SC12 ENERGY EFFICIENCY METRICS

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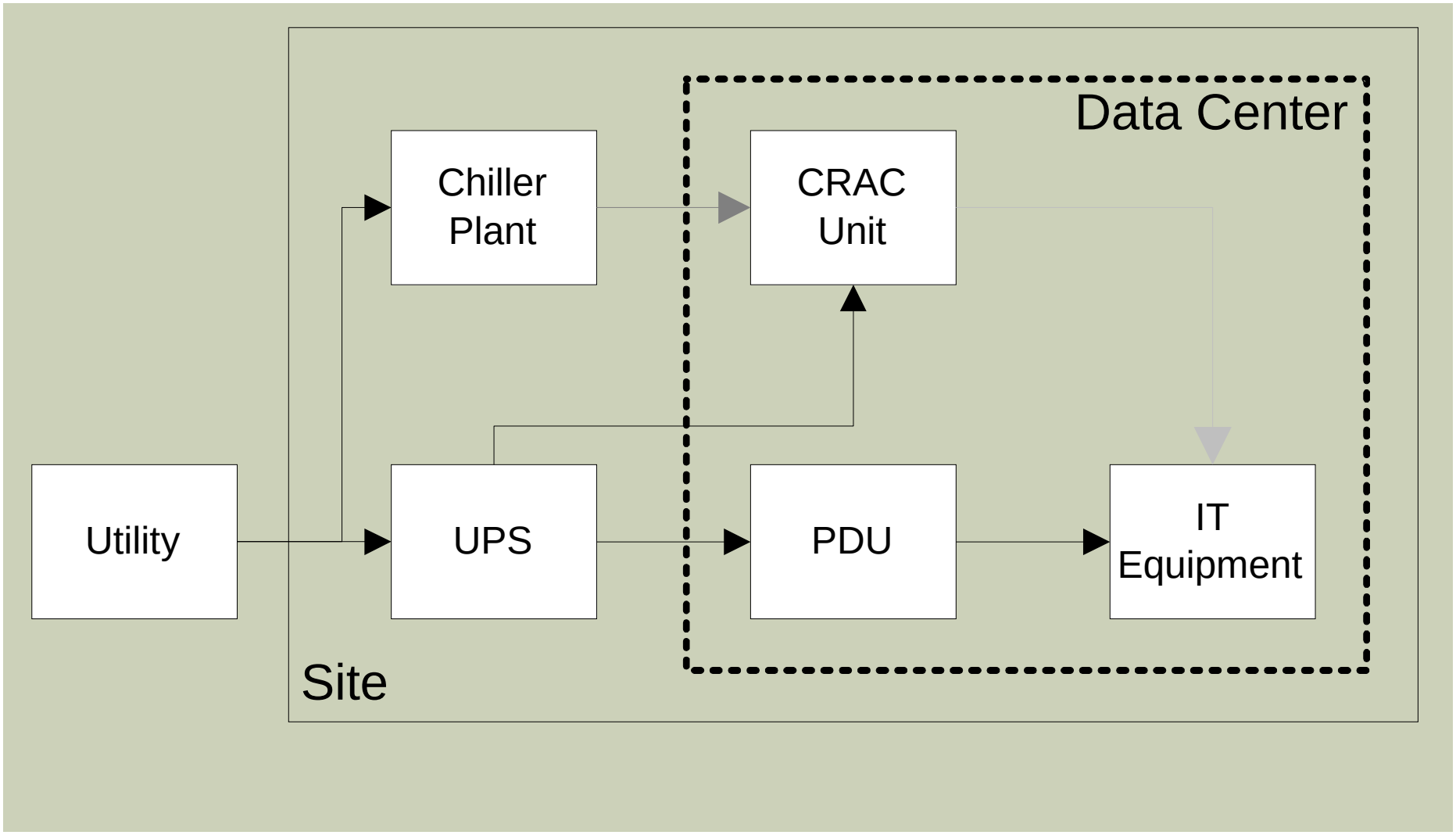
Exascale System Architecture Pathfinding

Intel Corporation

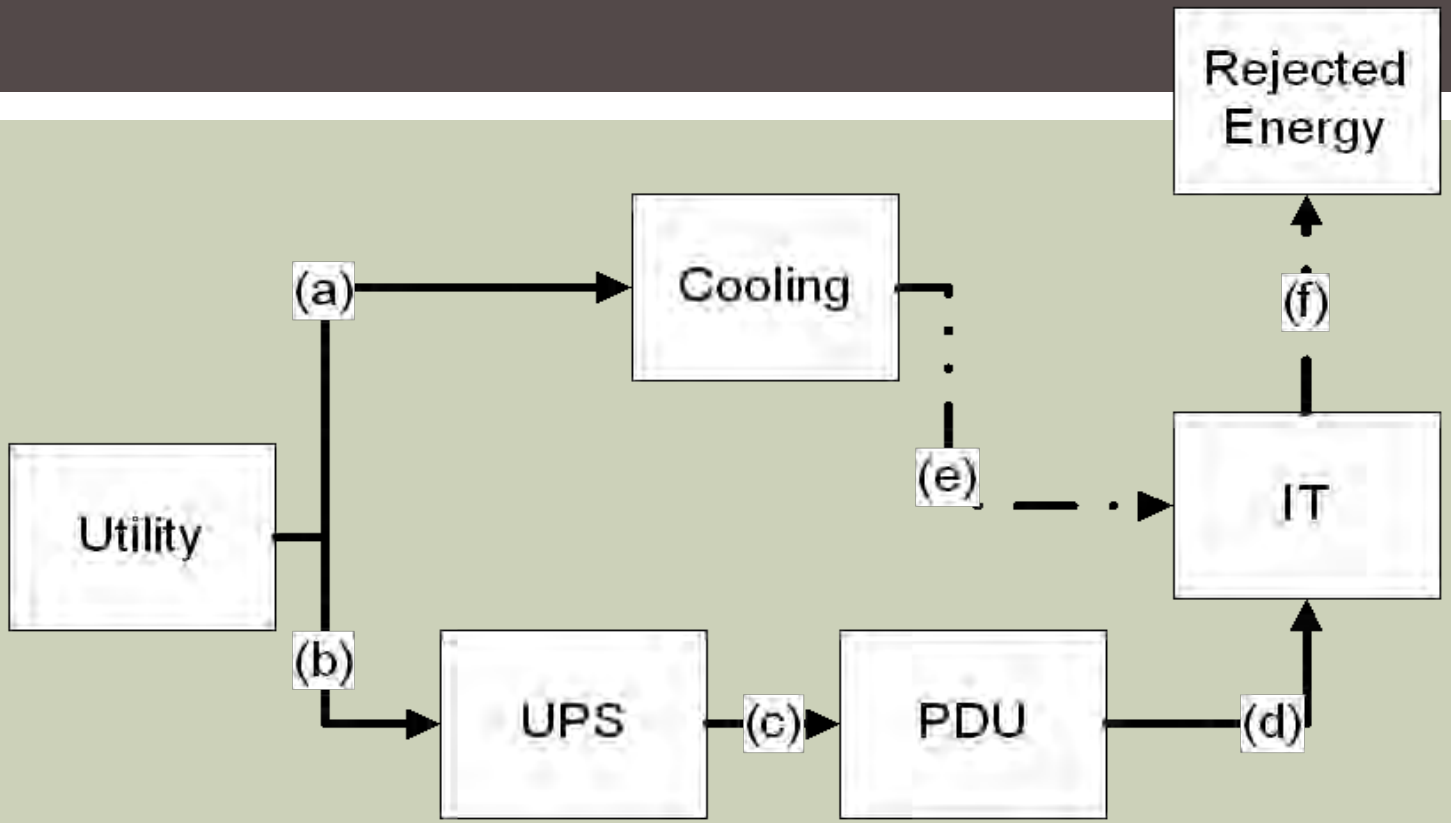
OVERVIEW

- Why Metrics?
  - We can't manage what we don't measure
  - Trends over time
  - Comparisons between clusters or data centers
- What makes a good metric?
  - a) simplicity, b) it matters, c) measureable, d) actionable
- What we will cover
  - Data Center Energy Efficiency
  - Infrastructure Specific Metrics
  - Sustainability
  - Compute Performance

THE DATA CENTER



PUE – SIMPLE AND EFFECTIVE



$$PUE = \frac{Total\ Energy}{IT\ Energy} = \frac{Cooling + PowerDistribution + Misc + IT}{IT} = \frac{a+b}{d}$$

PUE is defined in terms of total ***annual*** energy and total ***annual*** IT energy, allowing a more valid site-to-site comparison

Green Grid, ASHRAE, DOE, EPA and others agreed to detailed PUE definition

PUES: REPORTED AND CALCULATED

	PUE
Global bank's best data center (of more than 100)	2.25
EPA Energy Star Average	1.91
Intel average	>1.80
Intel Jones Farm, Hillsboro	1.41
ORNL	1.25
T-Systems & Intel DC2020 Test Lab, Munich	1.24
Google	1.16
Leibniz Supercomputing Centre (LRZ)	1.15
Containers	1.1-1.6
National Center for Atmospheric Research (NCAR)	1.10
Yahoo, Lockport	1.08
Facebook, Prineville	1.07
National Renewable Energy Laboratory (NREL)	1.06

MORE ON PUE

- Partial PUE (pPUE)
- DCiE – 1/PUE…. No longer used
- Power or Energy?
  - Both!
- Site or Source?
  - Source based, Energy conversion factors needed
  - All Electric data centers: $PUE_{source} = PUE_{site}$
- Subscripts
  - Global Harmonization has added PUE_0, PUE_1, PUE_2, PUE_3

RATING SYSTEMS

- Energy Star for Data Centers
- European Union Code of Conduct for Data Centers
- The Green Grid
- LEED
- Uptime Institute Tier Rating System
  - Tier 1 thru Tier IV

ERE DEFINITION

$$PUE = \frac{\text{Total Energy}}{\text{IT Energy}}$$

$$PUE = \frac{\text{Cooling} + \text{Power} + \text{Lighting} + \text{IT}}{\text{IT}}$$

$$ERE = \frac{\text{Total Energy} - \text{Reused Energy}}{\text{IT Energy}}$$

$$ERE = \frac{\text{Cooling} + \text{Power} + \text{Lighting} + \text{IT} - \text{Reused}}{\text{IT}}$$

ERE ALTERNATE DEVELOPMENT

Define energy reuse factor (ERF) as:

$$ERF = \frac{\text{Reuse Energy}}{\text{Total Energy}}$$

Then:

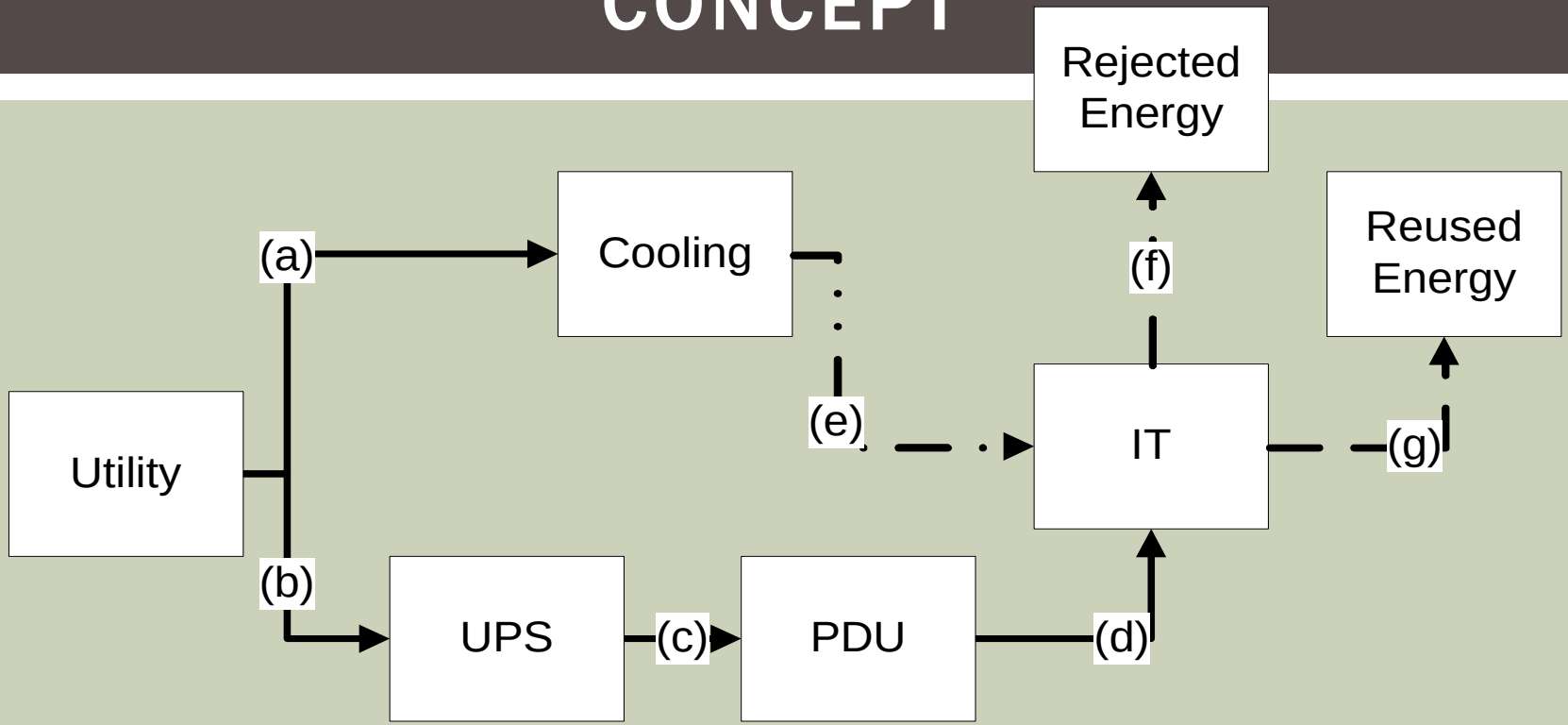
$$ERE = (1 - ERF) \times PUE$$

And finally:

$$ERE = \frac{Cool + Pwr + Light + IT - Reused}{IT} = (1 - ERF) \times PUE$$

ERF and PUE are mathematically related, but differ and need to defined and reported clearly.

ERE – ADDS ENERGY REUSE TO THE PUE CONCEPT



$$ERE = \frac{Total\ Energy - Reuse\ Energy}{IT\ Energy}$$

$$= \frac{Cooling + PowerDistribution + Misc + IT - Reuse}{IT} = \frac{a + b - g}{d}$$

WATER AND CARBON – INCREASING FOCUS ON SUSTAINABILITY

- Two new metrics for Data Center sustainability
- Published by The Green Grid
- Development of the Metrics will give better focus on Data Center sustainability

CUE – CARBON USAGE EFFECTIVENESS

$$PUE = \frac{Total\ Facility\ Energy}{IT\ Energy}$$

$$CUE = \frac{Total\ CO\ emissions\ caused\ by\ the\ Total\ Data\ Center\ Energy}{IT\ Energy}$$

CUE ~ $kgCO_2eq/kWh$

Includes scope 1 and scope 2, but not scope 3

WUE – WATER USAGE EFFECTIVENESS

$$PUE = \frac{Total\ Facility\ Energy}{IT\ Energy}$$

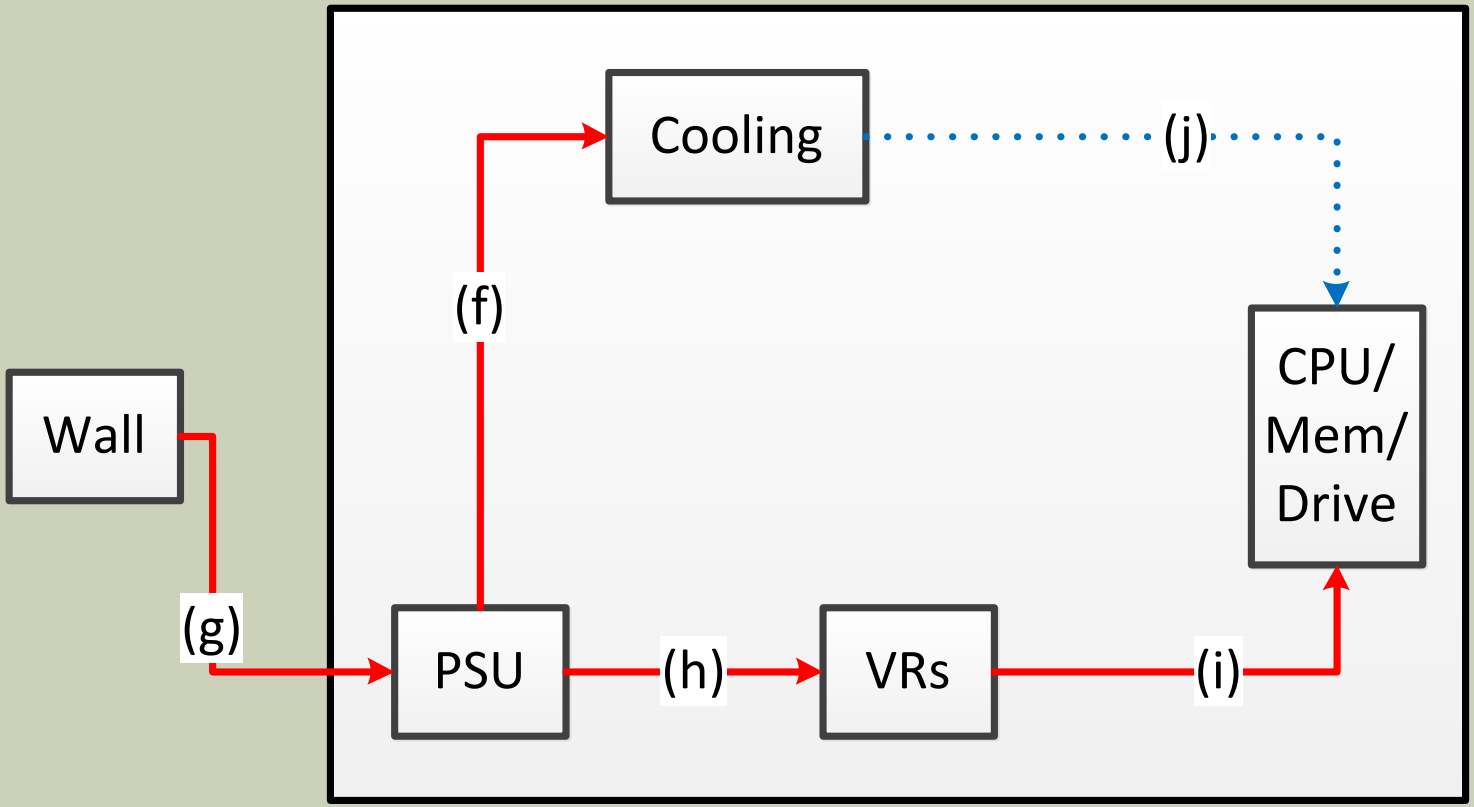
$$WUE = \frac{Annual\ Site\ Water\ Usage}{IT\ Energy}$$

$$WUE_{source} = \frac{Annual\ Source\ Energy\ Water\ Usage + Annual\ Site\ Water\ Usage}{IT\ Energy}$$

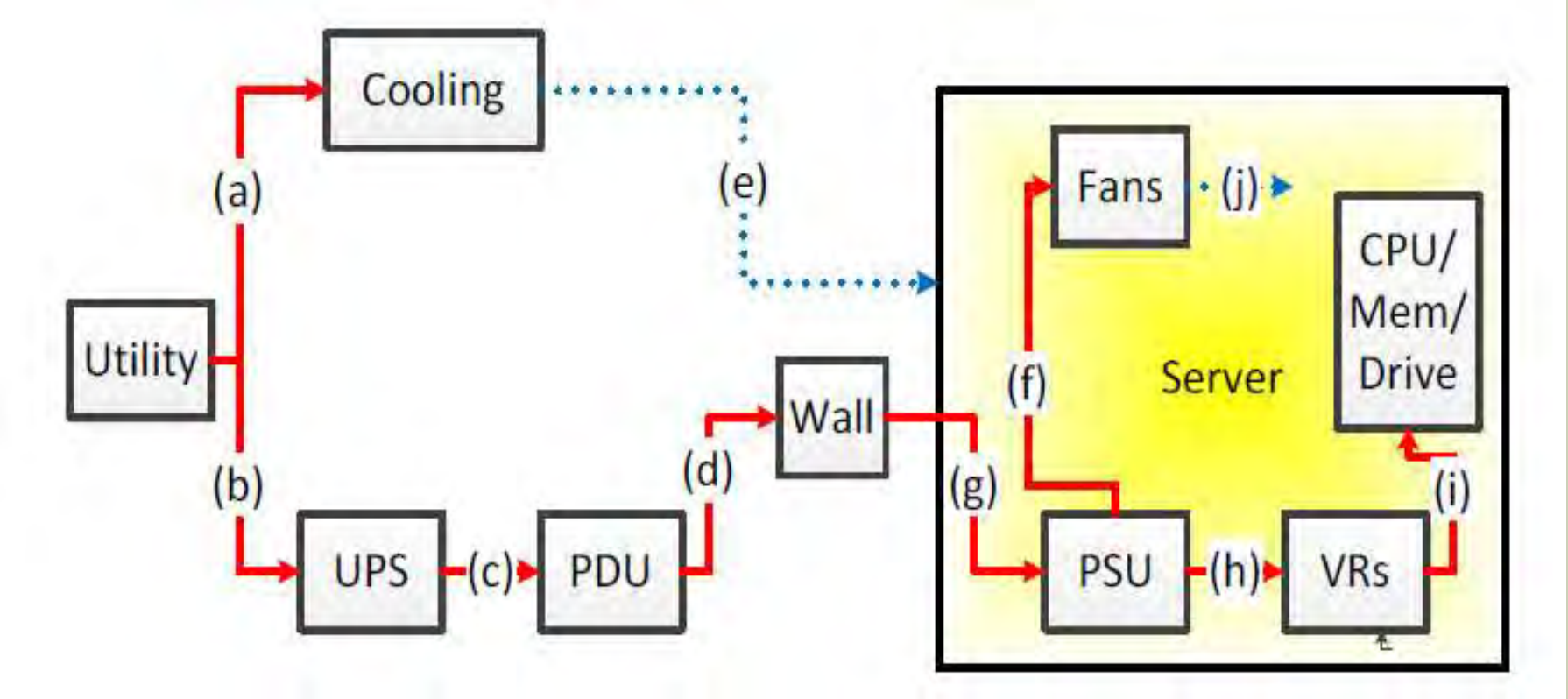
WUE ~ Liters/kWh

ITUE

$$ITUE = \frac{total\ energy\ into\ the\ IT\ equipment}{total\ energy\ into\ the\ compute\ components} = \frac{i}{g}$$



TUE



$$PUE = \frac{Total\ Energy}{IT\ Energy} = \frac{a+b}{d}$$

$$ITUE = \frac{Total\ Energy}{Compute\ Energy} = \frac{g}{i}$$

$$TUE = ITUE \times PUE = \frac{a+b}{i}$$

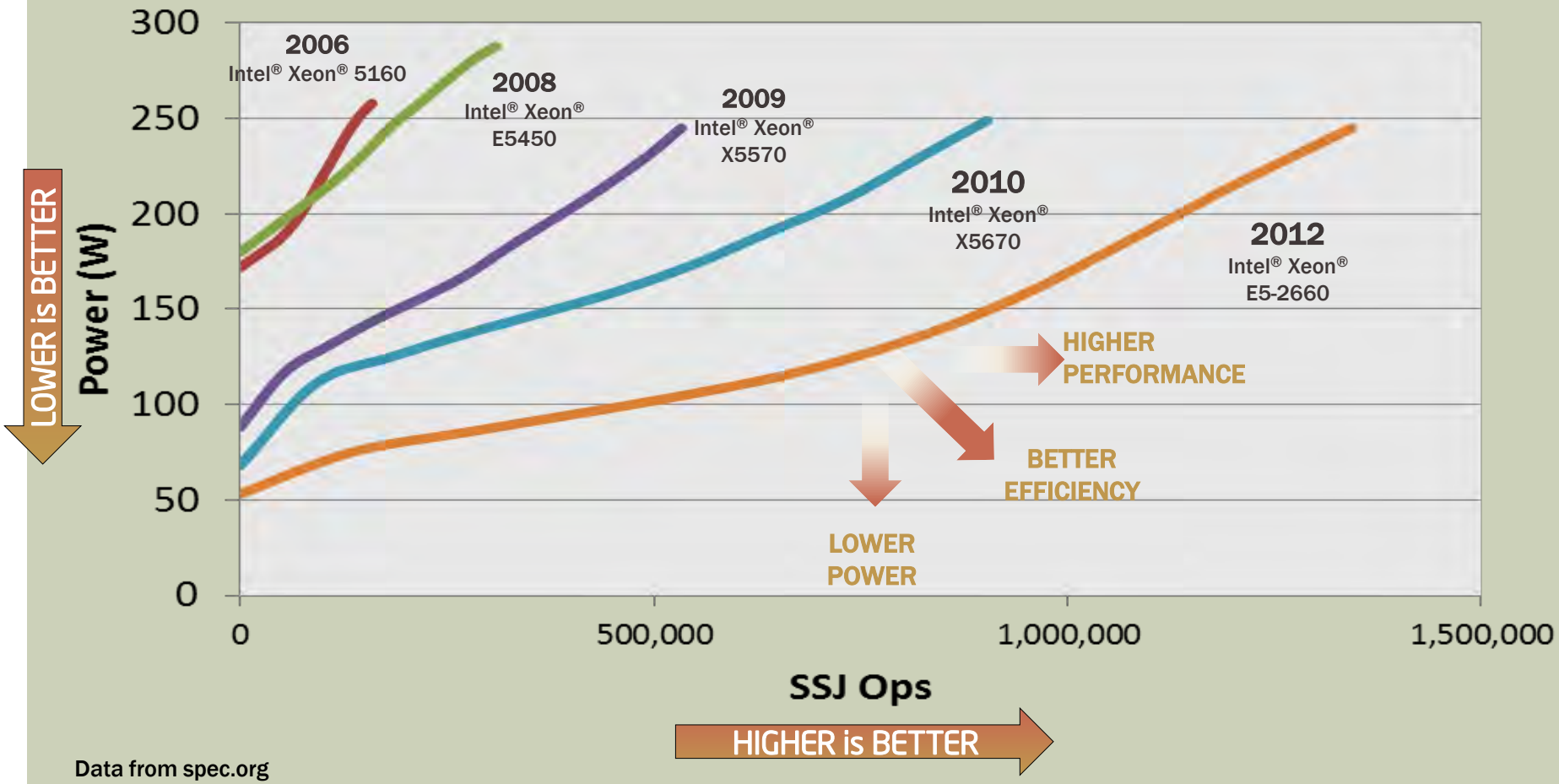
INFRASTRUCTURE METRICS

- Power / area – (W / sq. ft. or W / m^2)
- Power / rack – (kW / rack)
- Cost / area – ($ / sq. ft., € /m^2)
- Cost / power - ($ /kW, € /kW)
- Area/Area – Data Center "white space" / Infrastructure space
- Cost/Cost – Data Center / IT equipment
- Percentage of cost - % of each Civil/Structural/Architectural (CSA), Power, and Cooling
- Cost/Cost – Operational cost / purchase cost
- Area/Rack – sq ft / rack

COMPUTE EFFICIENCY

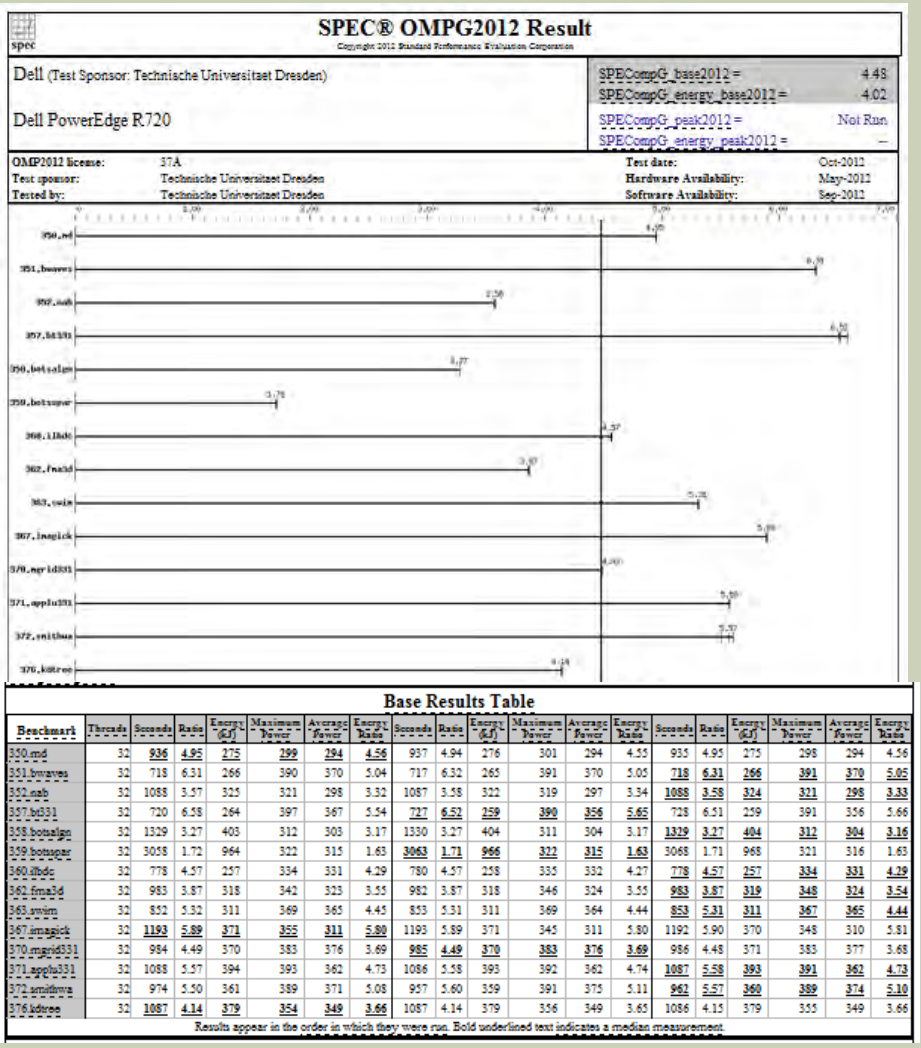
- We need a miles-per-gallon metric for compute efficiency
- Recall: what makes a good metric?
  - a) simplicity, b) it matters, c) measureable, d) actionable
- We have had decent ways to measure “miles” but the “gallons” have been missing
- Good recent progress. Let’s review….

SPECPOWER



Data from spec.org

SPEC OMP2012



SPEC® OMPG2012 Result

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Dell (Test Sponsor: Technische Universitaet Dresden)

Dell PowerEdge R720

SPECompG_base2012 = 4.48
SPECompG_energy_base2012 = 4.02
SPECompG_peak2012 = Not Run
SPECompG_energy_peak2012 = --

OMP2012 license: 37A
Test sponsor: Technische Universitaet Dresden
Tested by: Technische Universitaet Dresden

Test date: Oct-2012
Hardware Availability: May-2012
Software Availability: Sep-2012

Base Results Table

Benchmark	Threads	Seconds	Ratio	Energy (kJ)	Maximum Power	Average Power	Energy Ratio	Seconds	Ratio	Energy (kJ)	Maximum Power	Average Power	Energy Ratio	Seconds	Ratio	Energy (kJ)	Maximum Power	Average Power	Energy Ratio
350.md	32	936	4.95	275	299	294	4.56	937	4.94	276	301	294	4.55	935	4.95	275	298	294	4.56
351.bwaves	32	718	6.31	266	390	370	5.04	717	6.32	265	391	370	5.05	718	6.31	266	391	370	5.05
352.nab	32	1088	3.57	325	321	298	3.32	1087	3.58	322	319	297	3.34	1088	3.58	324	321	298	3.33
357.bt331	32	720	6.58	264	397	367	5.54	727	6.52	259	390	356	5.65	728	6.51	259	391	356	5.66
358.botsalgn	32	1329	3.27	403	312	303	3.17	1330	3.27	404	311	304	3.17	1329	3.27	404	312	304	3.16
359.botsspar	32	3058	1.72	964	322	315	1.63	3063	1.71	966	322	315	1.63	3068	1.71	968	321	316	1.63
360.ilbdc	32	778	4.57	257	334	331	4.29	780	4.57	258	335	332	4.27	778	4.57	257	334	331	4.29
362.fma3d	32	983	3.87	318	342	323	3.55	982	3.87	318	346	324	3.55	983	3.87	319	348	324	3.54
363.swim	32	852	5.32	311	369	365	4.45	853	5.31	311	369	364	4.44	853	5.31	311	367	365	4.44
367.imagick	32	1193	5.89	371	355	311	5.80	1193	5.89	371	345	311	5.80	1192	5.90	370	348	310	5.81
370.mgrid331	32	984	4.49	370	383	376	3.69	985	4.49	370	383	376	3.69	986	4.48	371	383	377	3.68
371.applu331	32	1088	5.57	394	393	362	4.73	1086	5.58	393	392	362	4.74	1087	5.58	393	391	362	4.73
372.smithwa	32	974	5.50	361	389	371	5.08	957	5.60	359	391	375	5.11	962	5.57	360	389	374	5.10
376.kdtree	32	1087	4.14	379	354	349	3.66	1087	4.14	379	356	349	3.65	1086	4.15	379	355	349	3.66

Results appear in the order in which they were run. Bold underlined text indicates a median measurement.

- SPEC OMP2012 updated from previous metrics (SPEC OMP2001)
- SPEC OMP2012 adds SPECpower power measuring tools and methods (Perf/Watt)
- Open MP – runs on shared memory systems
- BoF: Tuesday, 5:30-7:30, Room 155-B, *SPEC HPG Benchmarks For Next Generation Systems*
- http://www.spec.org/omp2012/

PERFORMANCE PER WATT FOR HPC

$$\varepsilon = \frac{Perf}{Watt}$$

- EEHPC WG working on the denominator
  - How do we measure the energy used in the benchmark run?
- Version 2 Beta-testing completed by a range of participating HPC Centers
- The Green Grid is a collaborator
- Working with Top 500, Green 500, and Green Graph 500
- BoF: Wednesday, 12:15-1:15, Room 250-AB, *Setting Trends for Energy Efficiency*
- http://eehpcwg.lbl.gov/

THANK YOU FOR YOUR ATTENTION

Questions?