A Computer Scientist Looks at the Energy Problem

Randy H. Katz
University of California, Berkeley

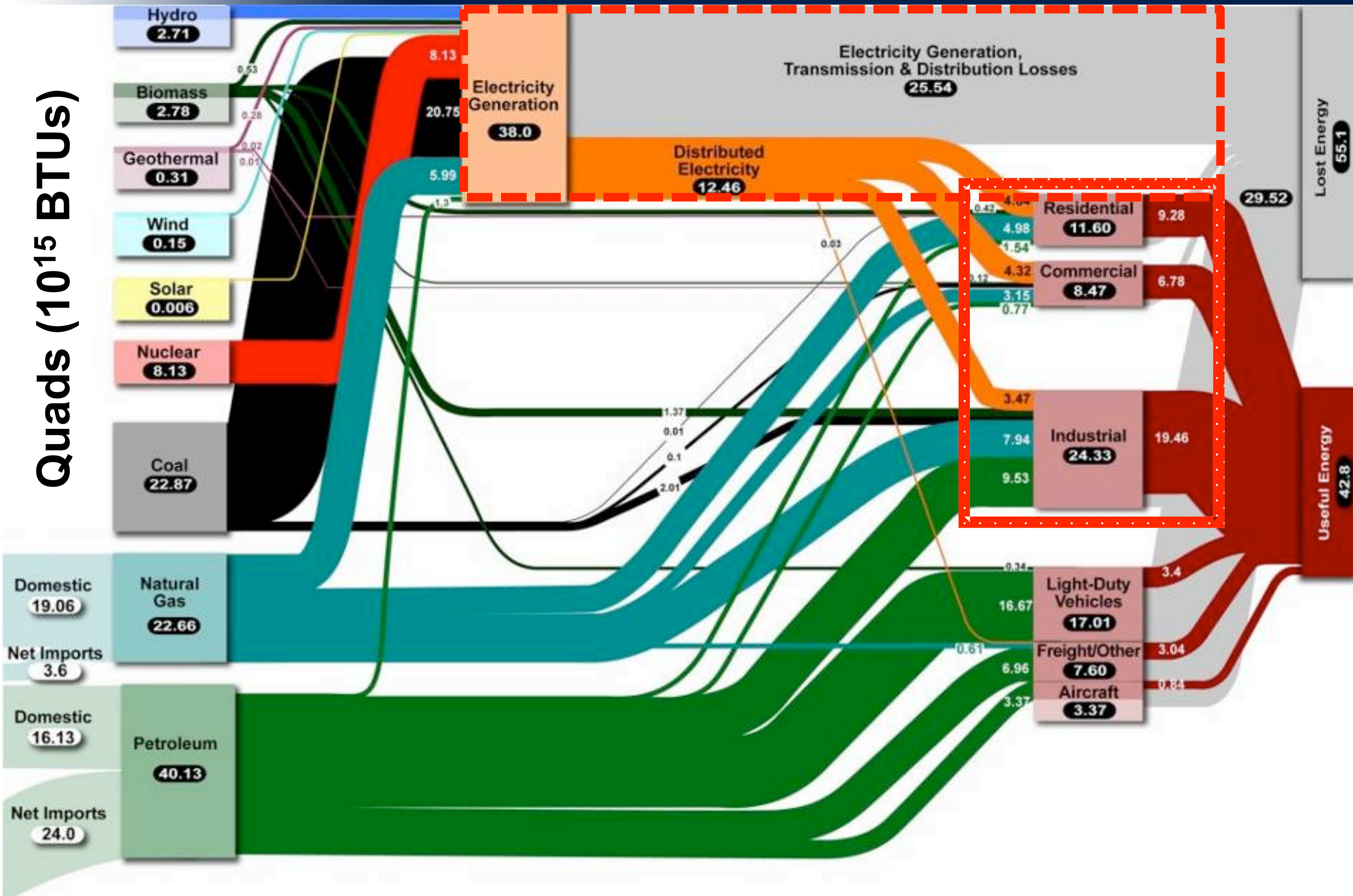
Usenix Technical Symposium
San Diego, CA
June 19, 2009

"Energy permits things to exist; information, to behave purposefully."
W. Ware, 1997

Agenda

- The Big Picture
- IT as an Energy Consumer
- IT as an Efficiency Enabler
- Summary and Conclusions

Energy "Spaghetti" Chart



Electricity is the Heart of the Energy Economy

Energy Policy & the Environment Report

October 2008

The Million-Volt Answer to Oil

by Peter W. Huber

EXECUTIVE SUMMARY

Electricity—not oil—is the heart of the U.S. energy economy. Power plants consume as much raw energy as oil delivers to all our cars, trucks, planes, homes, factories, offices, and chemical plants. Because big power plants operate very efficiently, they also deliver much more useful power than car engines and small furnaces. Electricity is comparatively cheap, we have abundant supplies and reliable access to the fuels we use to generate it, and the development of wind, solar, and other renewables will only expand our homegrown options. Our capital-intensive, technology-rich electrical infrastructure also keeps getting smarter and more efficient. With electricity, America controls its own destiny.

From the beginning, electricity has progressively displaced other forms of energy where factories, offices, and ordinary people end up using it day to day. Electrification has been propelled not by government mandates or subsidies but by normal market forces and rapid innovation in technologies that turn electricity into heat and motion. Over 60 percent of our GDP now comes from industries and services that run on electricity, and over 85 percent of the growth in U.S. energy demand since 1980 has been supplied by electricity. And the electrification of the U.S. economy isn't over. Electrically powered heaters, microwave systems, and lasers outperform oil- and gas-fired ovens in manufacturing and industrial applications, and with the advent of plug-in hybrids, electricity is now poised to begin squeezing oil out of the transportation sector.

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IN THE PRESS

New National Transmission Grid Needed, But Capital Will Be Scarce, Experts Suggest, Lynn Garner, *BNA Daily Report for Executives*, 10-15-08 (subscription required)

High-Voltage Interstate Transmission Gaining Support, But Major Hurdles Remain, *Energy Washington Week*, 10-16-08

The U.S. needs a new electrical grid, *Instapundit*, 10-15-08

Political Momentum Grows For US National Transmission Grid, Ian Talley, *Dow Jones Newswires*, 10-14-08

Concept of nationwide transmission grid with FERC siting role gains support , Kathleen Hart, *SNL Daily*, 10-14-08

A Different Kind of U.S. Power, *U.S. News & World Report*, 10-15-08

The Big Switch: Clouds + Smart Grids

Computing *as* a Utility

Energy Efficient Computing

Embedded Intelligence in Civilian Infrastructures

Large-scale industrialization of computing

Computing *in* the Utility

Energy + Information Flow = Third Industrial Revolution

Jeremy Rifkin

"The coming together of ***distributed communication technologies and distributed renewable energies via an open access, intelligent power grid***, represents "power to the people". For a younger generation that's growing up in a less hierarchical and more networked world, the ability to produce and share their own energy, like they produce and share their own information, in an open access intergrid, will seem both natural and commonplace."

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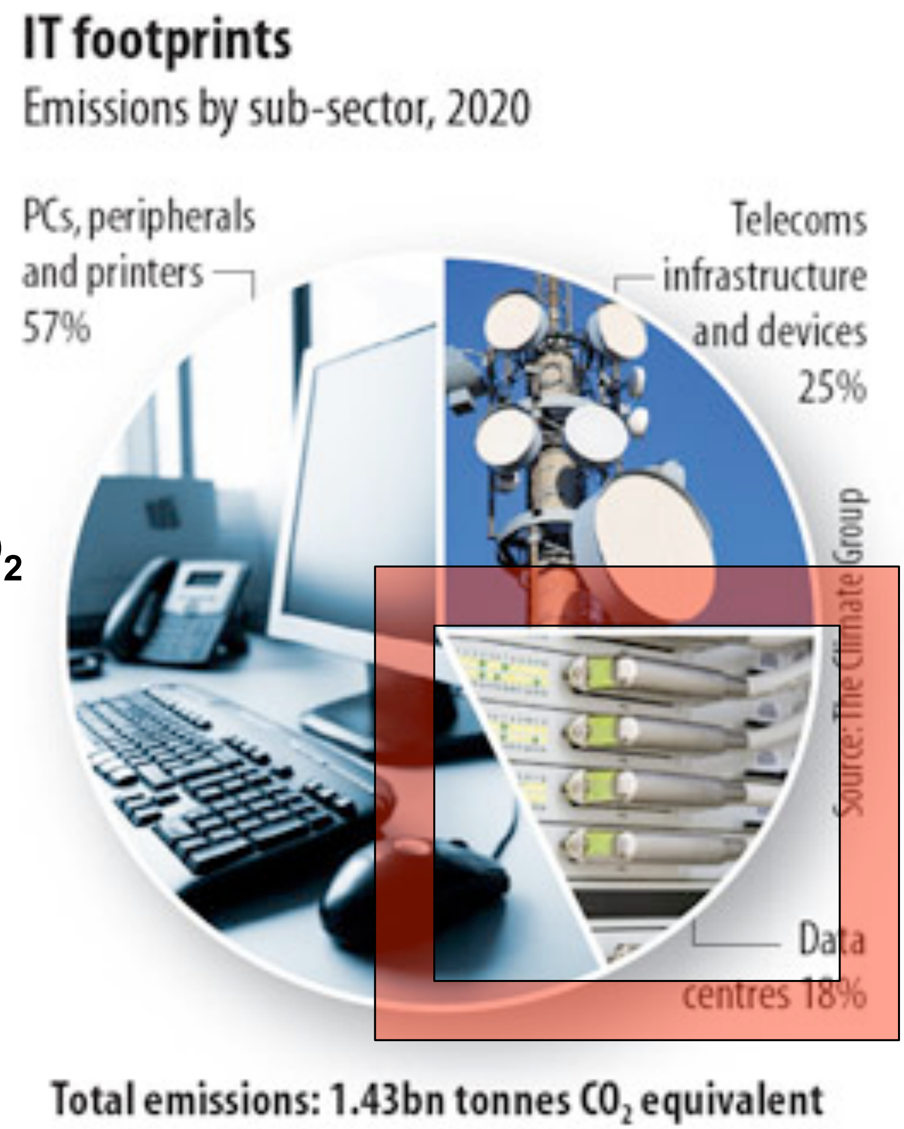
2020 IT Carbon Footprint

820m tons CO_2

360m tons CO_2



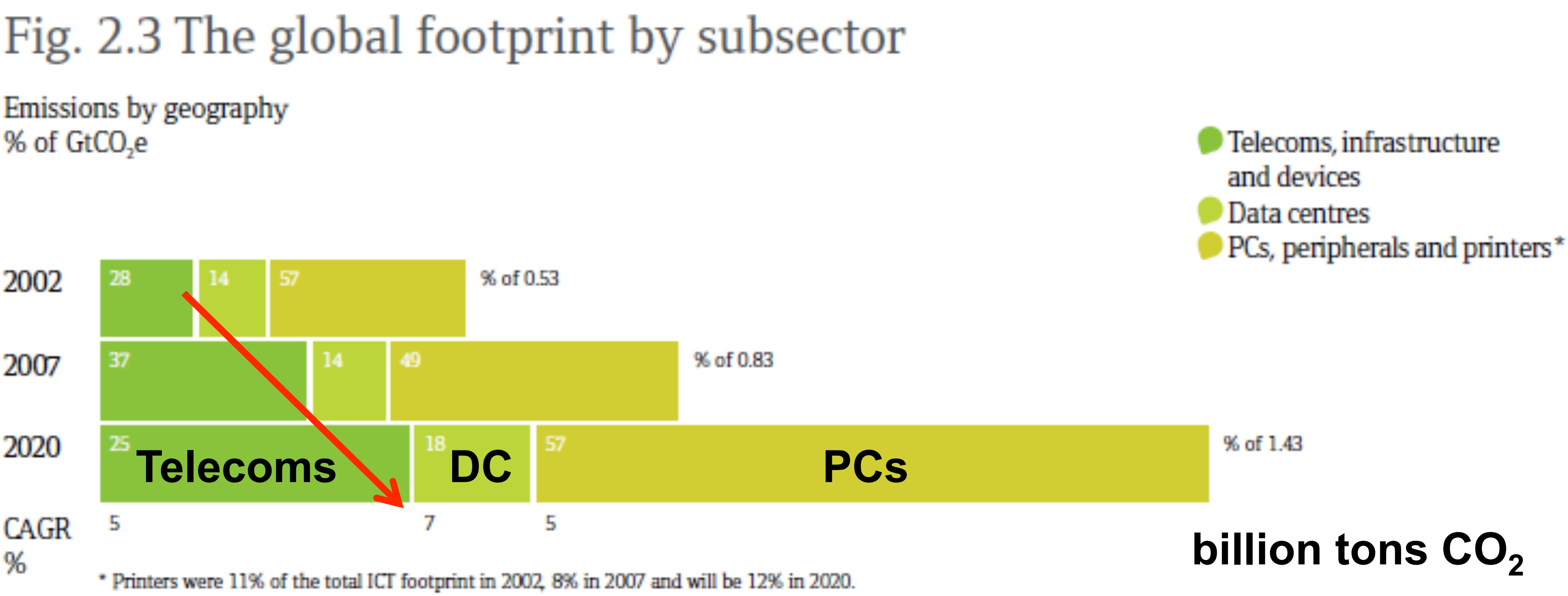
2007 Worldwide IT carbon footprint: 2% = 830 m tons CO_2 Comparable to the global aviation industry

Expected to grow to 4% by 2020

260m tons CO_2

2020 IT Carbon Footprint

"SMART 2020: Enabling the Low Carbon Economy in the Information Age", The Climate Group

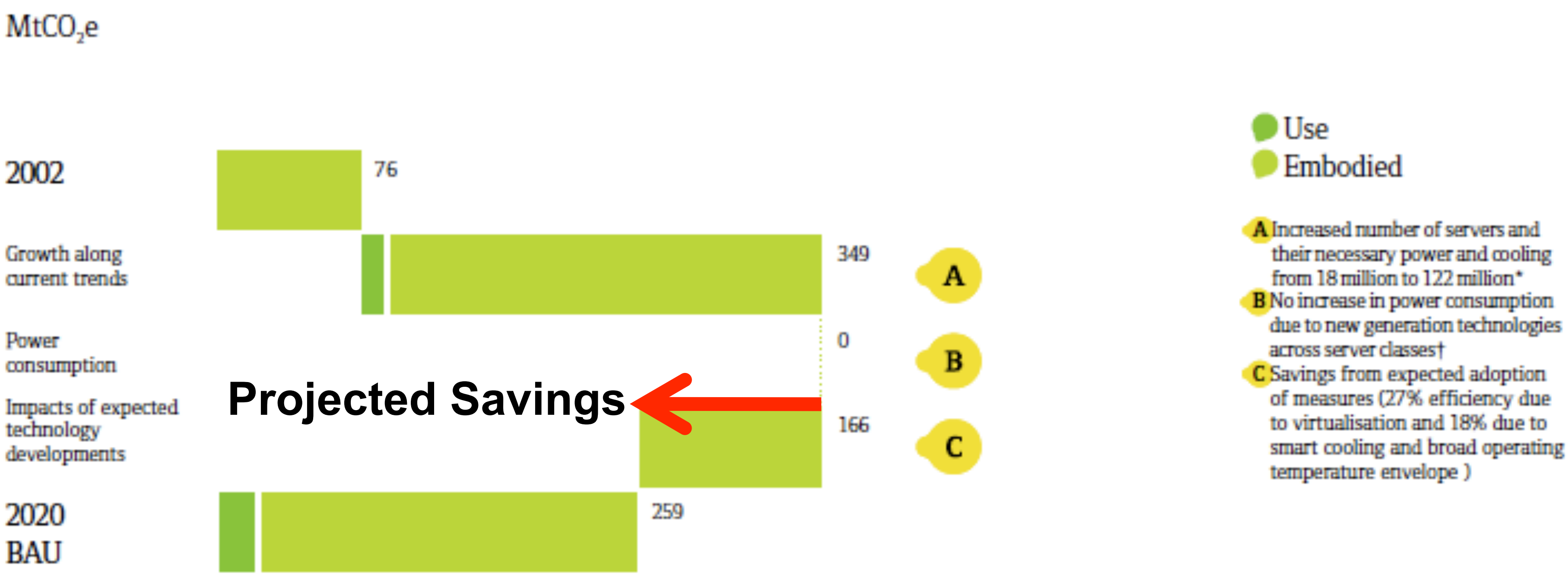


Datacenters: Owned by single entity interested in reducing opex

2020 IT Carbon Footprint

"SMART 2020: Enabling the Low Carbon Economy in the Information Age", The Climate Group

Fig. 4.1 The global data centre footprint



*Based on IDC estimates until 2011 and trend extrapolation to 2020, excluding virtualisation.
†Power consumption per server kept constant over time.

Energy Proportional Computing

"The Case for Energy-Proportional Computing,"
Luiz André Barroso,
Urs Hölzle,
IEEE Computer
December 2007

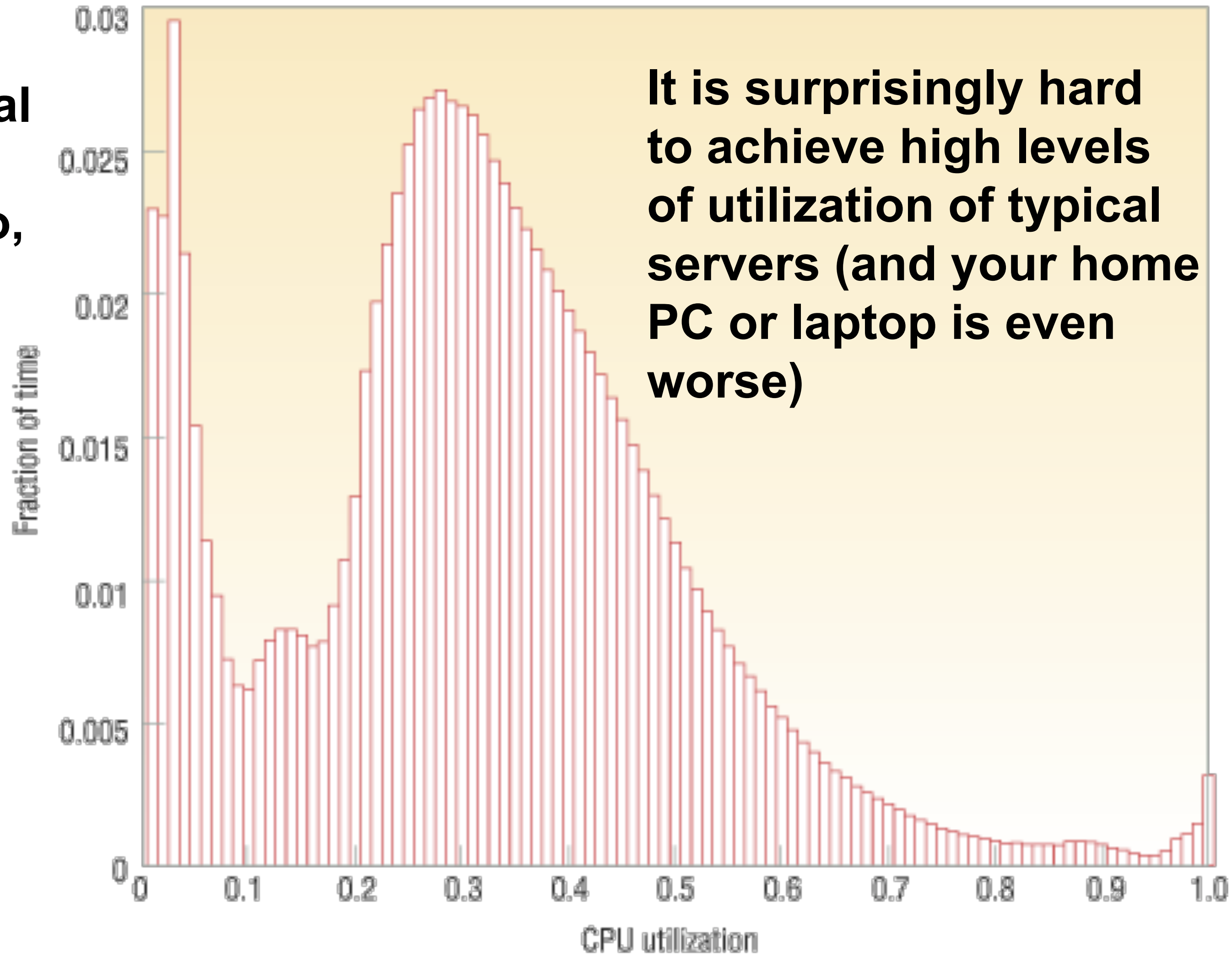


Figure 1. Average CPU utilization of more than 5,000 servers during a six-month period. Servers are rarely completely idle and seldom operate near their maximum utilization, instead operating most of the time at between 10 and 50 percent of their maximum

Energy Proportional Computing

“The Case for Energy-Proportional Computing,”
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Energy Efficiency = Utilization/Power

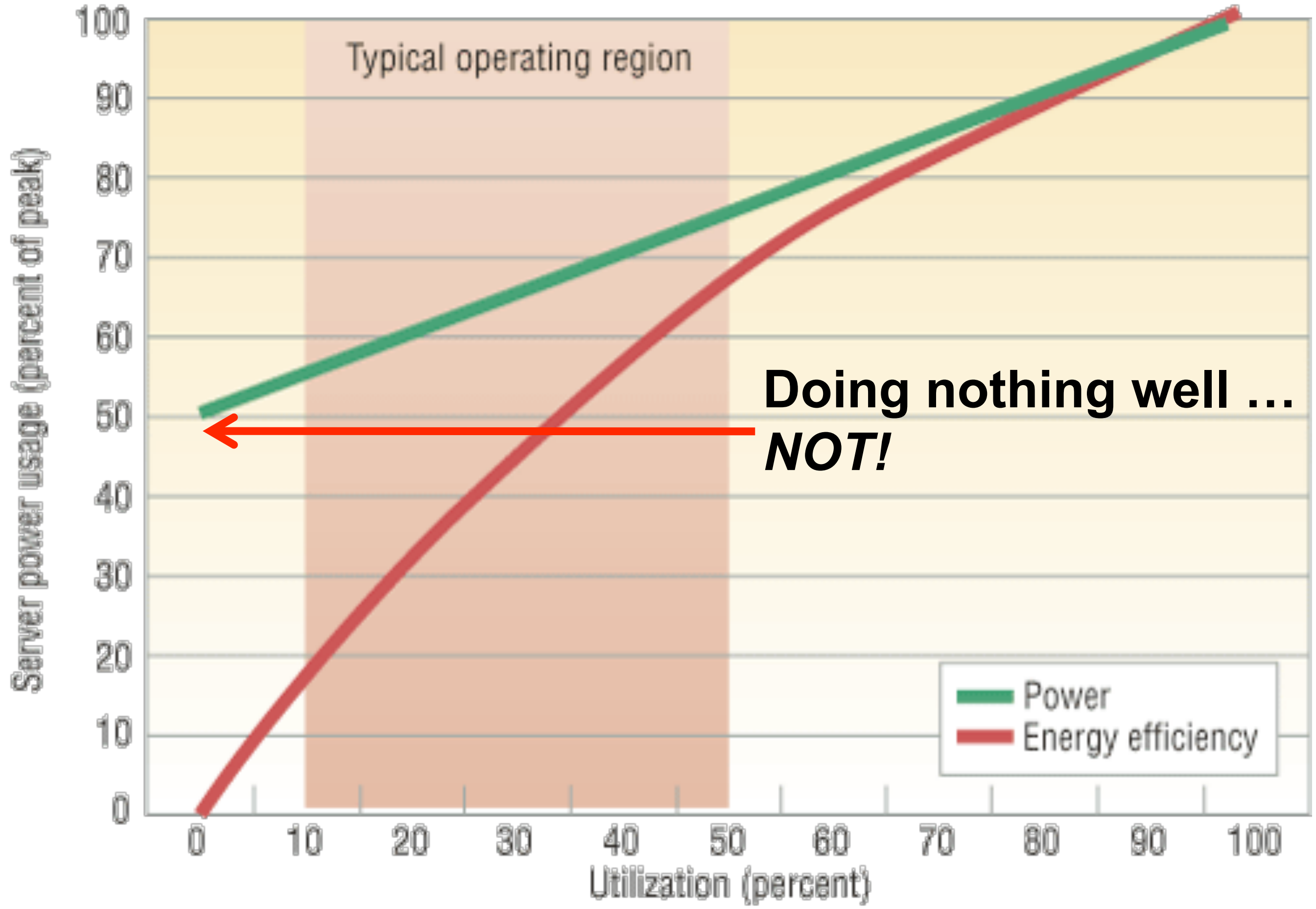

Figure 2. Server power usage and energy efficiency at varying utilization levels, from idle to peak performance. Even an energy-efficient server still consumes about half its full power when doing virtually no work.

Energy Proportional Computing

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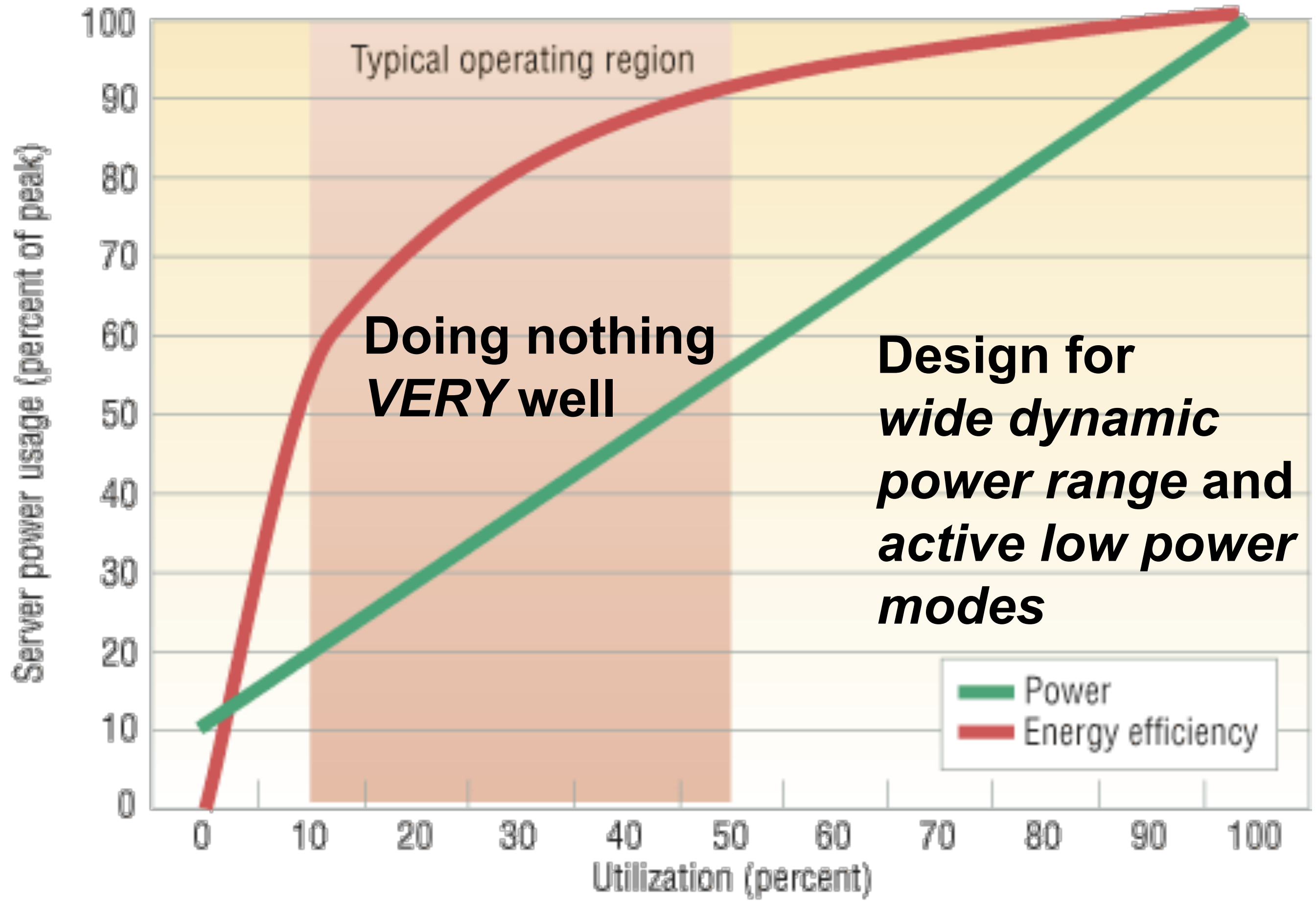
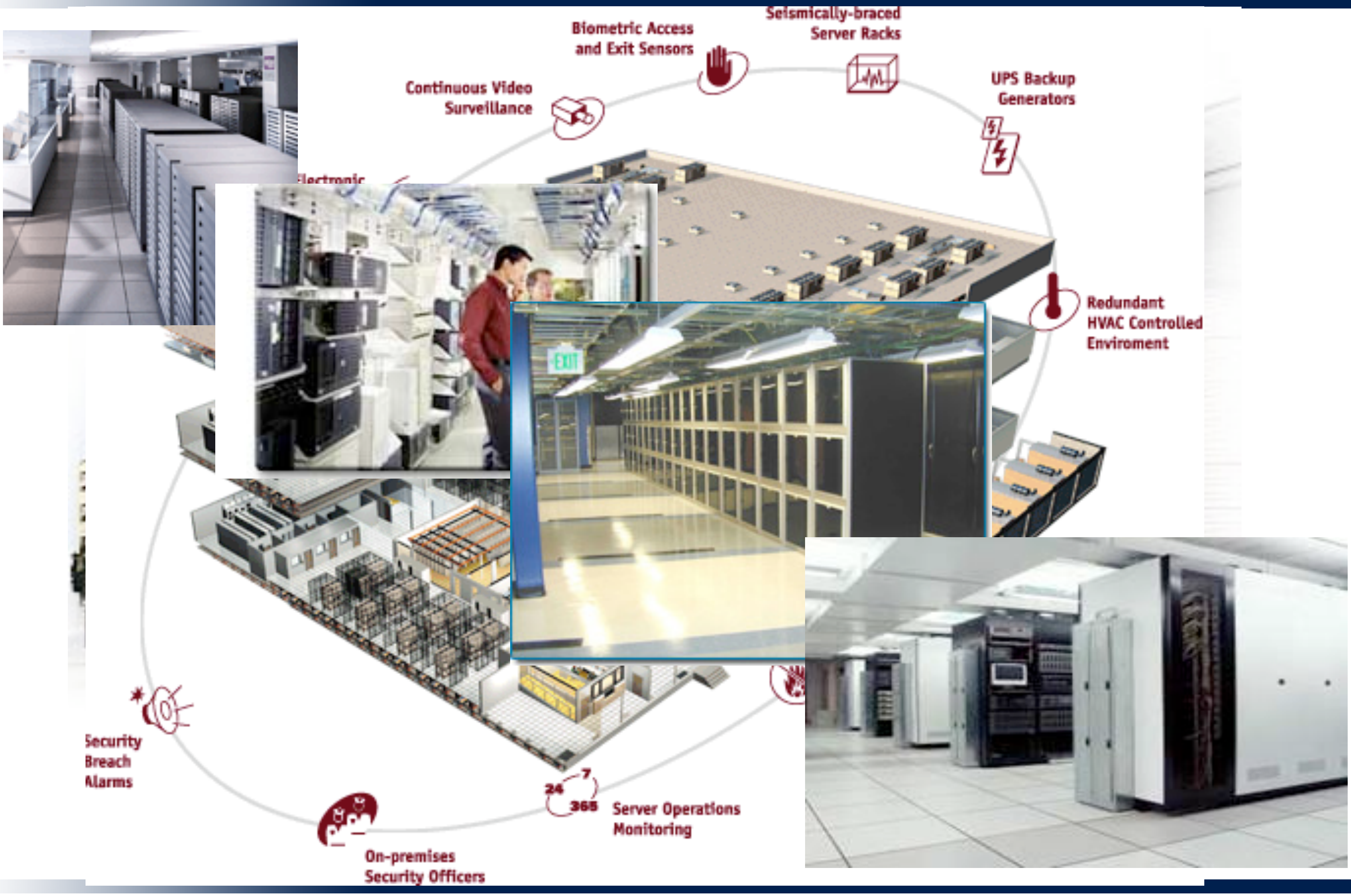
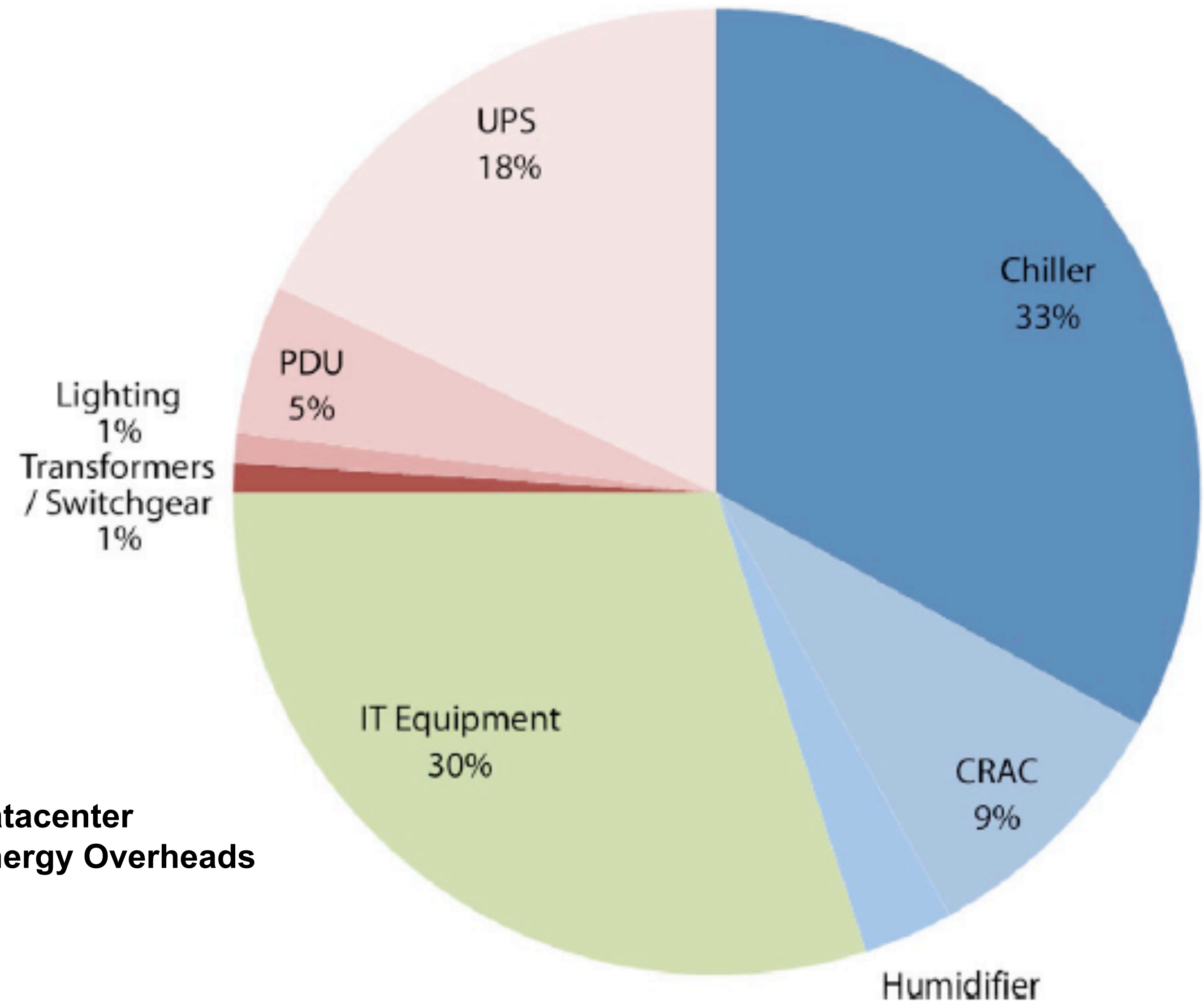


Figure 4. Power usage and energy efficiency in a more energy-proportional server. This server has a power efficiency of more than 80 percent of its peak value for utilizations of 30 percent and above, with efficiency remaining above 50 percent for utilization levels as low as 10 percent.

Internet Datacenters



Energy Use In Datacenters



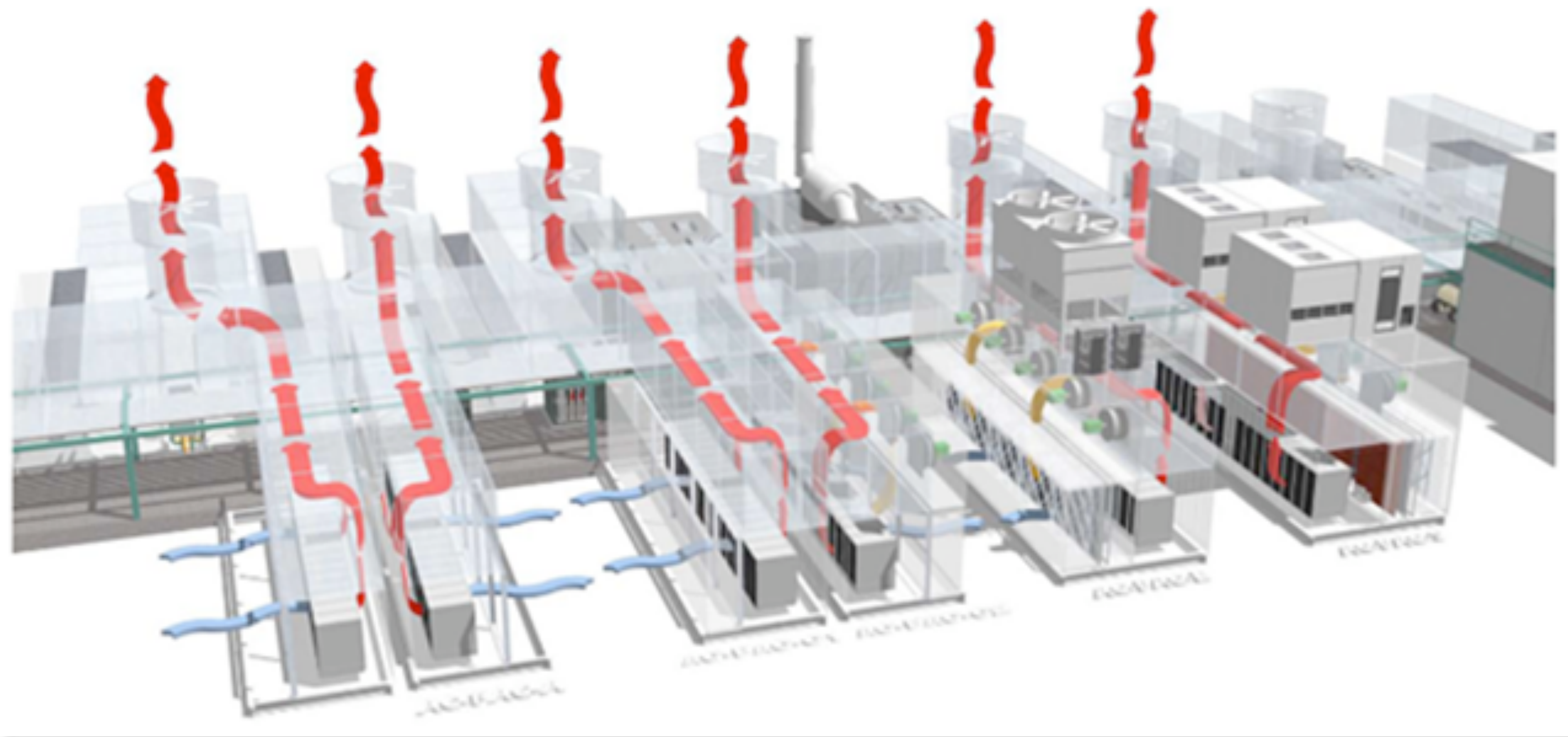
Datacenter
Energy Overheads

Cumulative power

BNL

DC Infrastructure Energy Efficiencies

Cooling (Air + Water movement) + Power Distribution



Containerized Datacenter Mechanical-Electrical Design

Microsoft Chicago Datacenter

Power Usage Effectiveness Rapidly Approaching 1!

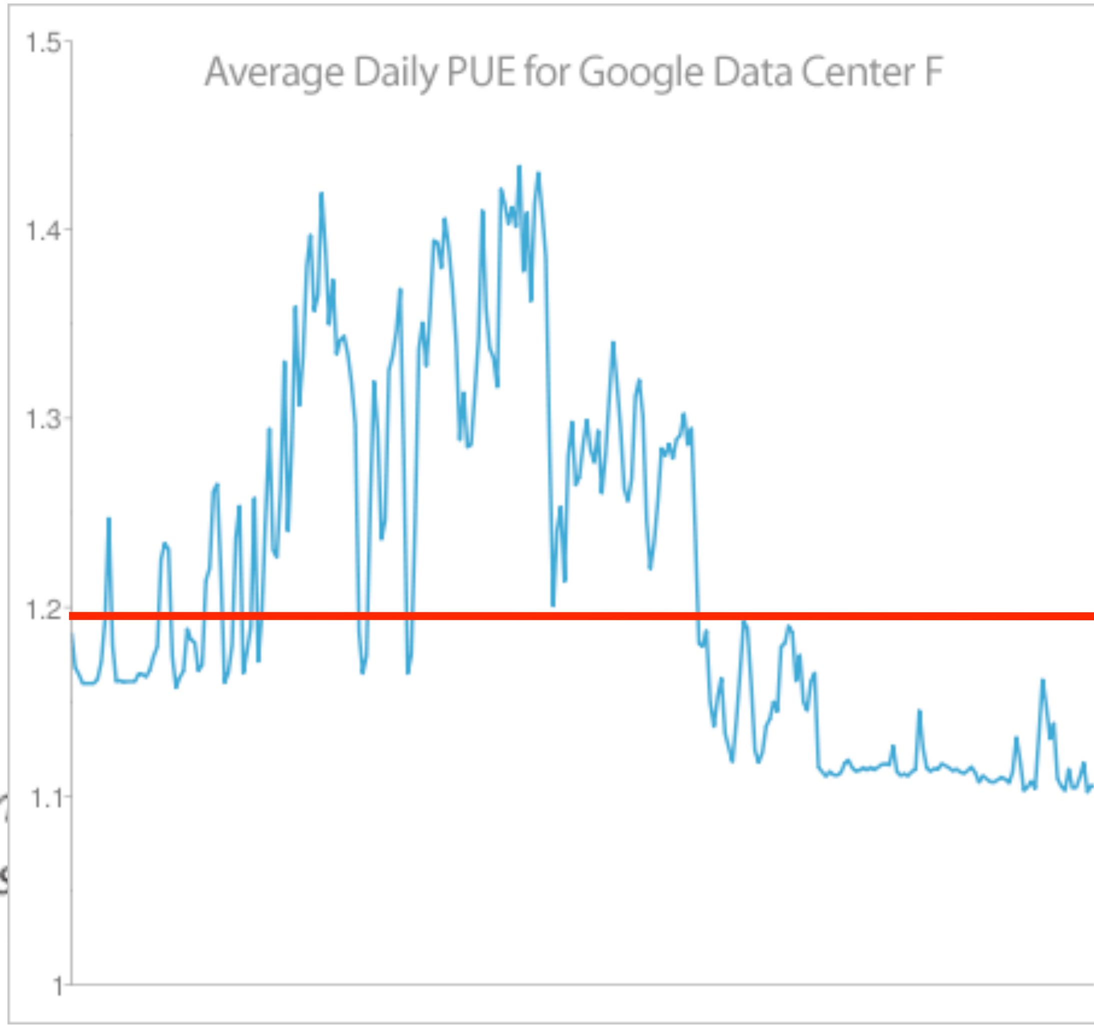
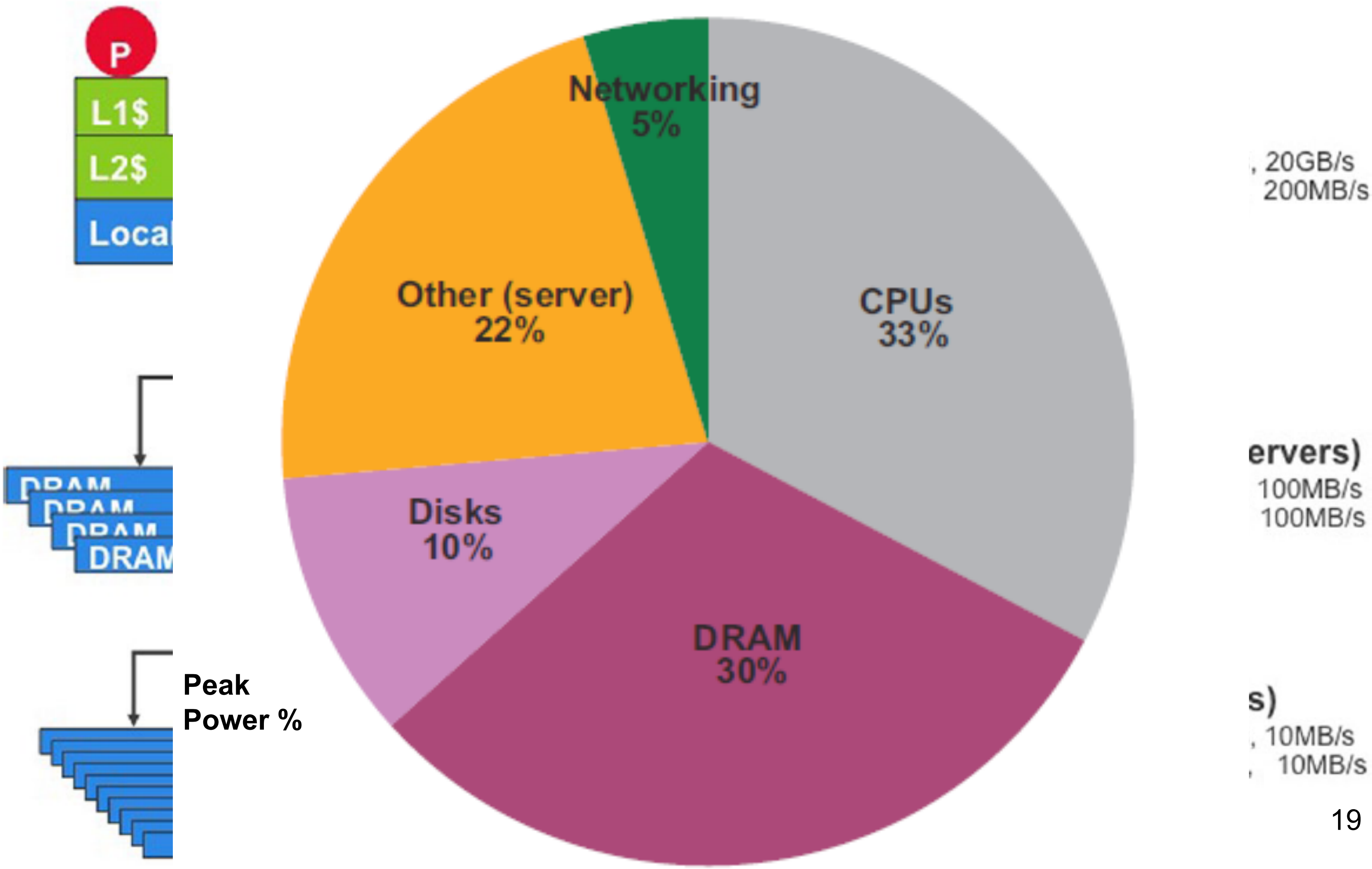


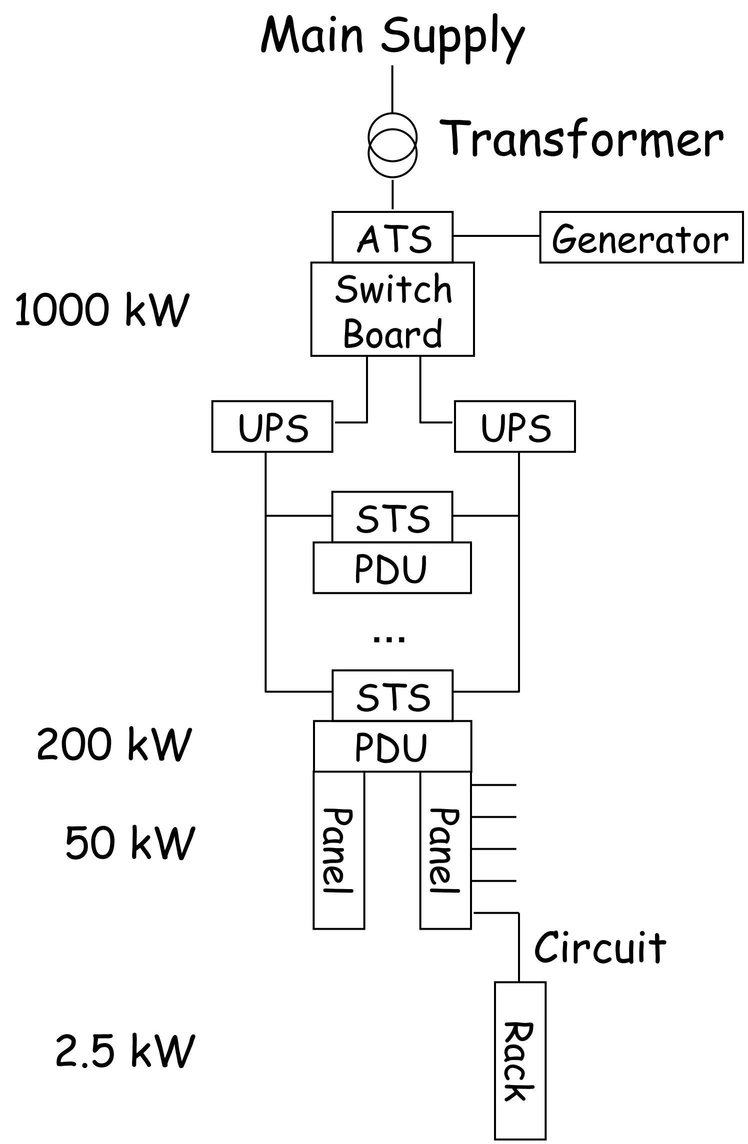
Figure 4. Our San… …ieved a PUE of 1.28, which trans… …ed to a target datacenter built…

Bottom-line: the frontier of DC energy efficiency IS the IT equipment
Doing nothing well becomes incredibly important

Datacenter Power



Datacenter Power



- Typical structure 1MW Tier-2 datacenter
- Reliable Power
  - Mains + Generator
  - Dual UPS
- Units of Aggregation
  - Rack (10-80 nodes)
  - PDU (20-60 racks)
  - Facility/Datacenter

X. Fan, W-D Weber, L. Barroso, “Power Provisioning for a Warehouse-sized Computer,” ISCA’07, San Diego, (June 2007).

Nameplate vs. Actual Peak

Component	Peak Power	Count	Total
CPU	40 W	2	80 W
Memory	9 W	4	36 W
Disk	12 W	1	12 W
PCI Slots	25 W	2	50 W
Mother Board	25 W	1	25 W
Fan	10 W	1	10 W
System Total			213 W

Nameplate peak

Measured Peak (Power-intensive workload) 145 W

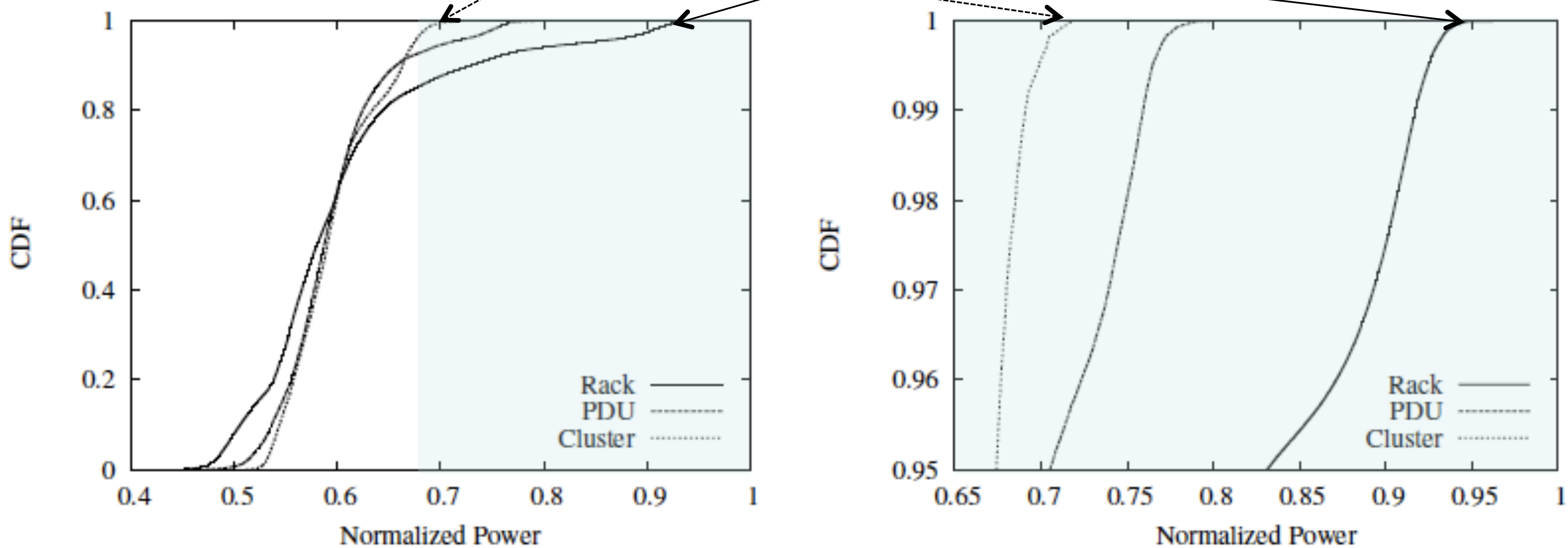
In Google's world, for given DC power budget, deploy as many machines as possible

X. Fan, W-D Weber, L. Barroso, "Power Provisioning for a Warehouse-sized Computer," ISCA'07, San Diego, (June 2007).

Typical Datacenter Power

Clusters driven to modest utilization/67% power

Racks can be driven to high utilization/95% power



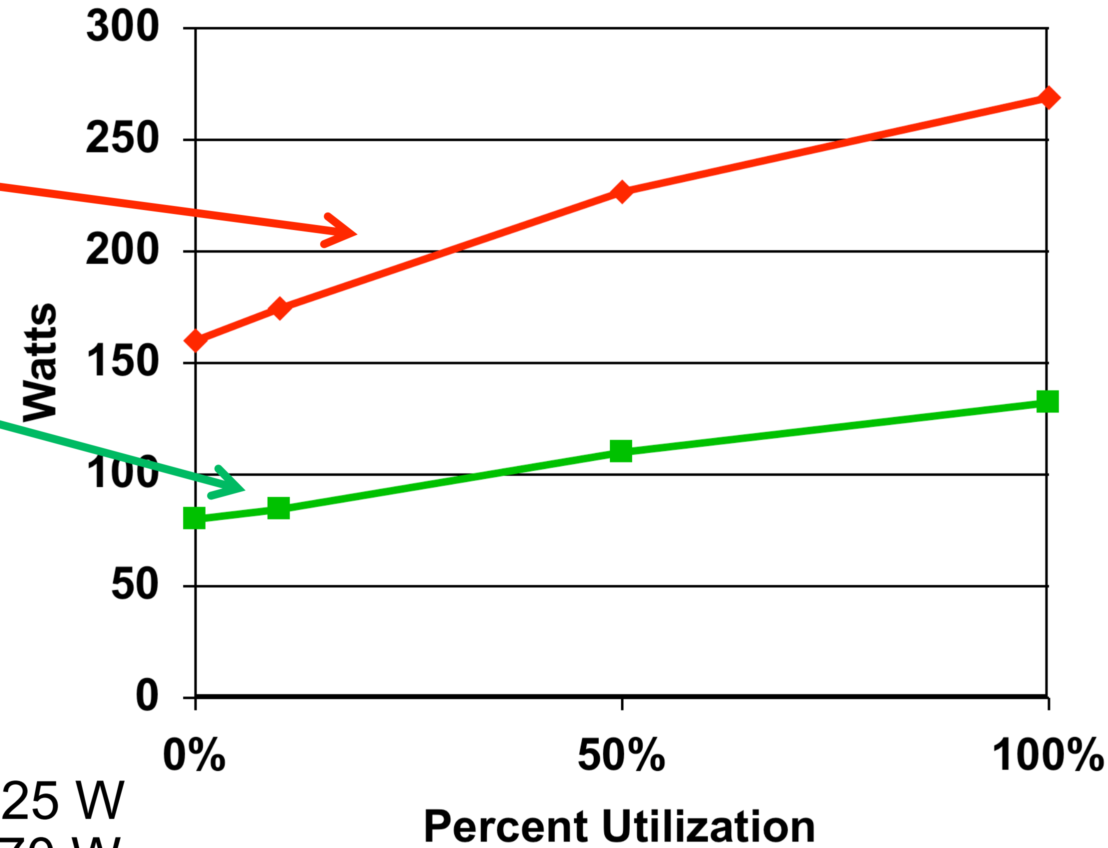
Power-aware allocation of resources can achieve higher levels of utilization – harder to drive a cluster to high levels of utilization than an individual rack

X. Fan, W-D Weber, L. Barroso, "Power Provisioning for a Warehouse-sized Computer," ISCA'07, San Diego, (June 2007).

"Power" of Consolidation: Keep Fewer Machines More Busy

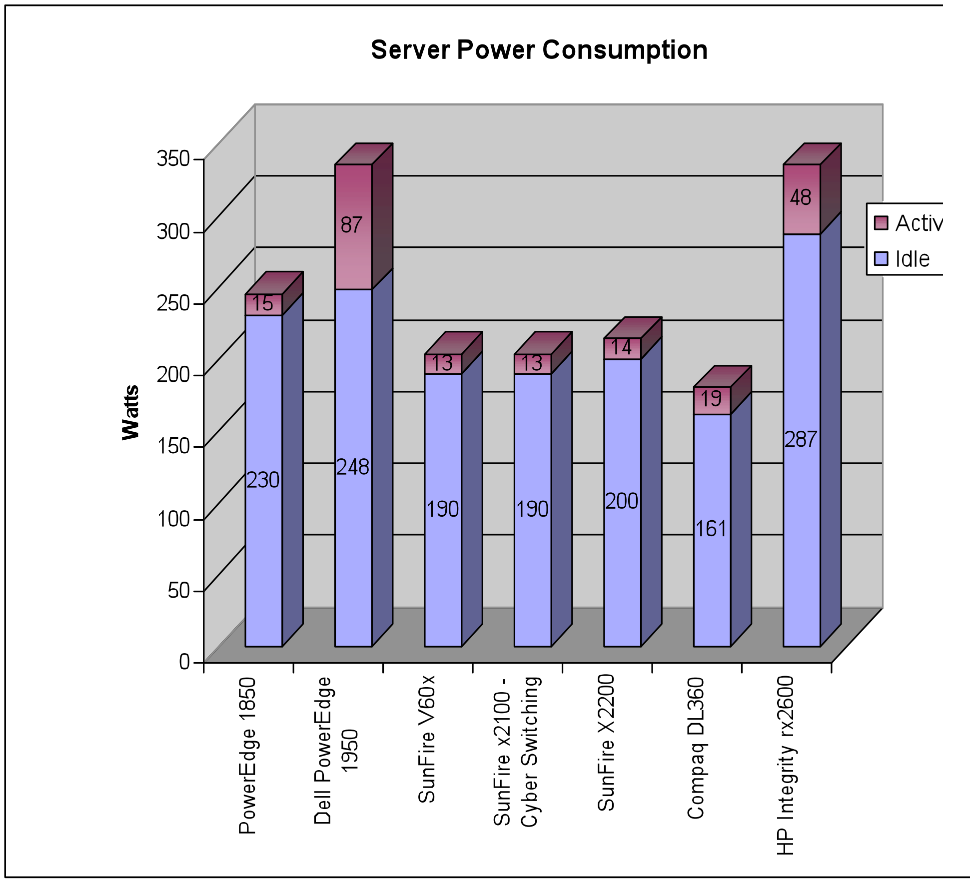
- SPECpower:
  - Two 3.0-GHz Xeons, 16 GB DRAM, 1 Disk
  - One 2.4-GHz Xeon, 8 GB DRAM, 1 Disk
- 50% utilization → 85% Peak Power
- 10% → 65% Peak Power
- Save 75% power if consolidate & turn off

  1 computer @ 50% = 225 W
  v. 5 computers @ 10% = 870 W

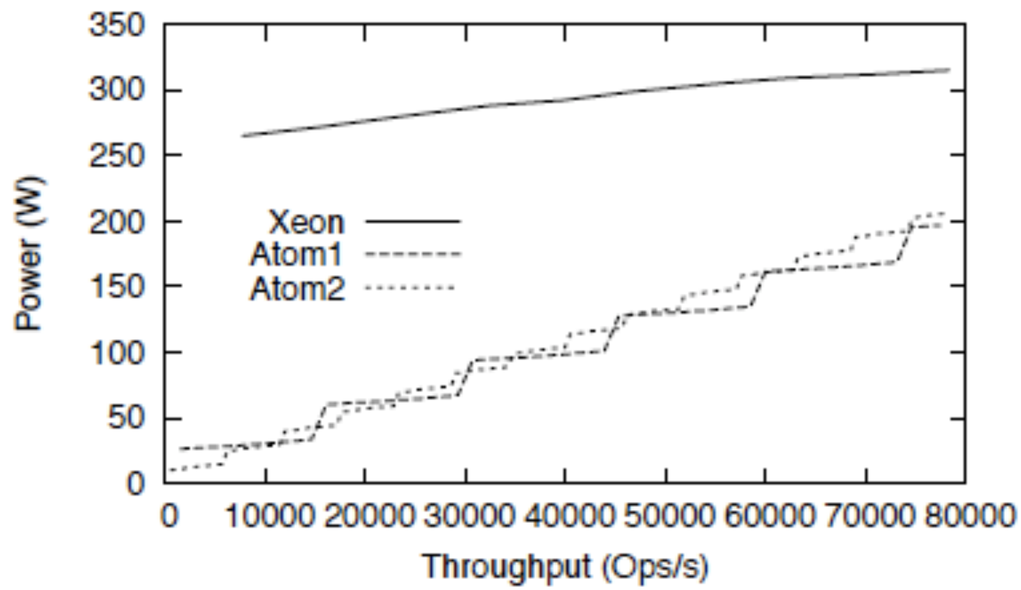


Better to have one computer at 50% utilization than five computers at 10% utilization: Save $ via Consolidation (& Save Power)

Atoms are Quite Better at Doing Nothing Well

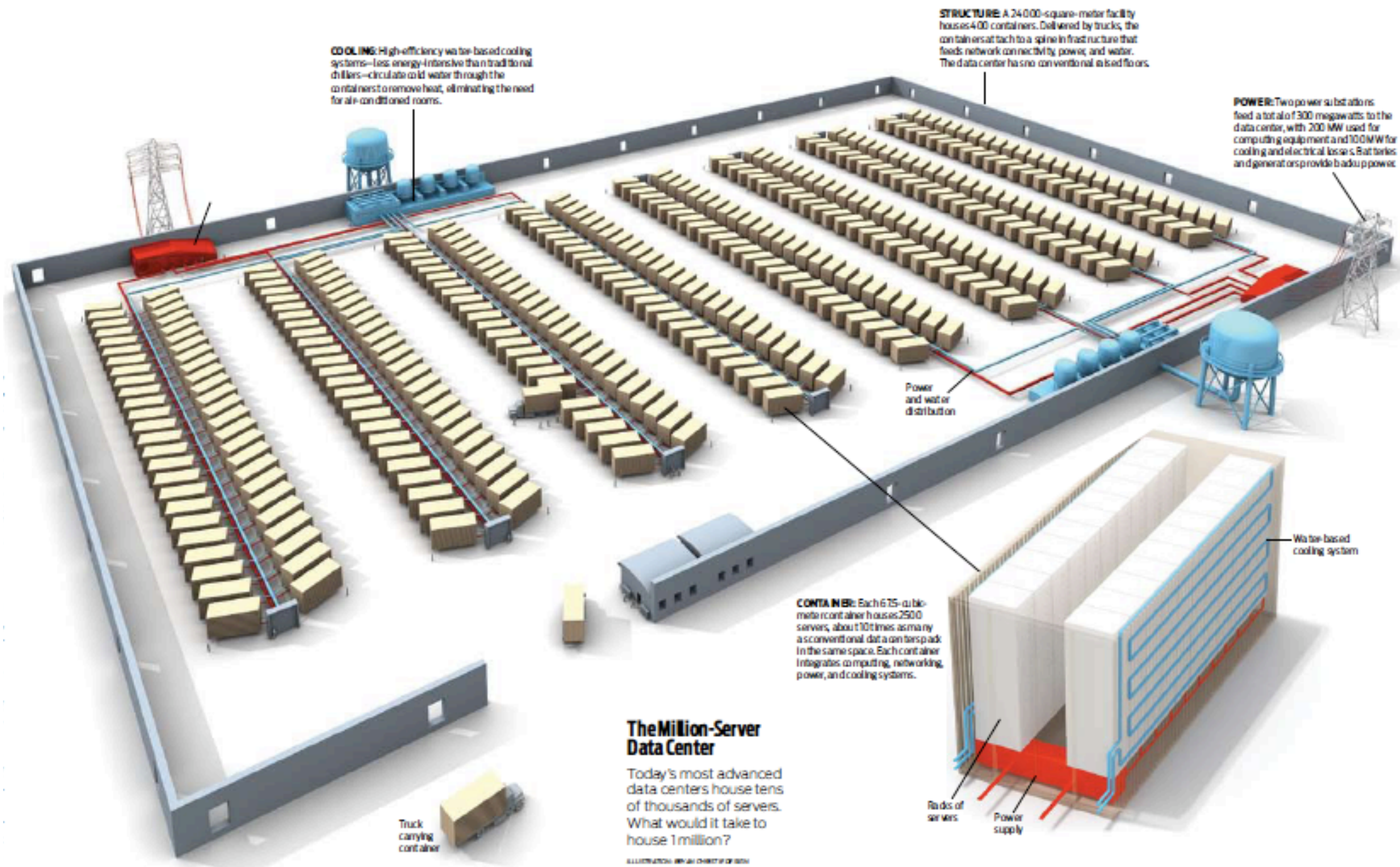


Measured Power in Soda Hall Machine Rooms



Name	Xeon L5420	Atom 330	Atom N270
Frequency	2.5GHz	1.6GHz	1.6GHz
Cache	2x6MB	2x512KB	512KB
CPU	2	1	1
Cores/CPU	4	2	1
Threads/Core	1	2	2
RAM	16GB	2GB	1GB
Storage	15k SAS	5.4k SATA	SSD (low-end)

Microsoft's Chicago Modular Datacenter



The Million Server Datacenter

- 24000 sq. m housing 400 containers
  - Each container contains 2500 servers
  - Integrated computing, networking, power, cooling systems
- 300 MW supplied from two power substations situated on opposite sides of the datacenter
- Dual water-based cooling systems circulate cold water to containers, eliminating need for air conditioned rooms

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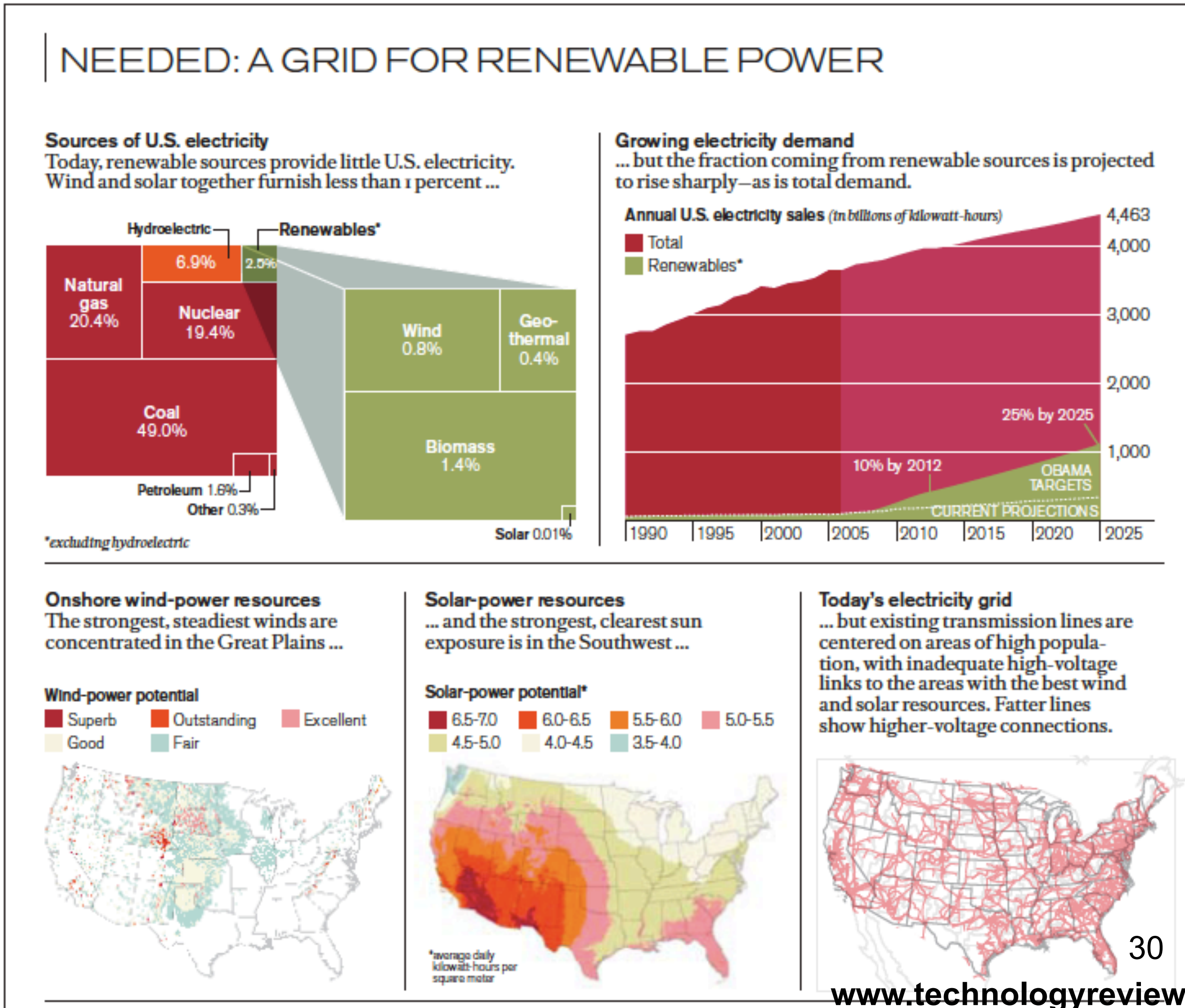
Machine Age
Energy Infrastructure

Accommodate 21st Century Renewable Energy Sources

Challenge of Integrating Intermittent Sources



Sun and wind aren't where the people – and the current grid – are located!

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California as a Testbed

Figure 5. Average power generation by source on July 2016 day - High-Renewable Penetration Case

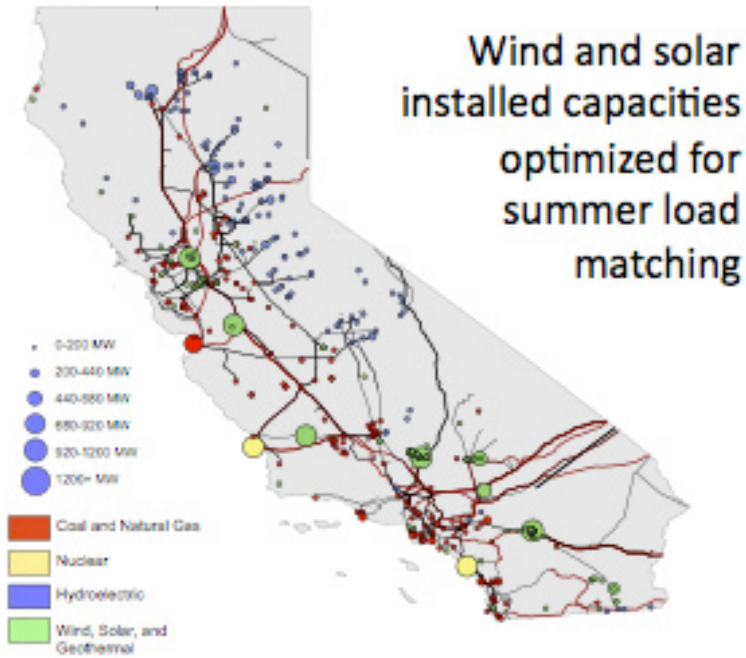
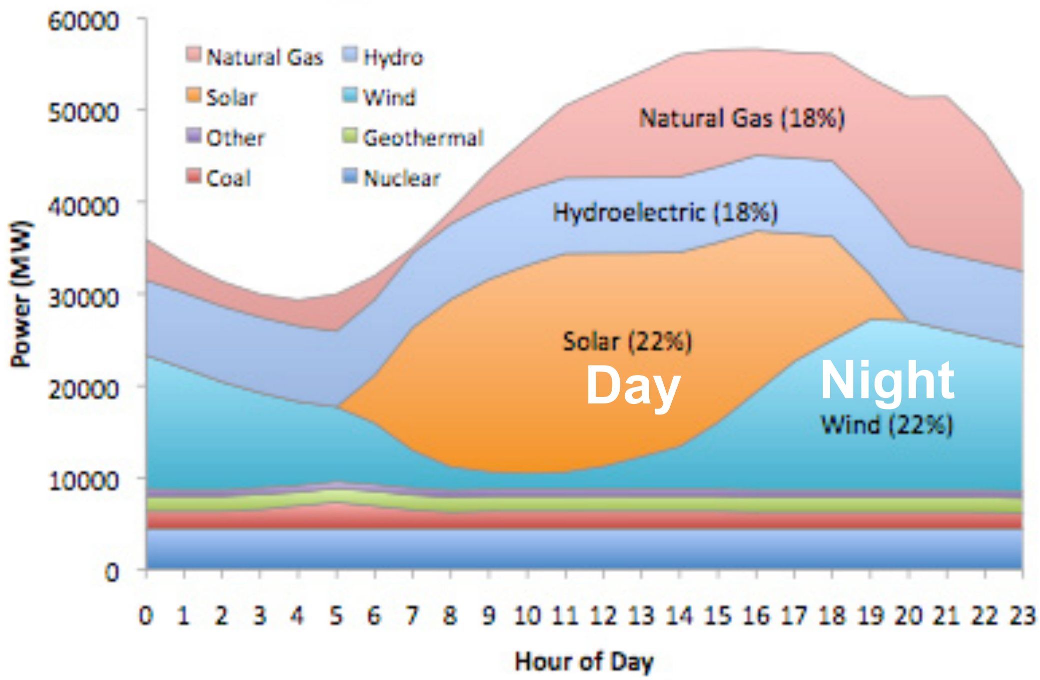


Figure 6. California power generation on July 2016 Day High-Renewable Penetration Case



If we do this, we will need to build a new grid to manage and move renewable energy around

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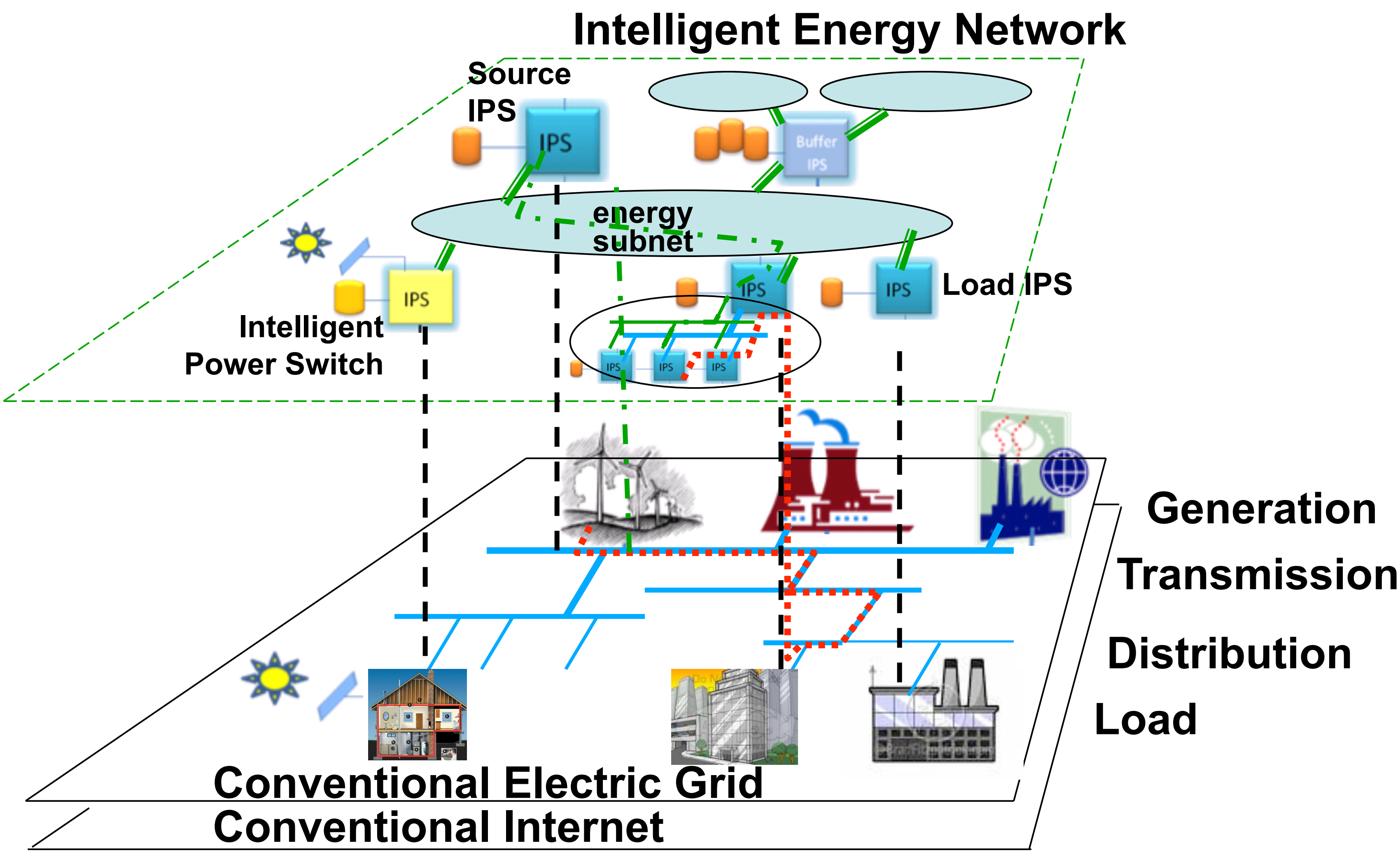
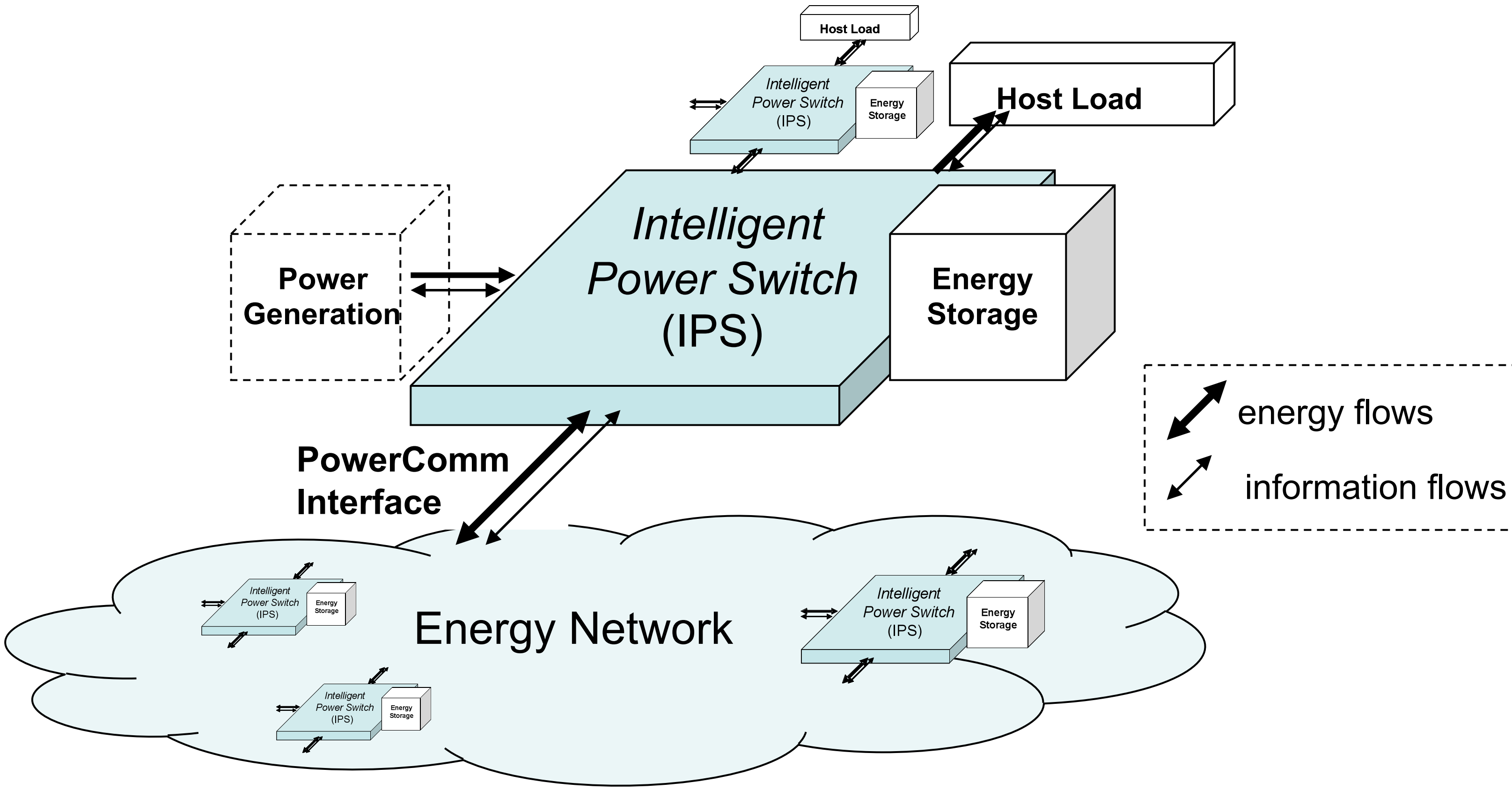
What if the Energy Infrastructure were Designed like the Internet?

- Energy: *the* limited resource of the 21st Century
- Information Age approach to Machine Age infrastructure: *bits follow current flow*
  - Break synchronization between sources and loads: energy storage/buffering is key
  - Lower cost, more incremental deployment, suitable for developing economies
  - Enhanced reliability and resilience to wide-area outages, such as after natural disasters
- Exploit information to match sources to loads, manage buffers, integrate renewables, signal demand response, and take advantage of locality

Information Overlay to the Energy Grid



Intelligent Power Switch

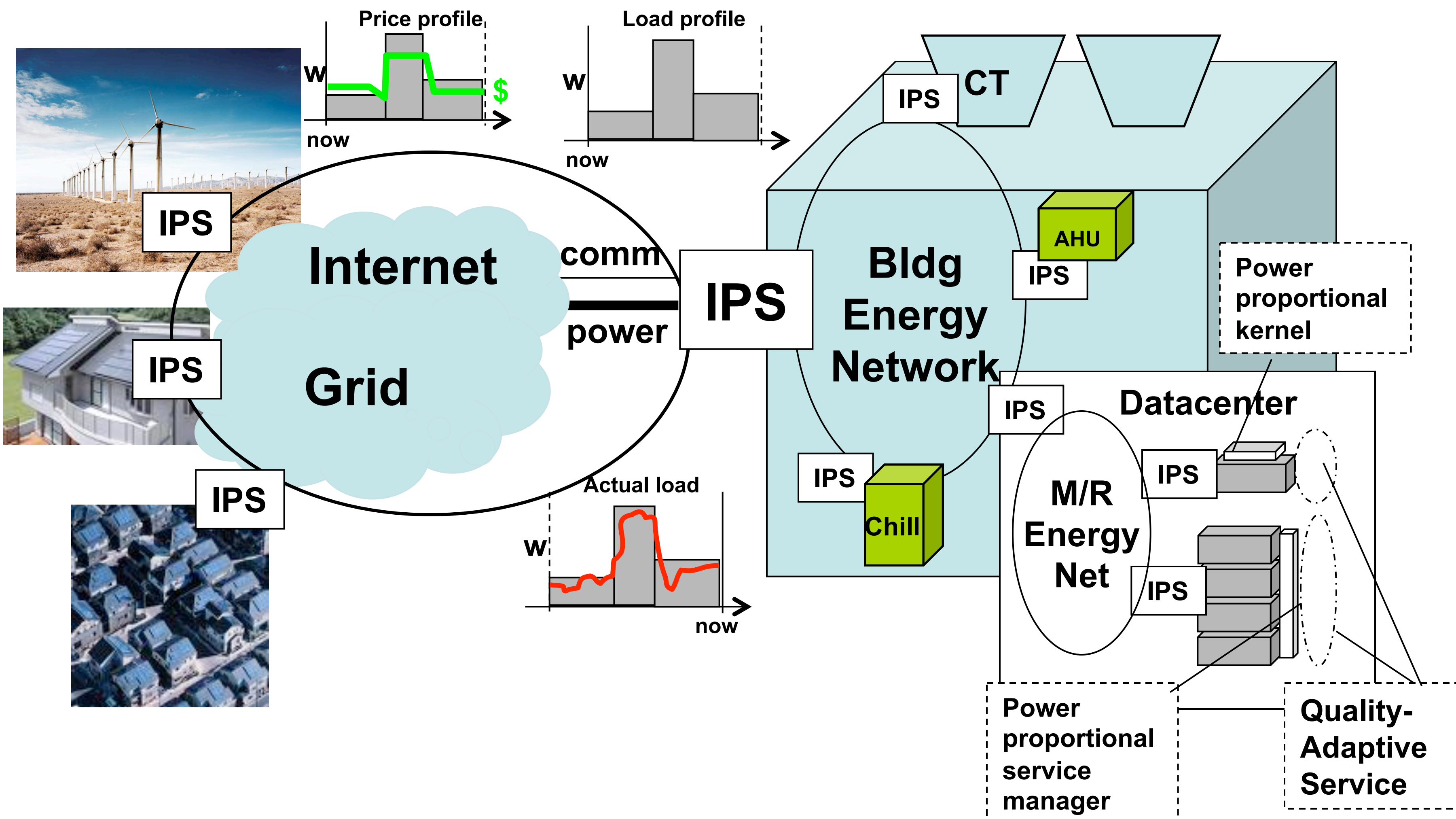


- PowerComm Interface: Network + Power connector
- Scale Down, Scale Out

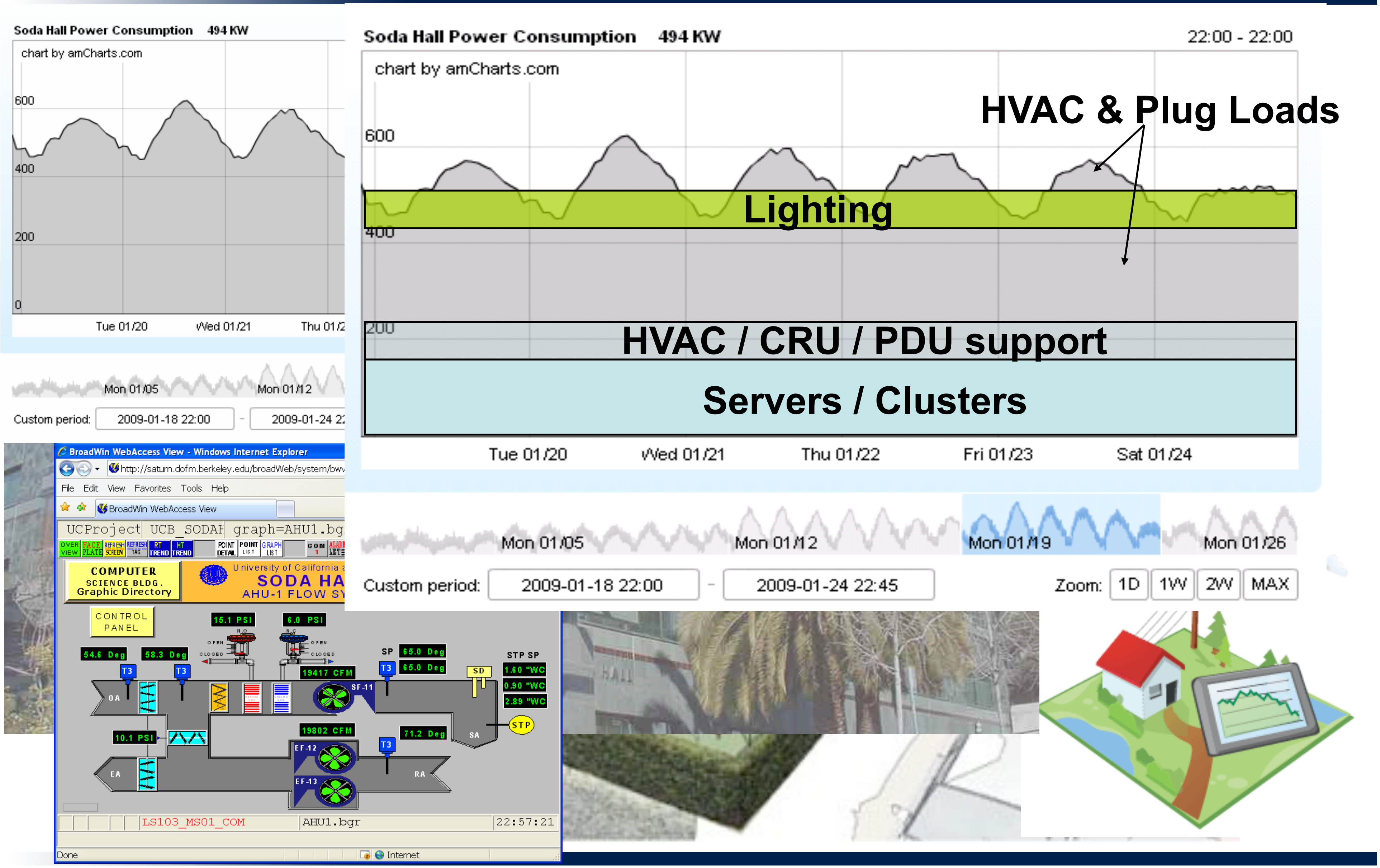
"Doing Nothing Well"

- Existing systems sized for peak and designed for continuous activity
  - Reclaim the idle waste
  - Exploit huge gap in peak-to-average power consumption
- Continuous demand response
  - Challenge "always on" assumption
  - Realize potential of energy-proportionality
- From IT Equipment …
  - Better fine-grained idling, faster power shutdown/ restoration
  - Pervasive support in operating systems and applications
- … to the OS for the Building

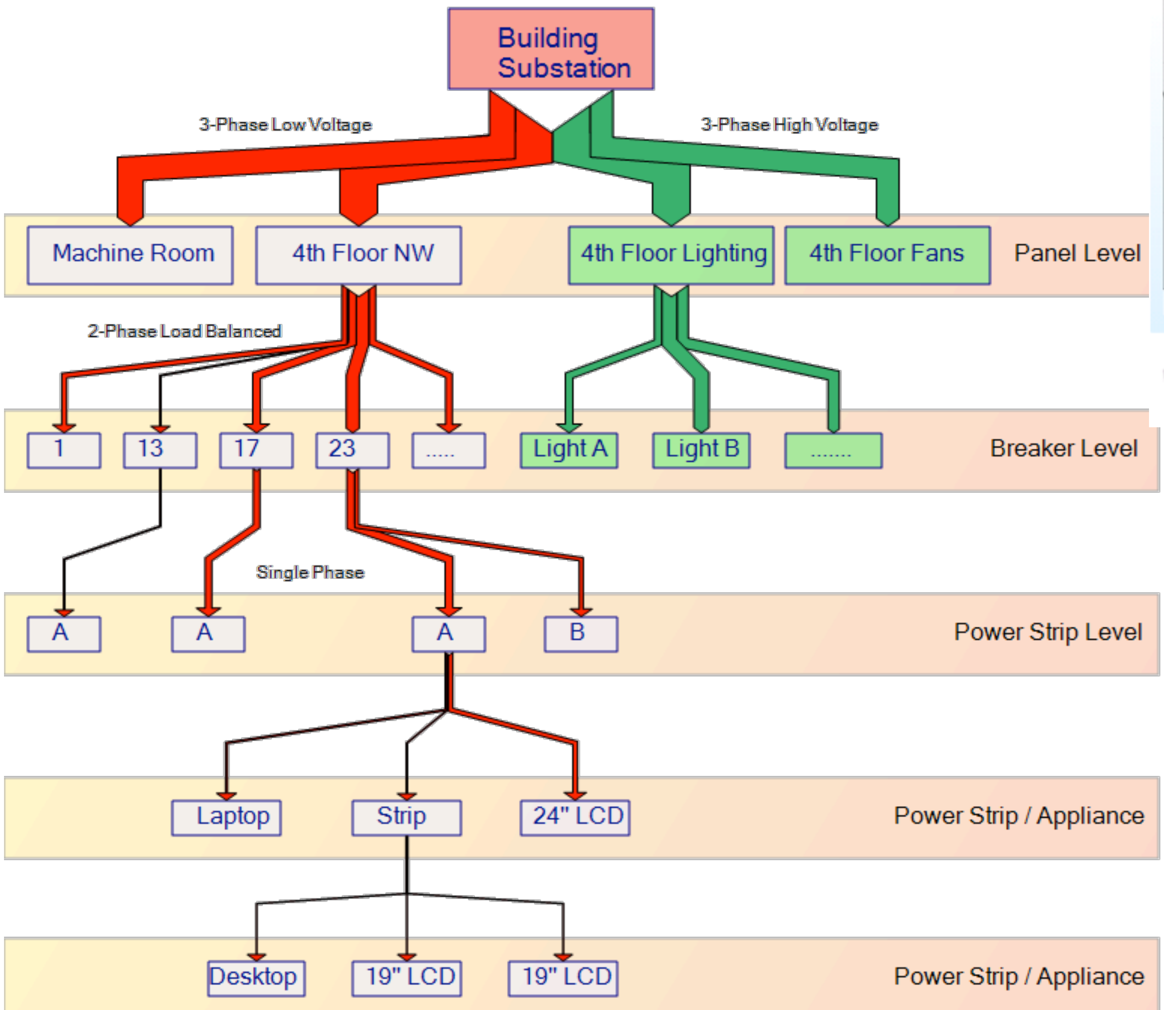
Multi-Scale Energy Internet

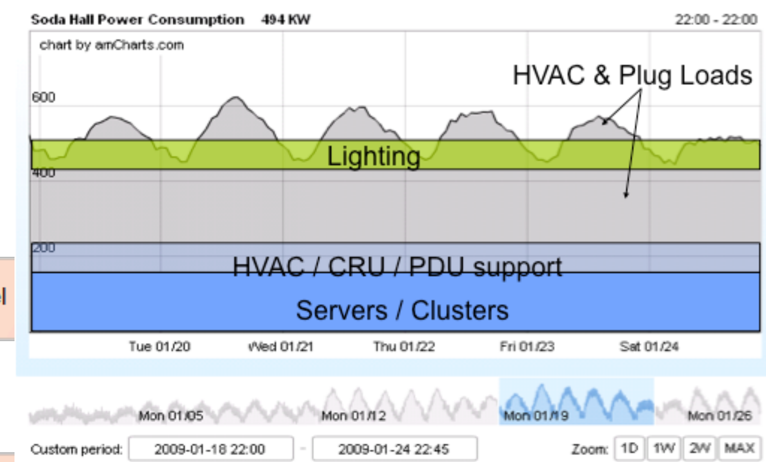


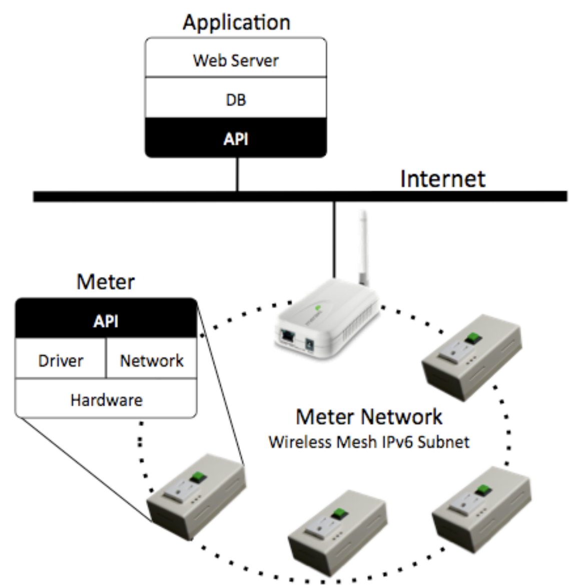
Smart Buildings



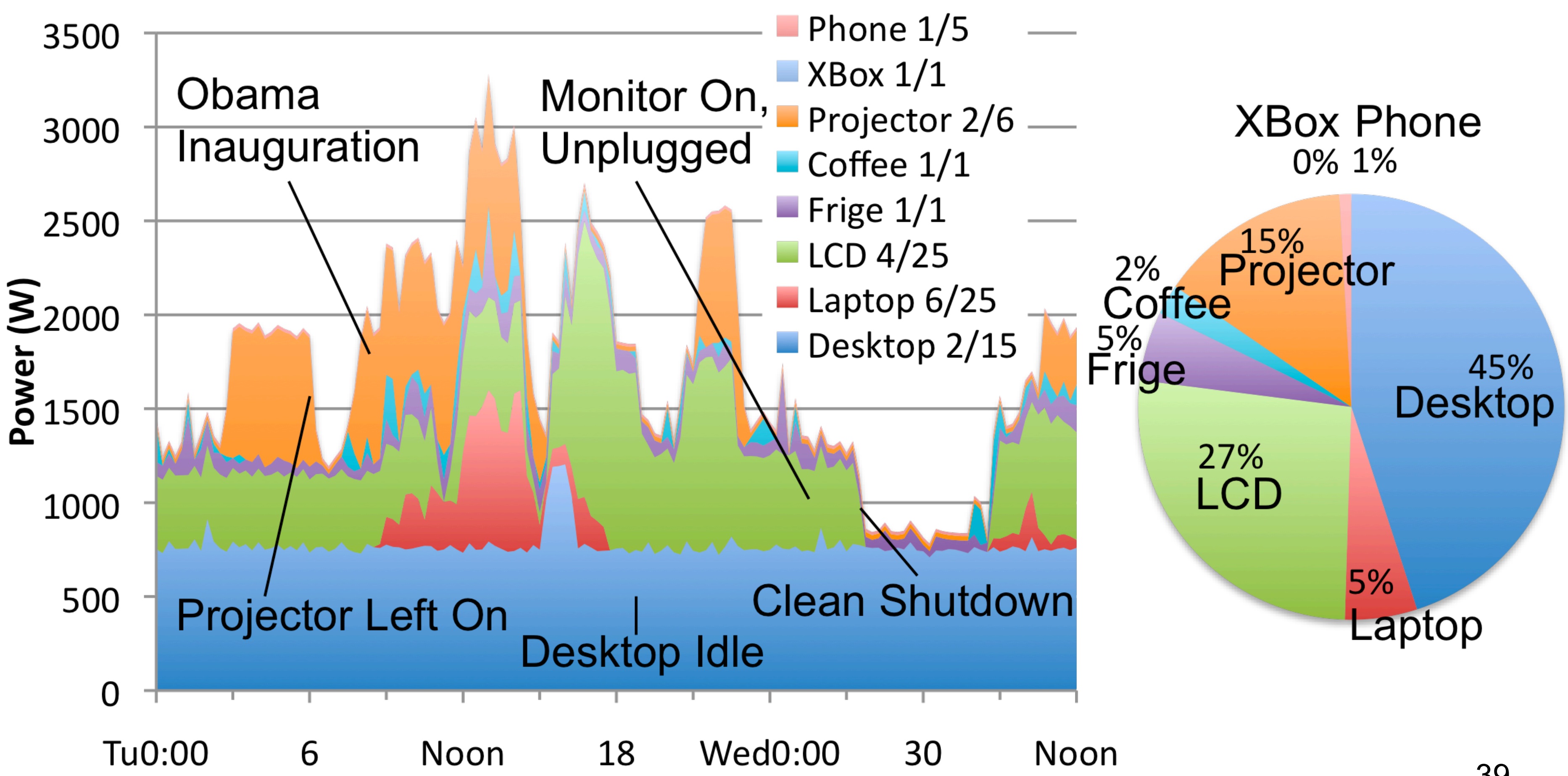
Physical Systems vs. Logical Use



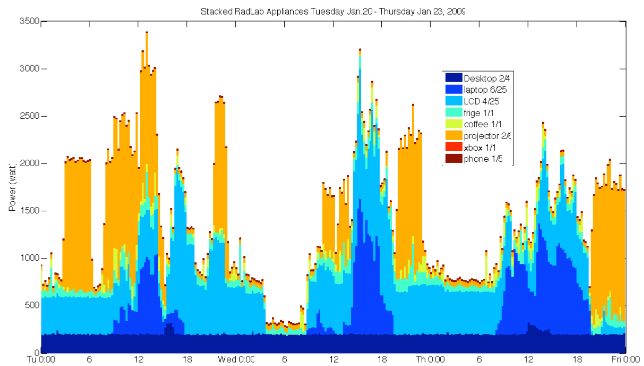


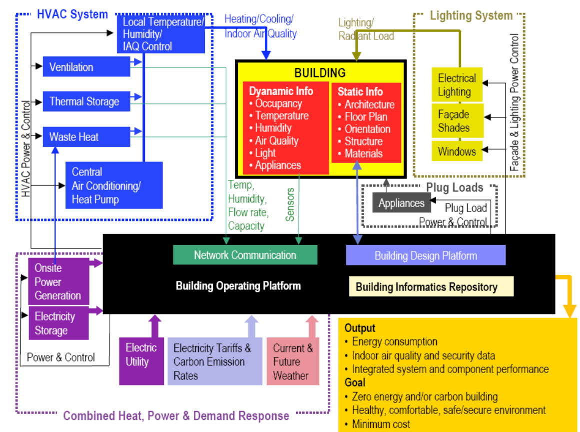


Energy Consumption Breakdown



Cooperative Continuous Energy Reduction





User Demand

Facility Mgmt

High-fidelity visibility

Automated Control

Supervisory Control

Community Feedback

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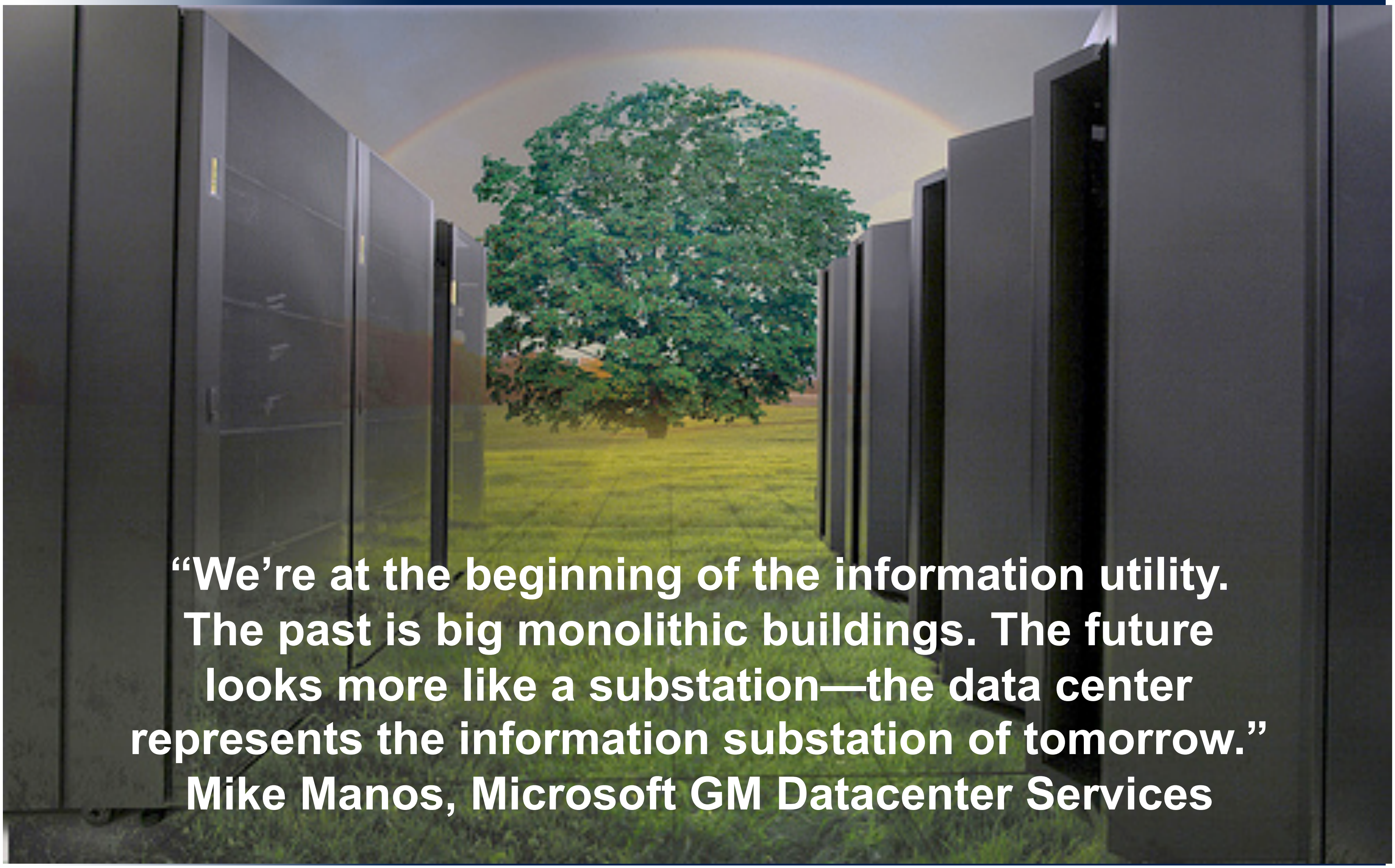
Summary and Conclusions

- Energy Consumption in IT Equipment
  - Energy Proportional Computing and "Doing Nothing Well"
  - Management of Processor, Memory, I/O, Network to maximize performance subject to power constraints
  - Internet Datacenters and Containerized Datacenters: New packaging opportunities for better optimization of computing + communicating + power + mechanical

Summary and Conclusions

- LoCal: a scalable energy *network*
  - Inherent inefficiencies at all levels of electrical energy distribution
  - Integrated energy generation and storage
  - IPS and PowerComm Interface
  - Energy matching at small, medium, large scale
- Demand response: doing nothing well
- Smart buildings beyond datacenters

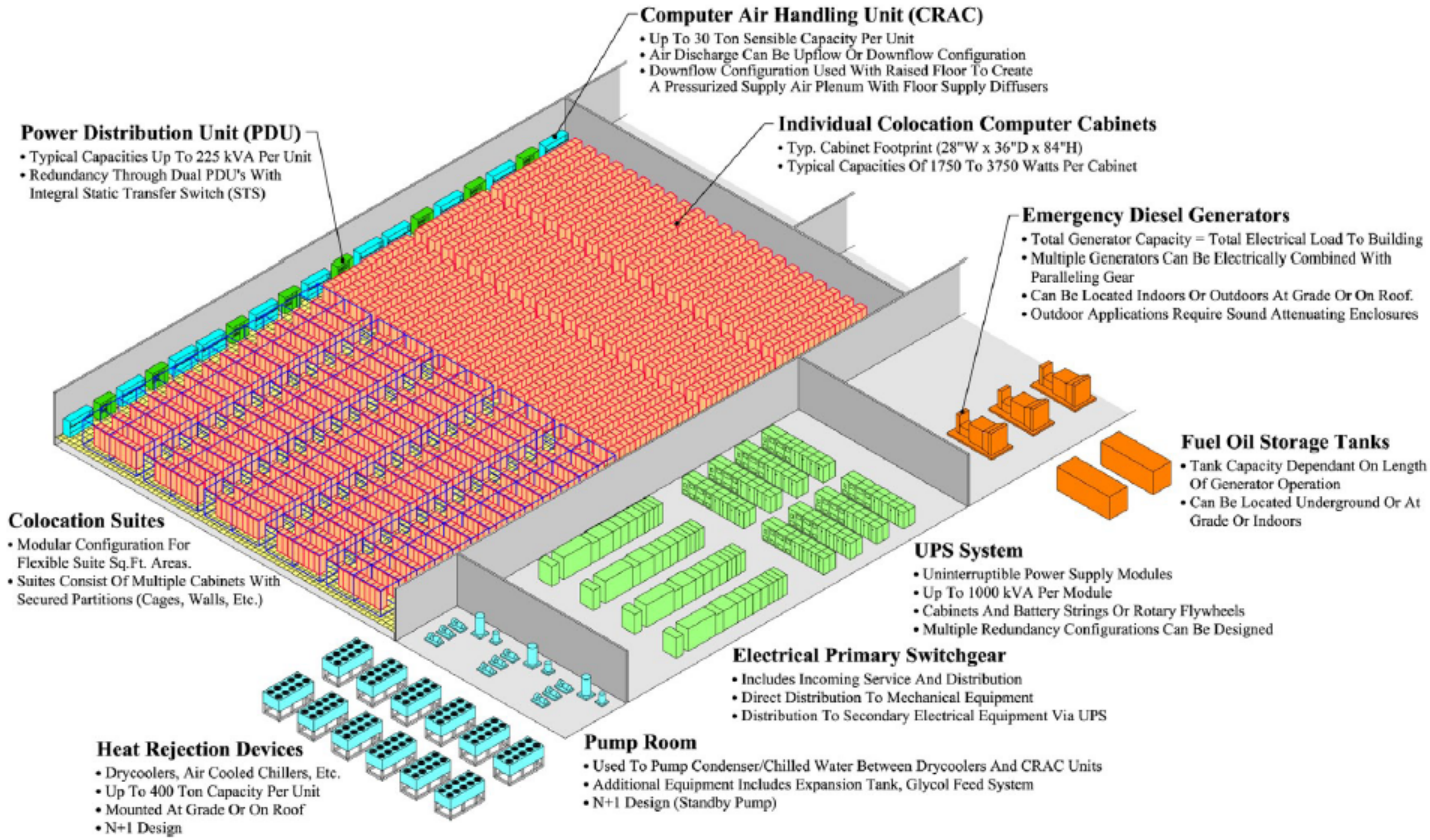
Thank You!



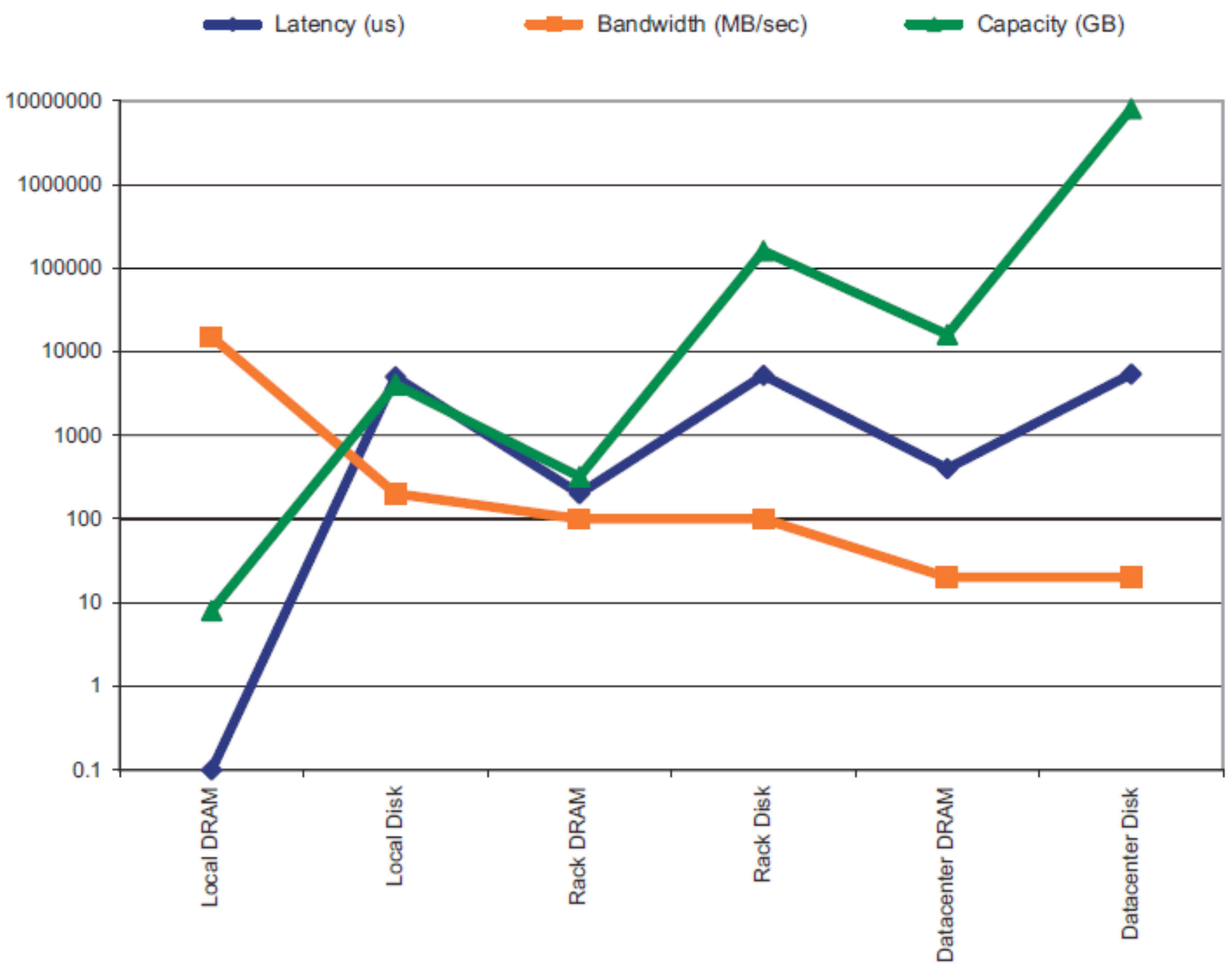
"We're at the beginning of the information utility. The past is big monolithic buildings. The future looks more like a substation—the data center represents the information substation of tomorrow."

Mike Manos, Microsoft GM Datacenter Services

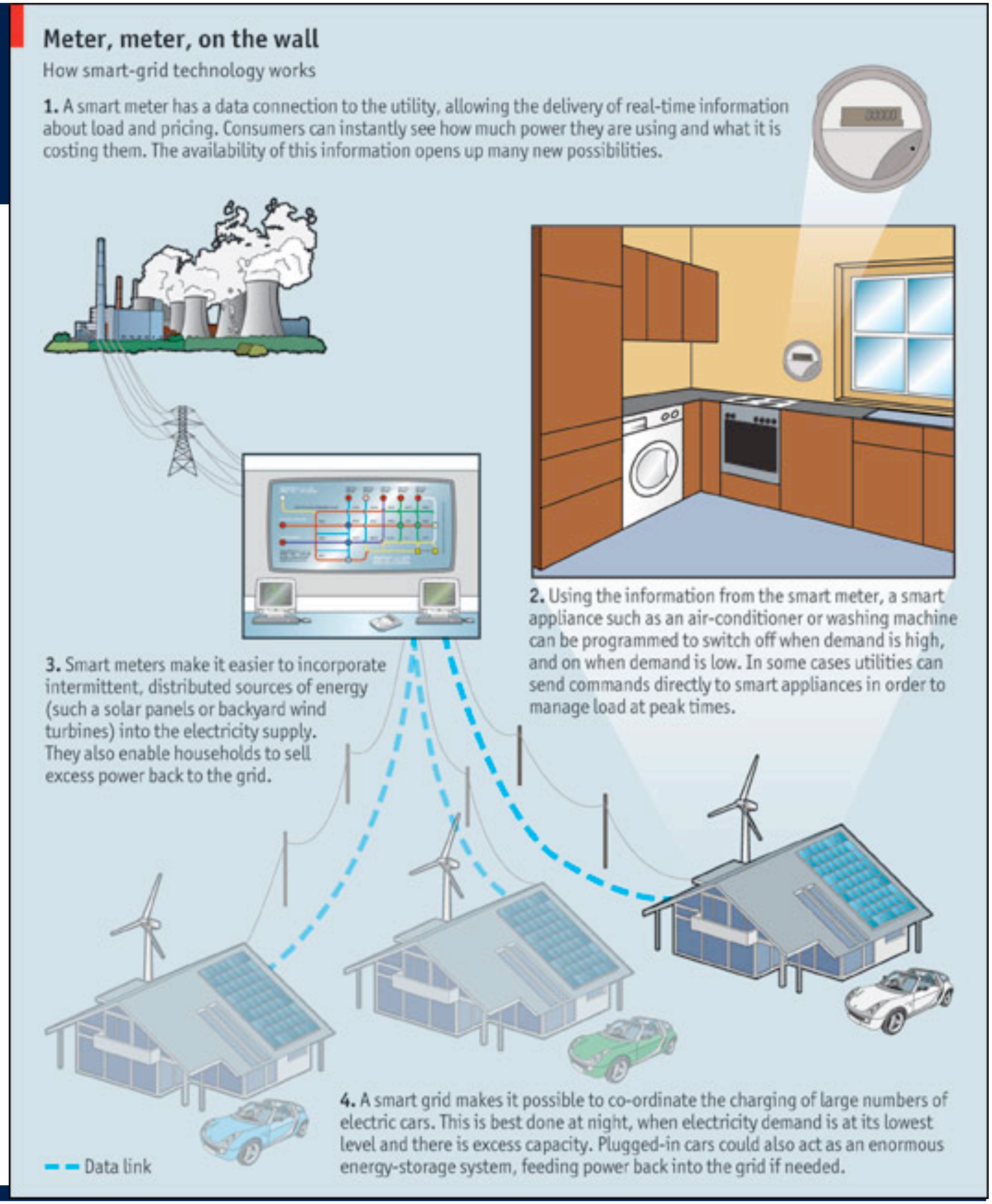
LoCal



Computer Air Handling Unit (CRAC)
• Up To 30 Ton Sensible Capacity Per Unit
• Air Discharge Can Be Upflow Or Downflow Configuration
• Downflow Configuration Used With Raised Floor To Create A Pressurized Supply Air Plenum With Floor Supply Diffusers
Power Distribution Unit (PDU)
• Typical Capacities Up To 225 kVA Per Unit
• Redundancy Through Dual PDU's With Integral Static Transfer Switch (STS)
Individual Colocation Computer Cabinets
• Typ. Cabinet Footprint (28"W x 36"D x 84"H)
• Typical Capacities Of 1750 To 3750 Watts Per Cabinet
Emergency Diesel Generators
• Total Generator Capacity = Total Electrical Load To Building
• Multiple Generators Can Be Electrically Combined With Paralleling Gear
• Can Be Located Indoors Or Outdoors At Grade Or On Roof.
• Outdoor Applications Require Sound Attenuating Enclosures
Fuel Oil Storage Tanks
• Tank Capacity Dependant On Length Of Generator Operation
• Can Be Located Underground Or At Grade Or Indoors
Colocation Suites
• Modular Configuration For Flexible Suite Sq.Ft. Areas.
• Suites Consist Of Multiple Cabinets With Secured Partitions (Cages, Walls, Etc.)
UPS System
• Uninterruptible Power Supply Modules
• Up To 1000 kVA Per Module
• Cabinets And Battery Strings Or Rotary Flywheels
• Multiple Redundancy Configurations Can Be Designed
Electrical Primary Switchgear
• Includes Incoming Service And Distribution
• Direct Distribution To Mechanical Equipment
• Distribution To Secondary Electrical Equipment Via UPS
Pump Room
• Used To Pump Condenser/Chilled Water Between Drycoolers And CRAC Units
• Additional Equipment Includes Expansion Tank, Glycol Feed System
• N+1 Design (Standby Pump)
Heat Rejection Devices
• Drycoolers, Air Cooled Chillers, Etc.
• Up To 400 Ton Capacity Per Unit
• Mounted At Grade Or On Roof
• N+1 Design



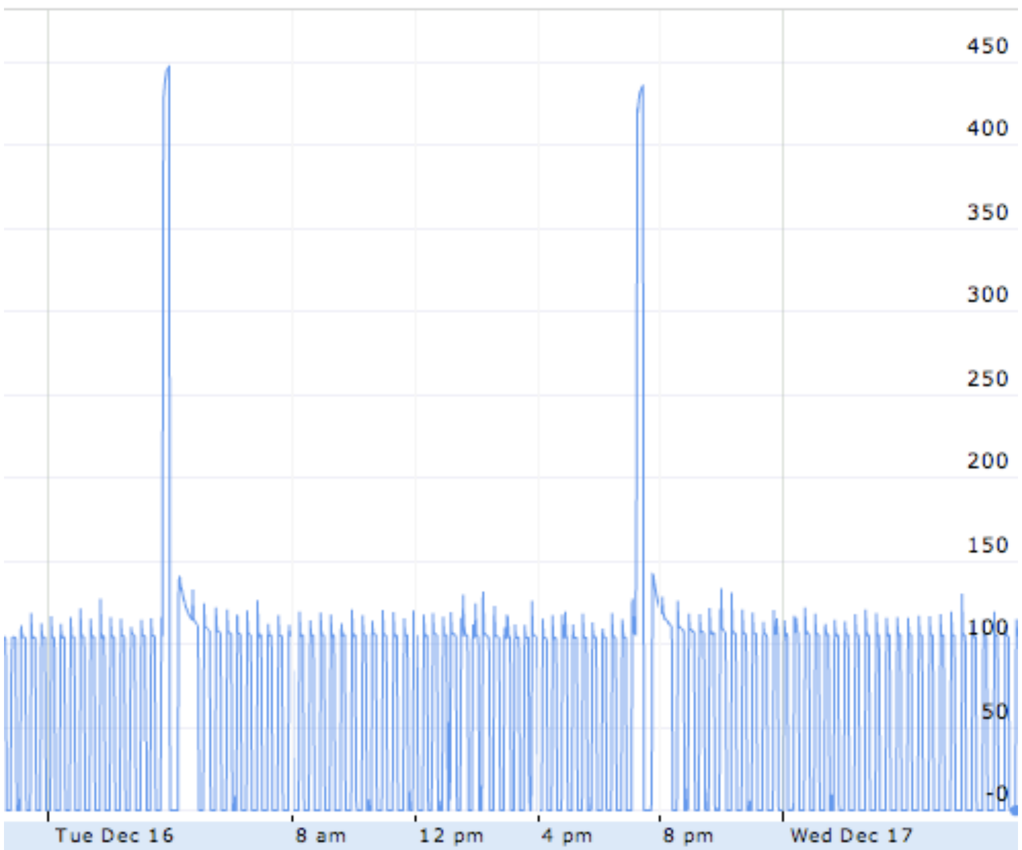
Latency (us)
Bandwidth (MB/sec)
Capacity (GB)
10000000
1000000
100000
10000
1000
100
10
1
0.1
Local DRAM
Local Disk
Rack DRAM
Rack Disk
Datacenter DRAM
Datacenter Disk

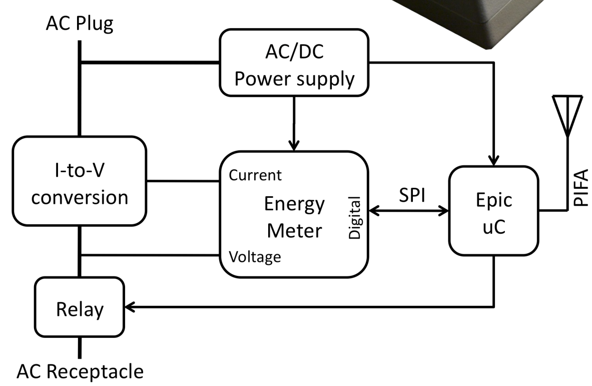

Meter, meter, on the wall
How smart-grid technology works
1. A smart meter has a data connection to the utility, allowing the delivery of real-time information about load and pricing. Consumers can instantly see how much power they are using and what it is costing them. The availability of this information opens up many new possibilities.
2. Using the information from the smart meter, a smart appliance such as an air-conditioner or washing machine can be programmed to switch off when demand is high, and on when demand is low. In some cases utilities can send commands directly to smart appliances in order to manage load at peak times.
3. Smart meters make it easier to incorporate intermittent, distributed sources of energy (such a solar panels or backyard wind turbines) into the electricity supply. They also enable households to sell excess power back to the grid.
4. A smart grid makes it possible to co-ordinate the charging of large numbers of electric cars. This is best done at night, when electricity demand is at its lowest level and there is excess capacity. Plugged-in cars could also act as an enormous energy-storage system, feeding power back into the grid if needed.
Data link

"The Big Switch" and Cloud Computing

"A hundred years ago, ***companies stopped generating their own power with steam engines and dynamos and plugged into the newly built electric grid***. The cheap power pumped out by electric utilities didn't just change how businesses operate. It set off a chain reaction of economic and social transformations that brought the modern world into existence. Today, a similar revolution is under way. ***Hooked up to the Internet's global computing grid, massive information-processing plants have begun pumping data and software code into our homes and businesses.*** This time, it's computing that's turning into a utility."

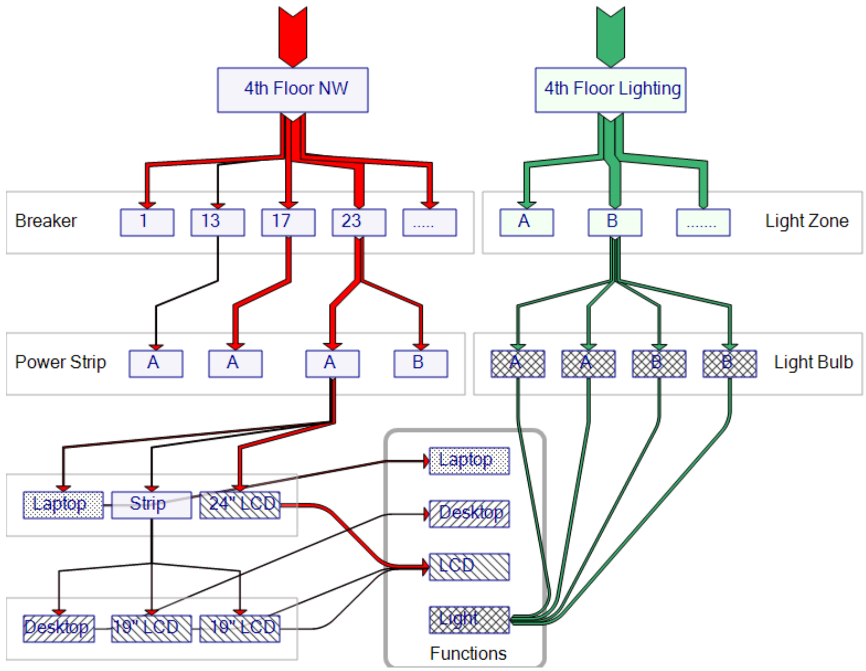
ACme – HiFi Metering

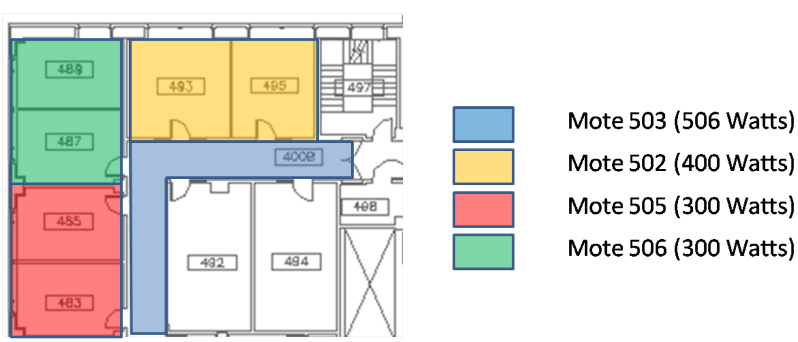


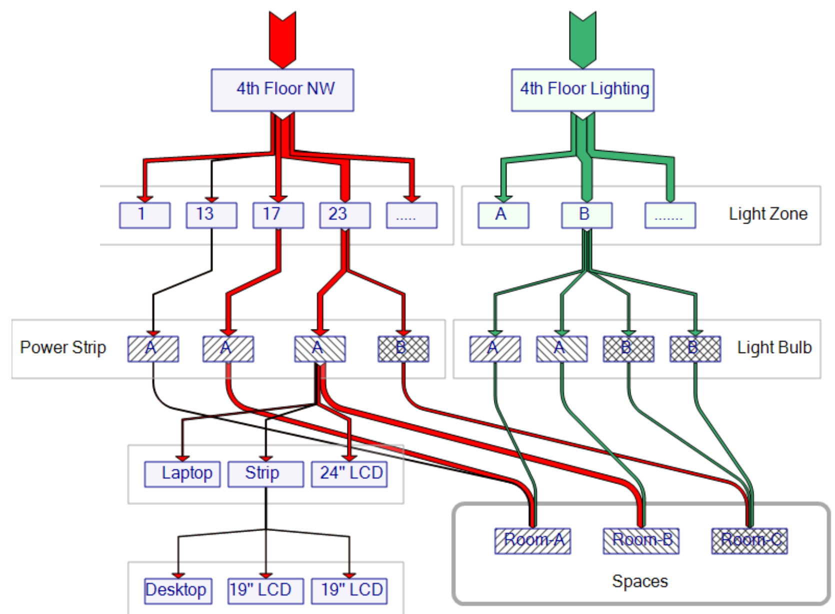


ACme Summary	
Measurements	real, reactive, apparent
Resolution	$40mW$
Sampling speed	$14k$Hz
Report speed	$2.8k$Hz
Maximum power	$1800W$
Energy accumulation	6.26min
Radio range	multiple floors
Idle power	$1W$
Size	10x5.6x4cm

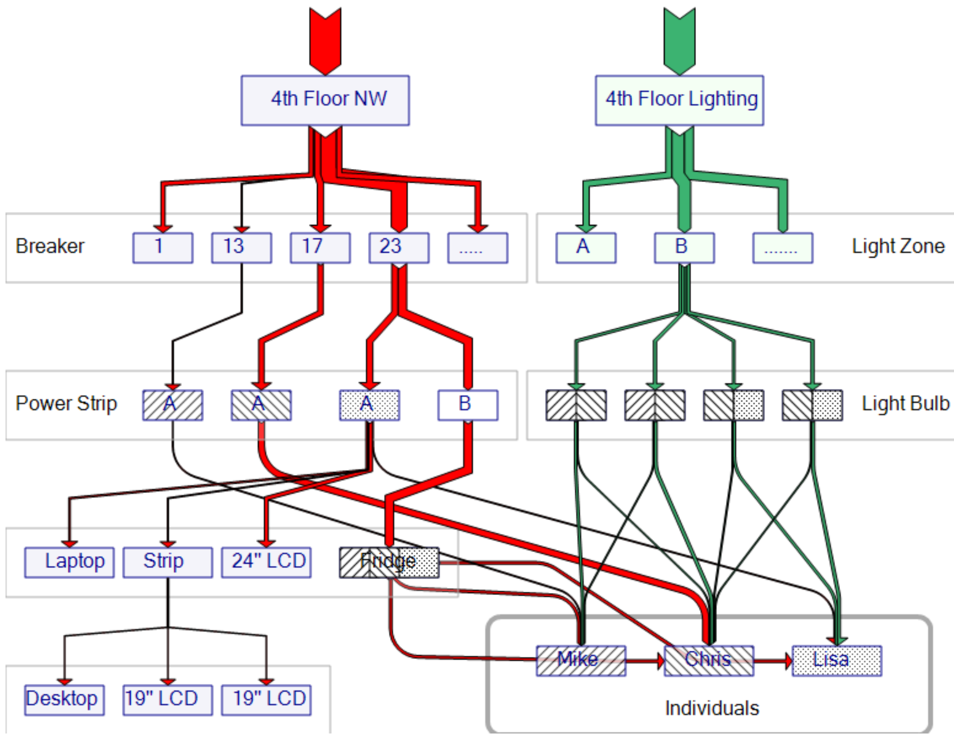
Re-aggregation

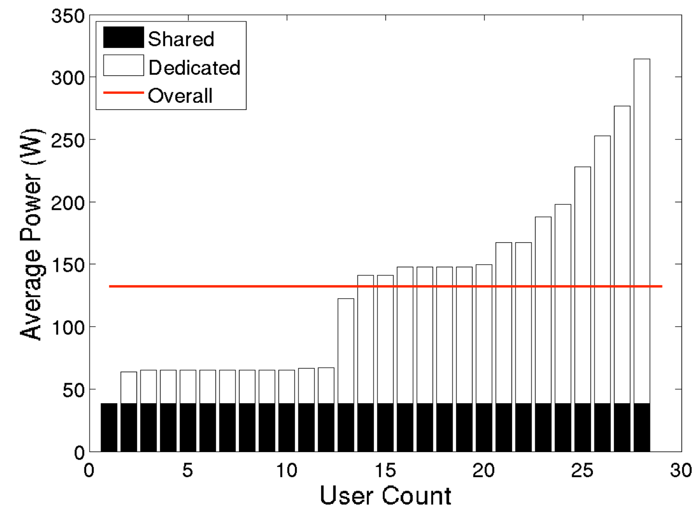


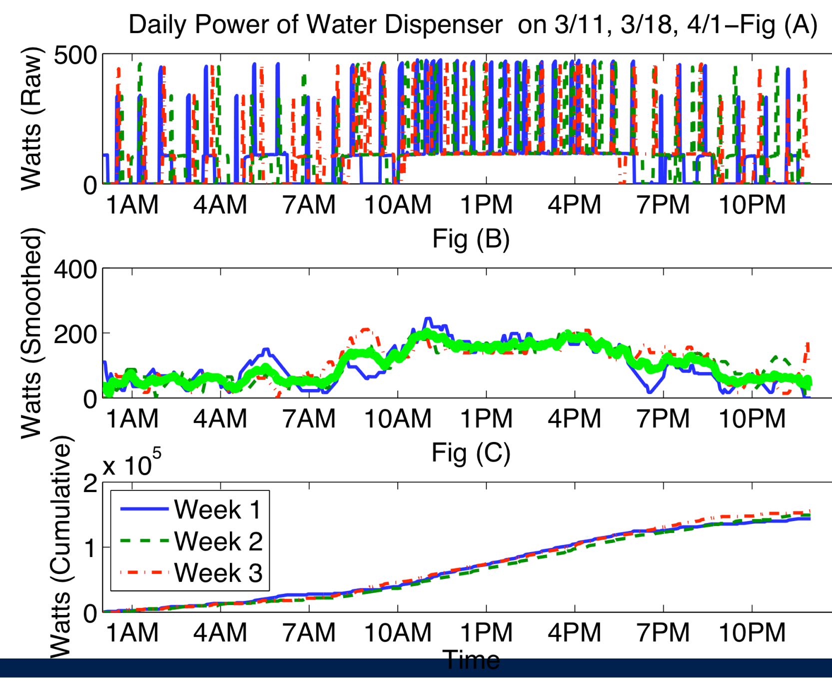




By Individual







Energy Awareness and Adaptation

- Export existing facilities instrumentation into real-time feed and archival physical information base
- Augment with extensive usage-focused sensing
- Create highly visible consumer feedback and remediation guidance
- Develop whole-building dynamic models
- Basis for forecasting and load sculpting