits from reduced utility costs?

- *Efficiency ROI is real and <u>all</u> stakeholders must benefit for it to work.*

- Thus, organizational alignment is key.

What have we accomplished?

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NREL Data Center

Showcase Facility

- ESIF 182,000 s.f. research facility
- Includes 10MW, 10,000 s.f. data center
- LEED Platinum Facility, PUE 1.06
- NO mechanical cooling (*eliminates expensive and inefficient chillers*).
- Use evaporative cooling only.

Utilize the bytes and the BTUs!

Data Center Features

- Direct, component-level liquid cooling (25C cooling water supply).
- 35-40C return water (waste heat), captured and used to heat offices and lab space.
- Pumps more efficient than fans.
- High voltage 480VAC power distribution directly to high power density 70-80KW compute racks.

Compared to a typical data center:
- *Lower CapEx – cost less to build*
- *Lower OpEx – efficiencies save ~$1M per year in operational expenses.*

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).
  - +95% 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.

Liquid Cooling – New Considerations
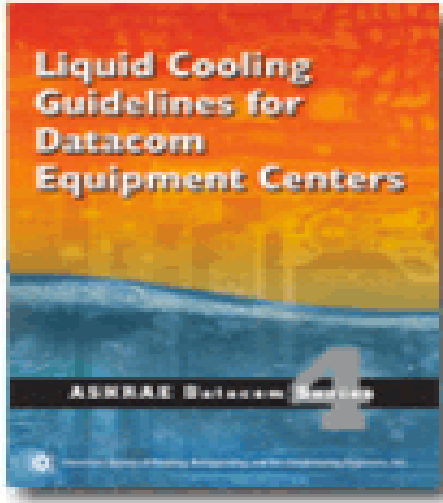
- Air Cooling:
  - Humidity, Condensation, Fan failures.
  - Cable blocks and grated floor tiles.
  - Mixing, hot spots, "top of rack" issues.

- 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.

Liquid Cooling Guidelines for Datacom Equipment Centers

ASHRAE Datacom Series

4

NREL Experience with Liquid Cooling

- ~4 years of operation, <u>zero</u> incidents
    - This includes work with engineering prototypes starting in Jan 2013.
    - Liquids in the rack, no water on the floor!
- First HP Apollo 8000 racks delivered in Sept 2013.
- "Peregrine" passed acceptance test in Nov 2013.
- In production use since Jan 2014.
- Early and ongoing engagement with prototypes was positive experience for both HP and NREL.

- *HP Apollo 8000 – Central to the World's Most Energy Efficient Data Center*

Lessons Learned

- Liquid cooling essential at high power density.
- Compatible metals and water chemistry is crucial.
- Plan for a hierarchy of systems.
  - Cooling in series rather than parallel
  - Most "sensitive" systems gets "coolest" cooling
  - Highest quality waste heat, essential for waste heat re-use.
- Requires closer cooperation between facilities and IT staff.

View in NREL Data Center Ops

What's Next?

Into the Future!
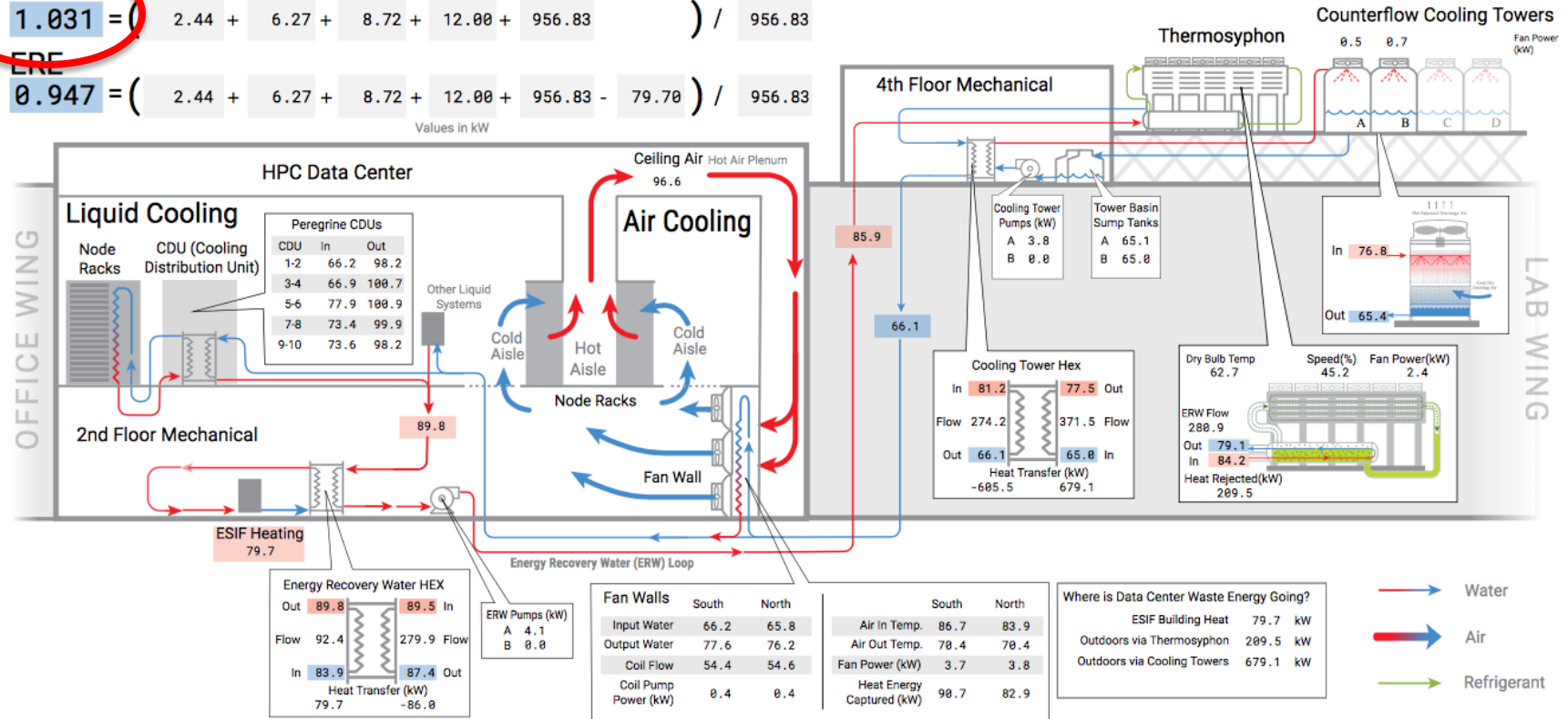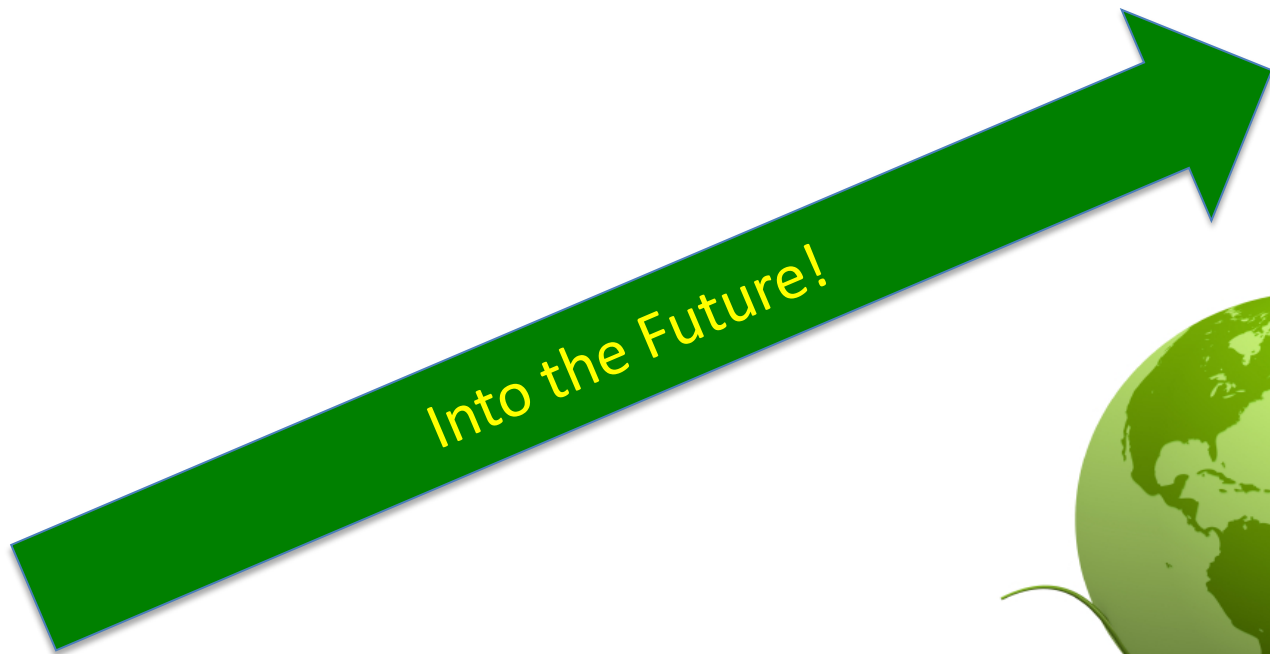
Futures: Water Efficiency

- Data center water usage, a big concern
- Evap. cooling - water demand, ~2 million gallons per MW-year
- Installed Johnson Controls thermosyphon dry cooler

- Collaboration with Sandia, compare & contrast JCI dry cooler w/ evaporative towers
- Report on tradeoffs in PUE
- Look to share best practices with community

Carbon-Free Data Center
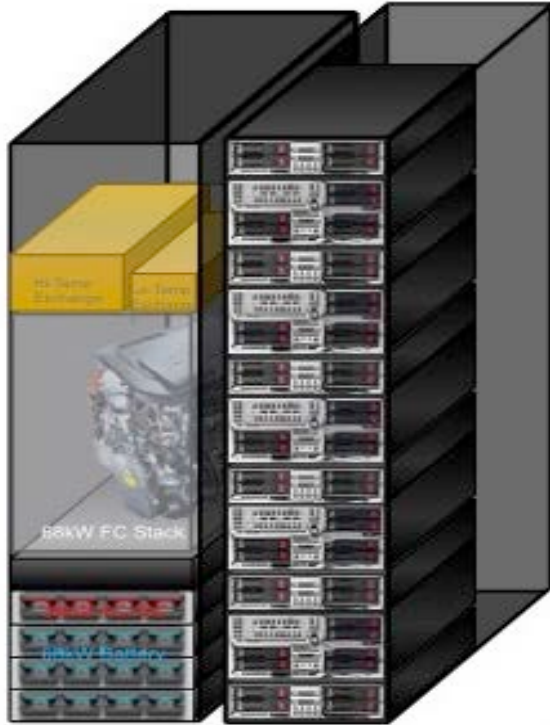
- Leverage advances & cost reductions in renewables, electrolyzers, hydrogen fuel cells – *carbon free data center* prototype.

- Just starting to investigate direct use of renewable solar power, fuel cells integrated with compute racks in the data center.

- Utilize H2 Fuel Cell generated DC directly to the rack.

- Combined heat and power: utilize 65C - 70C return water from the fuel cell for heating or cooling (adsorption chiller).
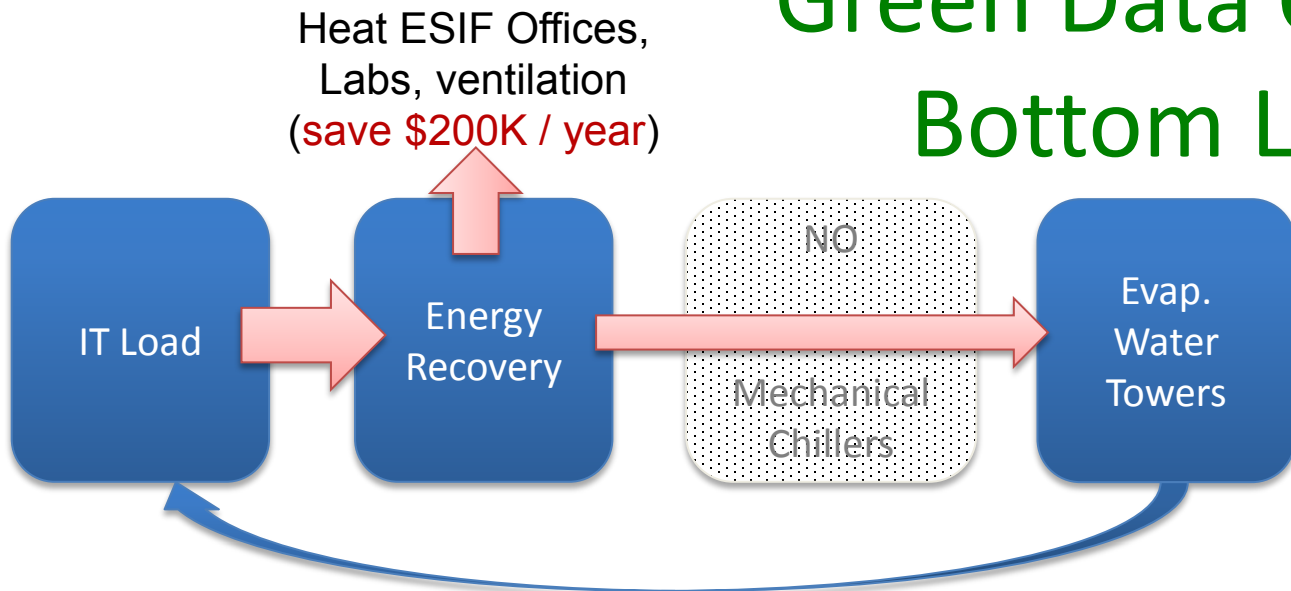
Final Thoughts

- **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_2O: Liquid cooling will be increasingly prevalent.
  - PUE of 1.0X, focus on the "1" and find creative waste heat re-use.
- **Organizational Alignment is Crucial**
  - All stake holders have to benefit – Facilities, IT, and CFO.
- **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.
  - Efficiency not enough, reduce water use and eliminate carbon footprint.

Questions?

Green Data Center Bottom Line

Heat ESIF Offices, Labs, ventilation (save $200K / year)

IT Load → Energy Recovery → NO Mechanical Chillers → Evap. Water Towers

Cost less to build
Cost less to operate

Comparison of ESIF PUE 1.06 vs efficient 1.3 data center.

| **CapEx**	**Savings**	**OpEx** (10MW IT Load)		**Utilities**
No Chillers	No Chillers	PUE of 1.3	$13M	$10.6M
Initial Build: 600 tons	$.9M	PUE of 1.06		$2.4M
10 Yr. growth: 2400 tons	$3.6M	Annual Savings		**$24M**
10-year Savings:	**$4.5M**	**10-year Savings**		*(excludes heat recovery benefit)*
($1.5K / ton)		*($1M / MW year)*		

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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| Air Cooled IT | → | CRAC | → | Liquid Cooled IT | → | Heat Rejection |
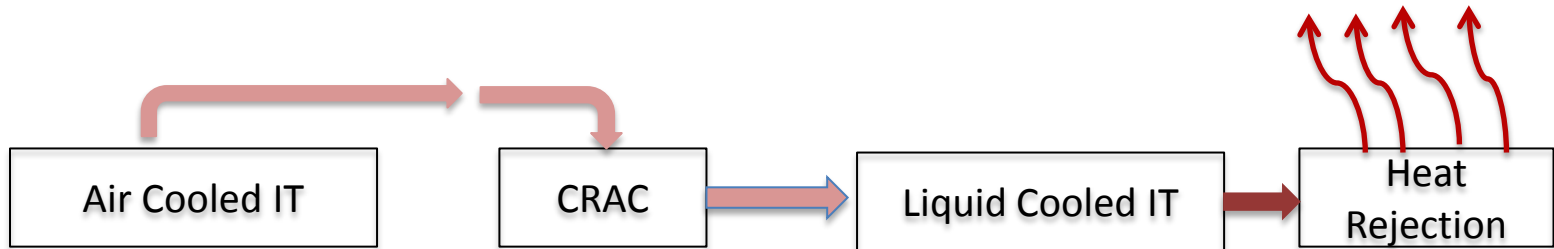
Liquid Cooling Checklist

- 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 <u>back to PDU</u>.
- Heat exchange at the heat source.
- Robust, well engineered solution.
- At least 95% of rack heat load captured directly to liquid.