



# A Computer Scientist Looks at the Energy Problem

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EECS BEARS Symposium  
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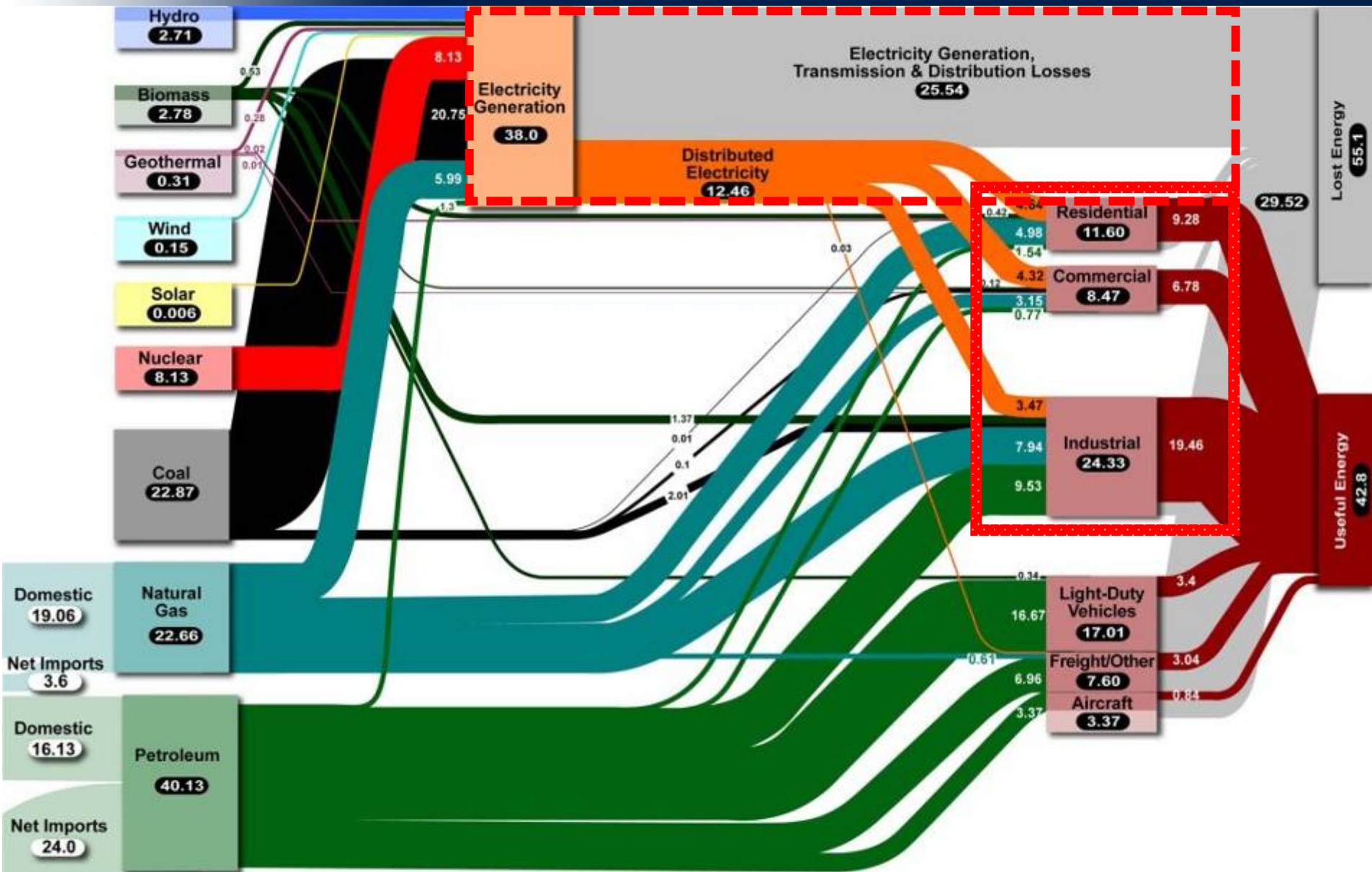
“Energy permits things to exist; information, to behave purposefully.”  
W. Ware, 1997



# 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,” Redux



“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.”



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# Start with IT: 2020 Carbon Footprint

**820m tons CO<sub>2</sub>**

**2007 Worldwide IT  
carbon footprint:  
2% = 830 m tons CO<sub>2</sub>  
Comparable to the  
global aviation  
industry**

**Expected to grow  
to 4% by 2020**

## IT footprints

Emissions by sub-sector, 2020

PCs, peripherals  
and printers  
57%

Telecoms  
infrastructure  
and devices  
25%



**360m tons CO<sub>2</sub>**

**260m tons CO<sub>2</sub>**

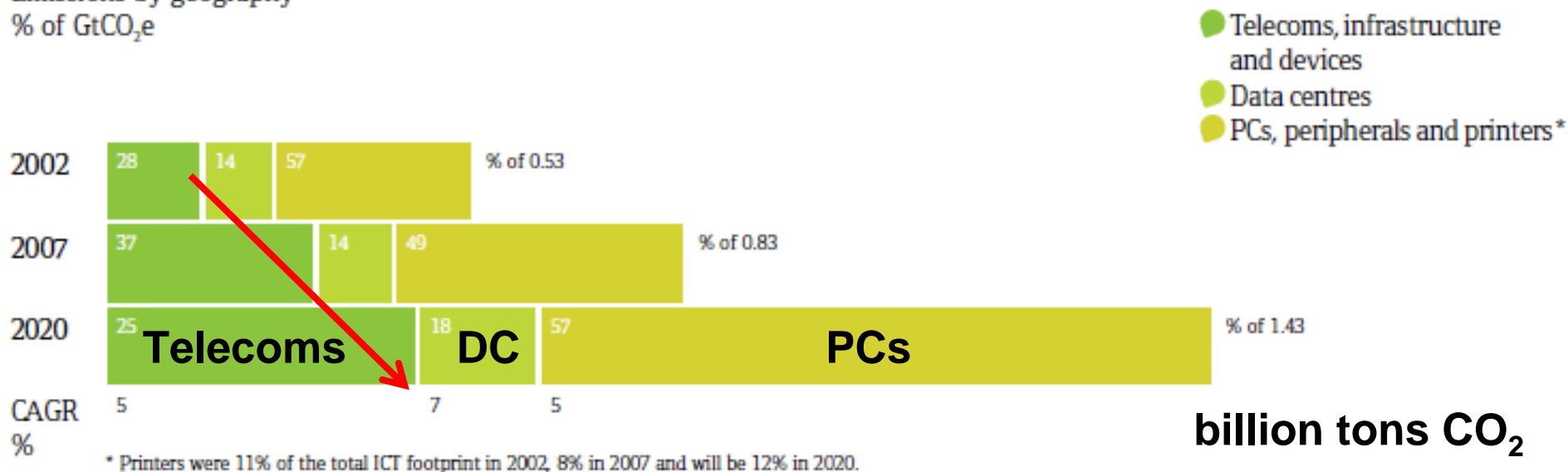
**Total emissions: 1.43bn tonnes CO<sub>2</sub> equivalent**

# 2020 IT Carbon Footprint

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

Fig. 2.3 The global footprint by subsector

Emissions by geography  
% of GtCO<sub>2</sub>e



**Datacenters: Owned by single entity interested in reducing opex**





# Energy Proportional Computing

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

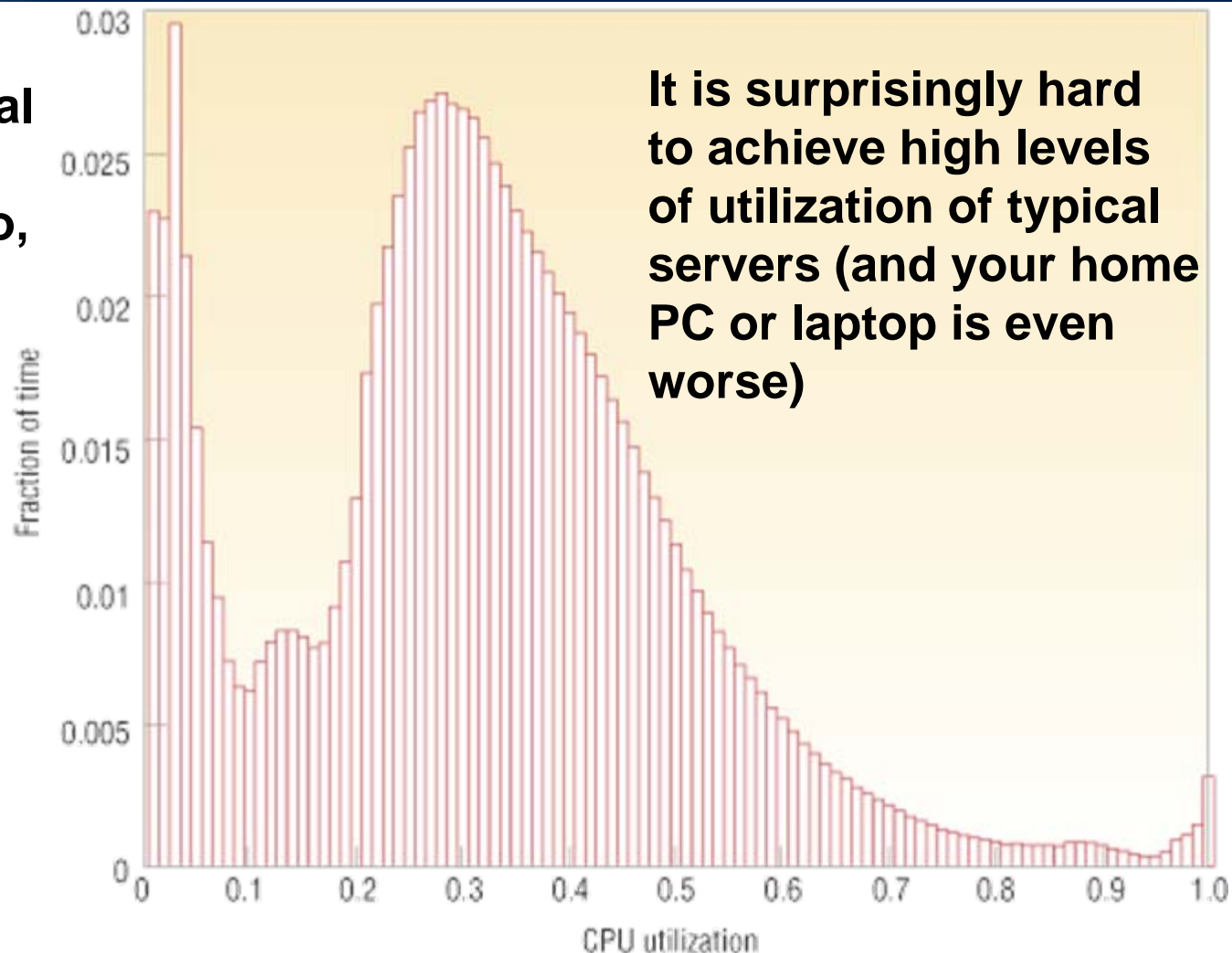


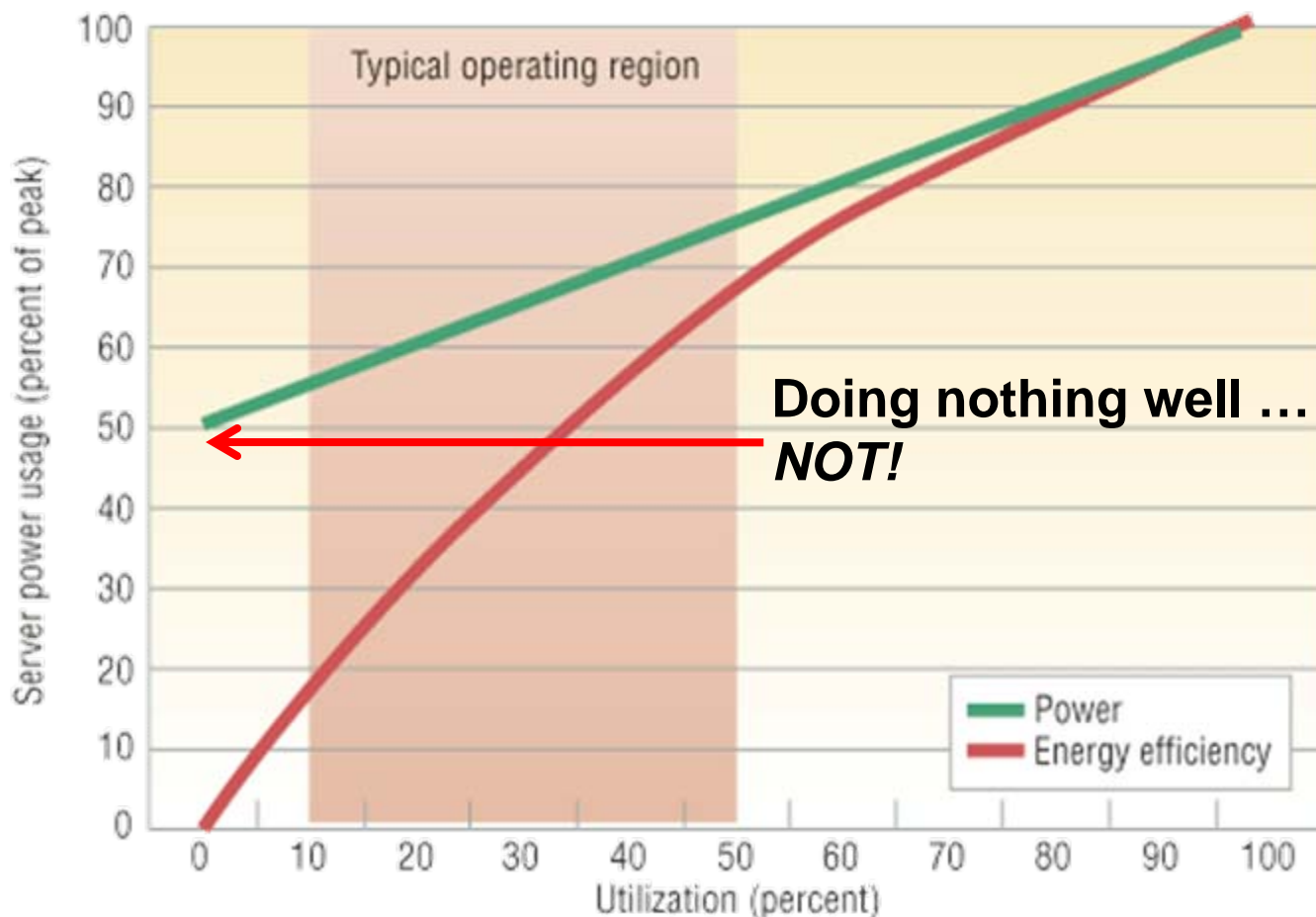
Figure 1. Average CPU utilization of more than 5,000 servers during a six-month period. Servers are rarely completely idle and seldom operate near their maximum utilization, instead operating most of the time at between 10 and 50 percent of their maximum <sup>9</sup>



# 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.**



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**Memory?  
Storage?  
Network?**

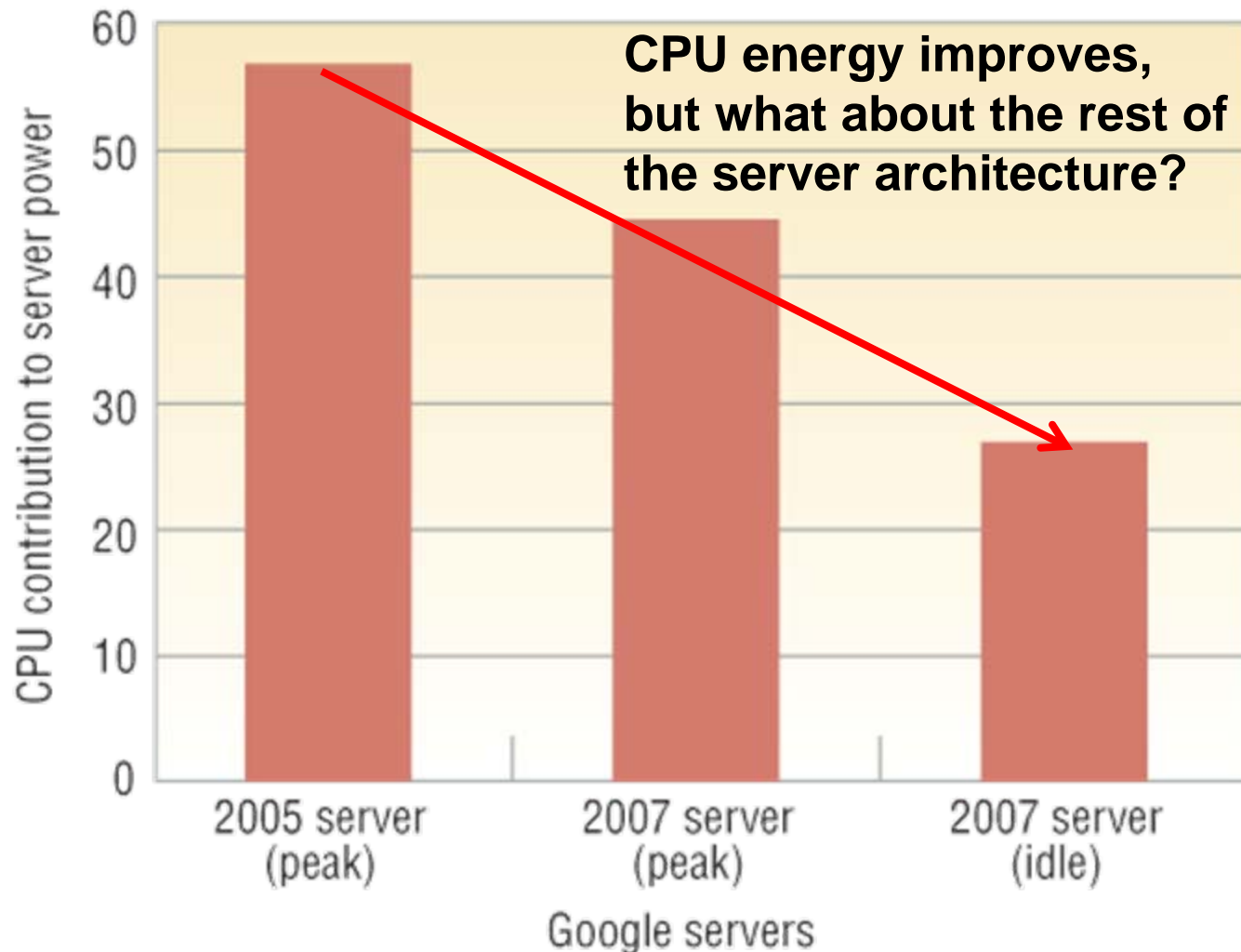


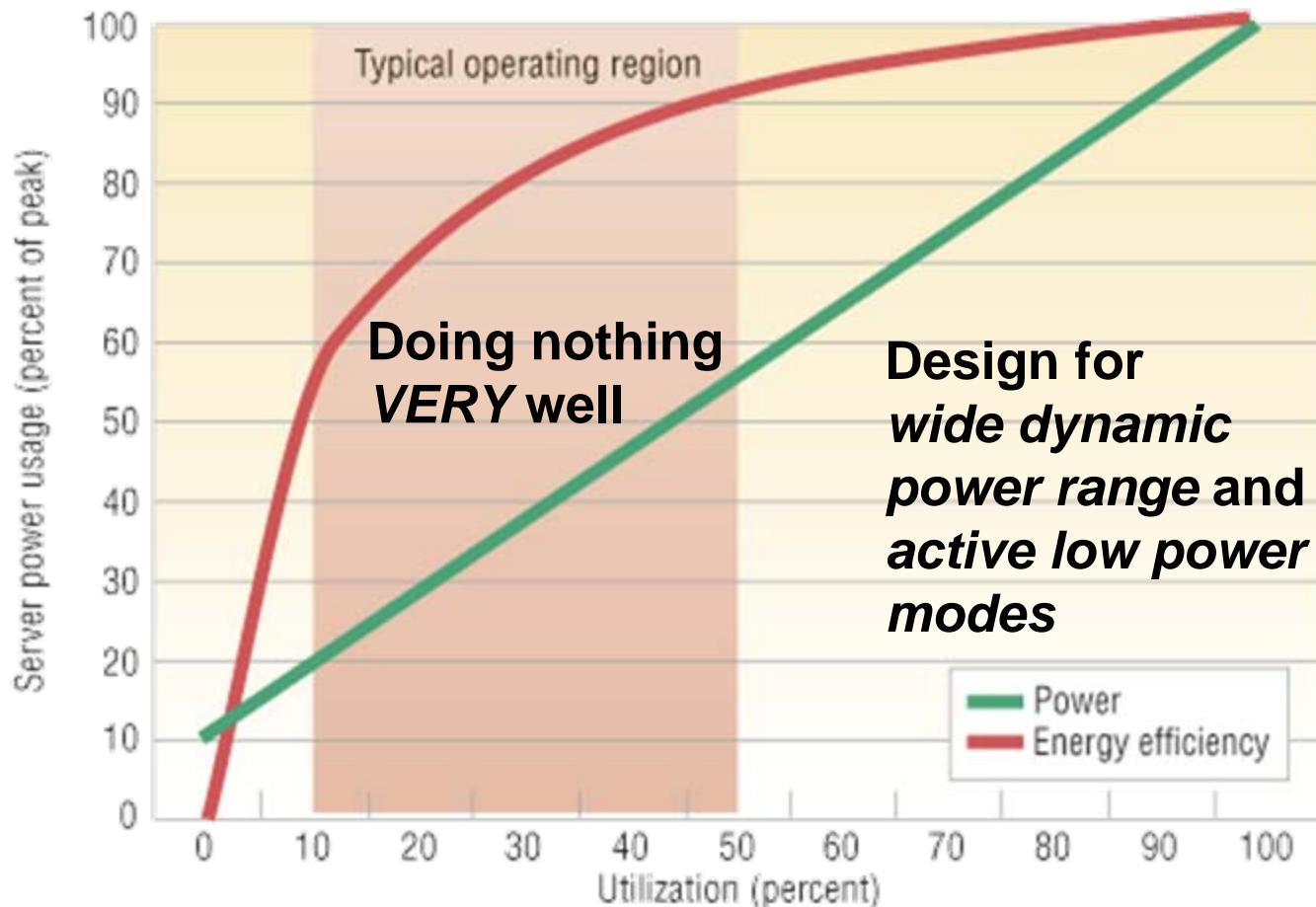
Figure 3. CPU contribution to total server power for two generations of Google servers at peak performance (the first two bars) and for the later generation at idle (the rightmost bar). 11



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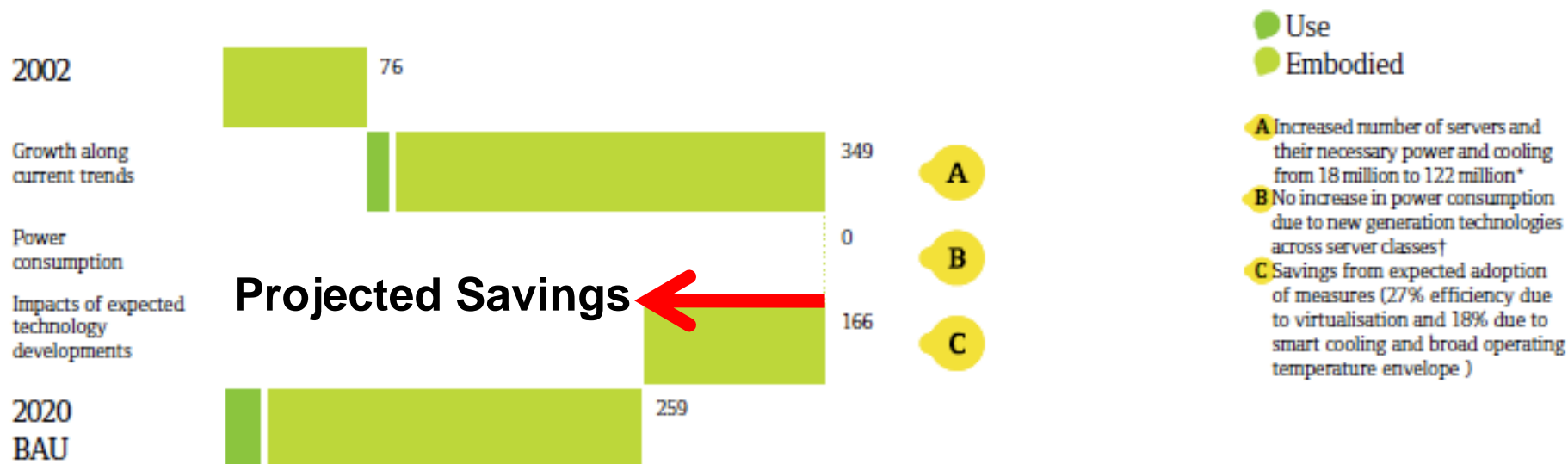


**Figure 4. Power usage and energy efficiency in a more energy-proportional server. This server has a power efficiency of more than 80 percent of its peak value for utilizations of 30 percent and above, with efficiency remaining above 50 percent for utilization levels as low as 10 percent.**

## “SMART 2020: Enabling the Low Carbon Economy in the Information Age”, The Climate Group

Fig. 4.1 The global data centre footprint

MtCO<sub>2</sub>e



\*Based on IDC estimates until 2011 and trend extrapolation to 2020, excluding virtualisation.

†Power consumption per server kept constant over time.



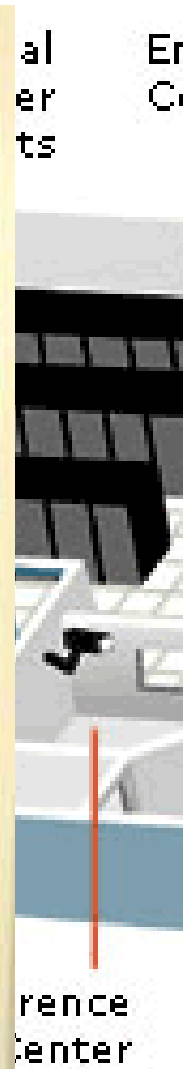


# Internet Datacenters



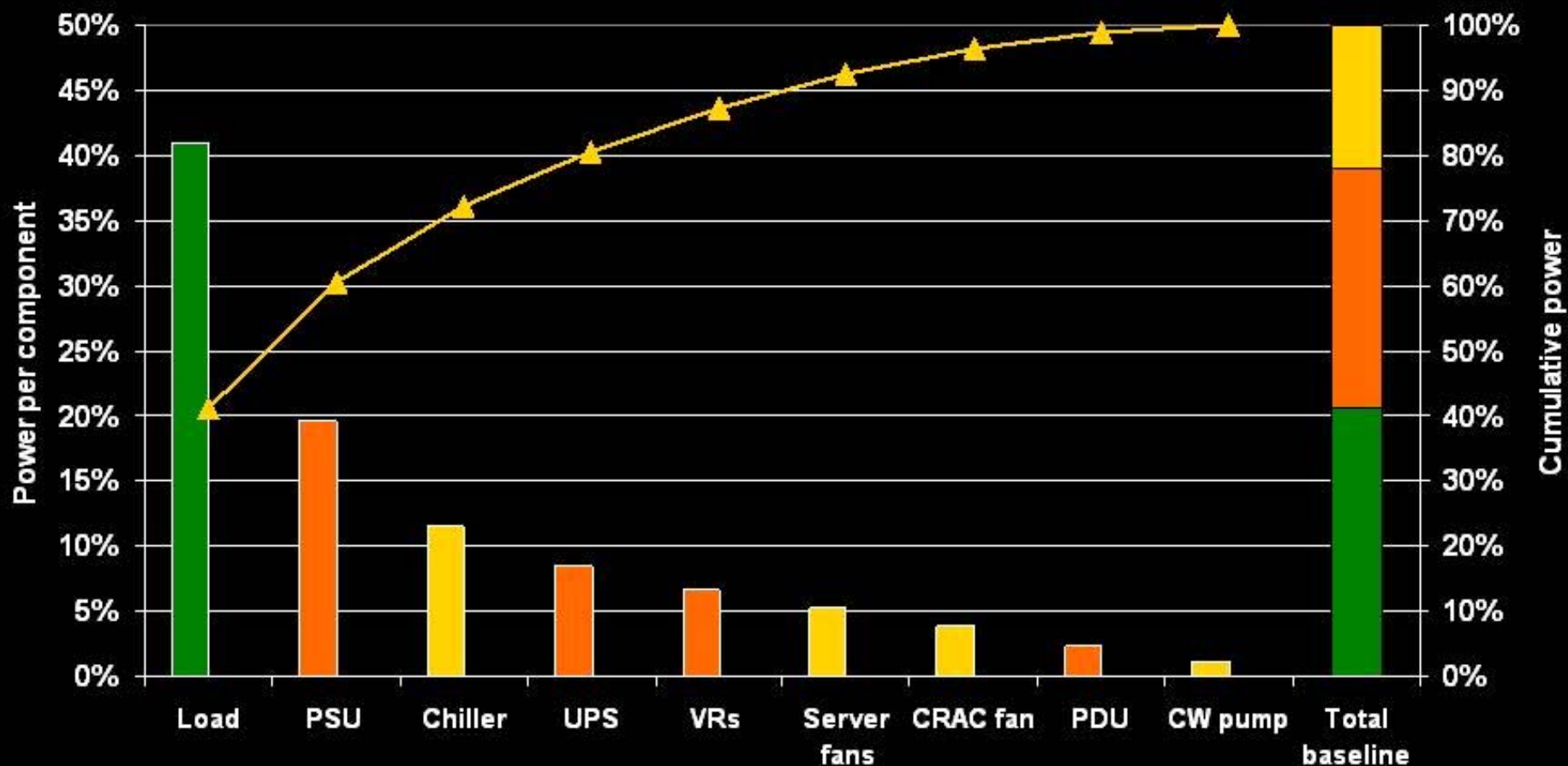


# Computers + Net + Storage + *Power* + *Cooling*



# Energy Use In Datacenters

## Electricity Flows in Data Centers



# Containerized Datacenter Mechanical-Electrical Design

Inside Project Blackbox, racks of up to 38 servers apiece generate tremendous heat. A panel of fans in front of each rack forces warm exhaust air through a heat exchanger, which cools the air for the next rack (left), and so on in a continuous loop.

## DESIGN SPECS

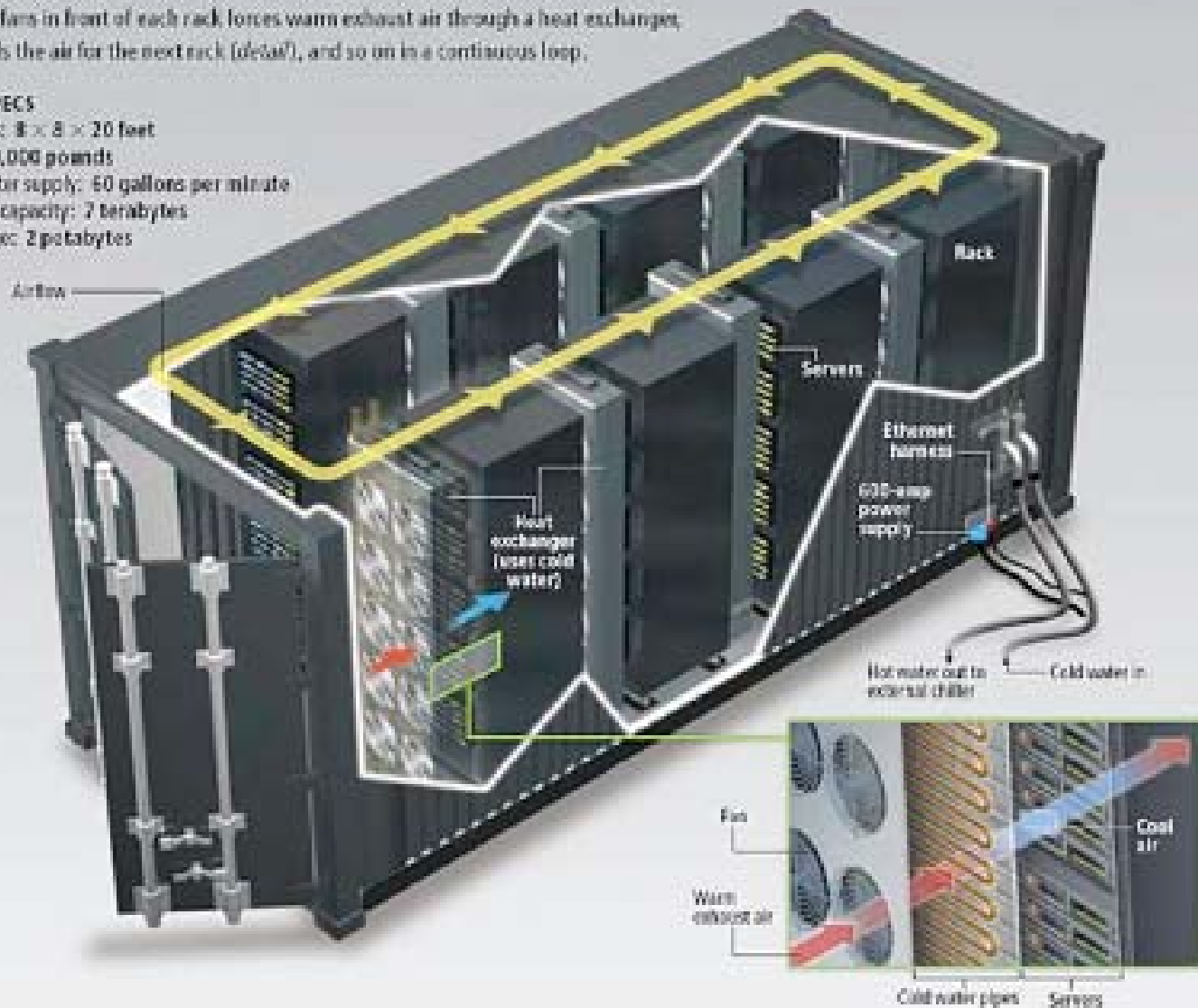
Dimensions: 8 x 8 x 20 feet

Weight: 20,000 pounds

Cooling water supply: 60 gallons per minute

Computing capacity: 7 terabytes

Data storage: 2 petabytes







# Microsoft's Chicago Modular Datacenter

**COOLING:** High-efficiency water-based cooling systems—less energy-intensive than traditional chillers—circulate cold water through the containers to remove heat, eliminating the need for air-conditioned rooms.

**STRUCTURE:** A 24,000-square-meter facility houses 400 containers. Delivered by trucks, the containers attach to a spine in a structure that feeds network connectivity, power, and water. The data center has no conventional aisled floors.

**POWER:** Two power substations feed a total of 300 megawatts to the data center, with 200 MW used for computing equipment and 100 MW for cooling and electrical losses. Batteries and generators provide backup power.

Power and water distribution

Water-based cooling system

**CONTAINERS:** Each 675-cubic-meter container houses 2500 servers, about 10 times as many as a conventional data center packs in the same space. Each container integrates computing, networking, power, and cooling systems.

Racks of servers  
Power supply

Truck carrying container

## The Million-Server Data Center

Today's most advanced data centers house tens of thousands of servers. What would it take to house 1 million?

ILLUSTRATION: MPM AND CHARTER OF CHICAGO



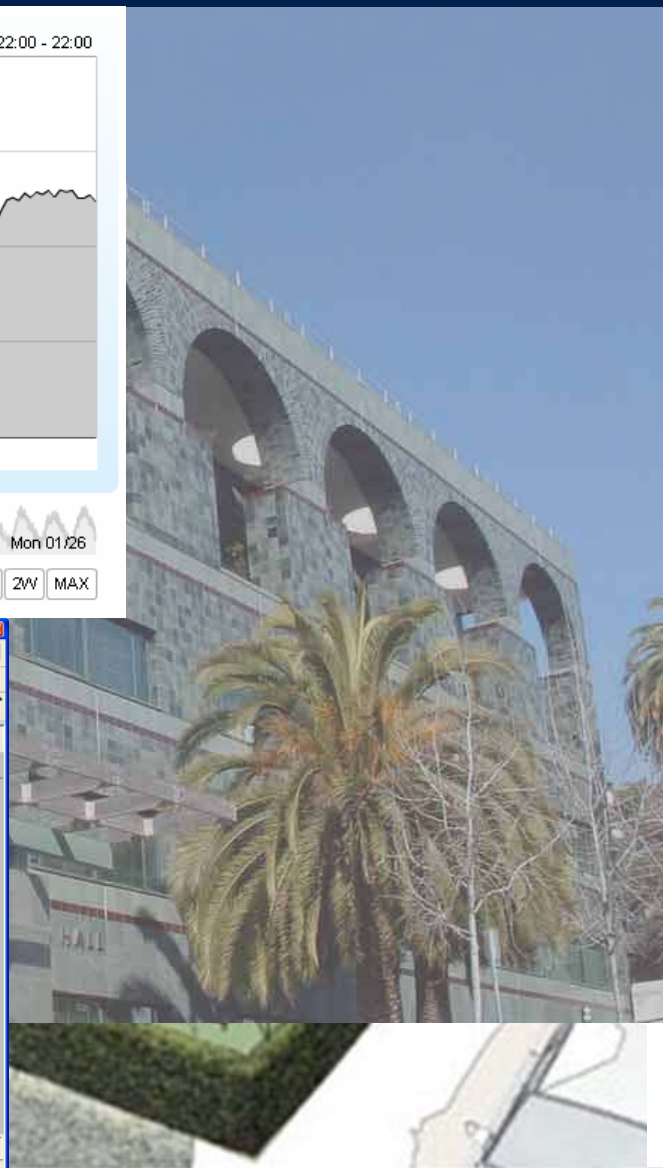
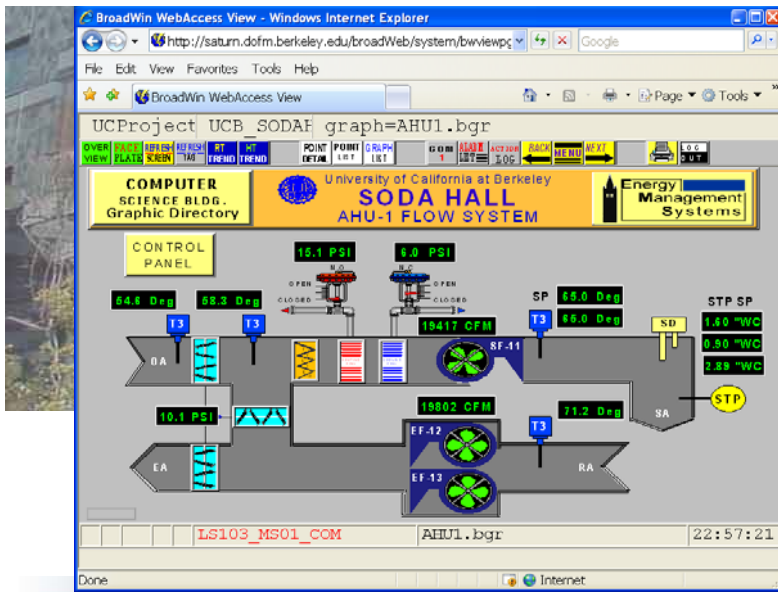
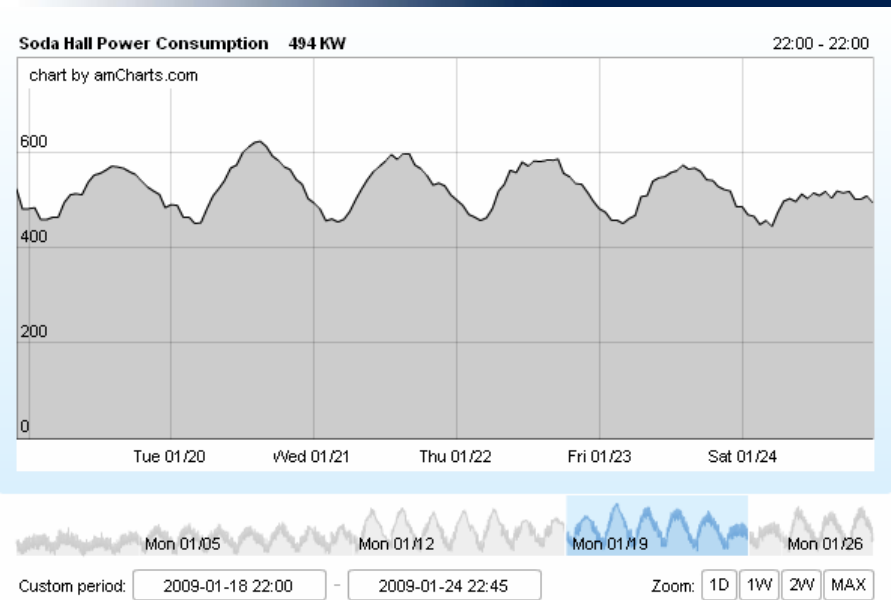


# The Million Server Datacenter

- 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<sub>19</sub>



# Smart Buildings





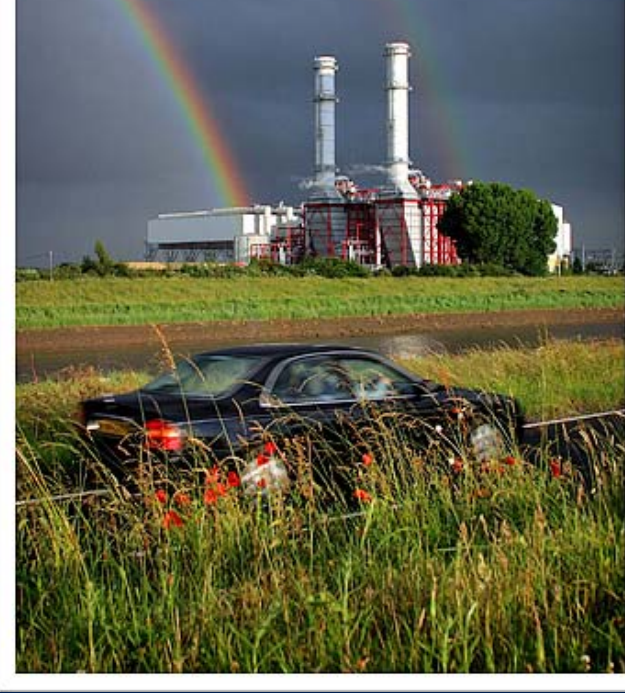
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- IT as an **Efficiency Enabler**
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# Machine Age Energy Infrastructure





# Accommodate 21<sup>st</sup> Century Renewable Energy Sources



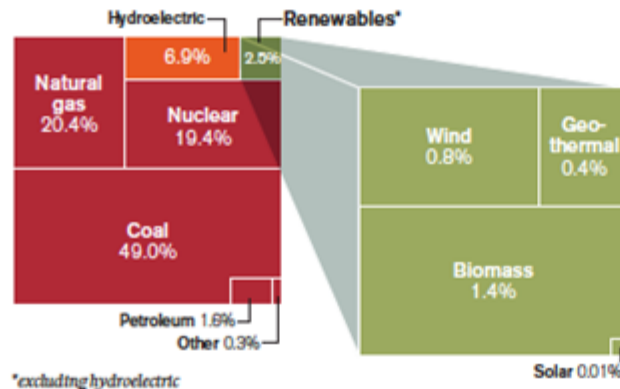


# Challenge of Integrating Intermittent Sources

## NEEDED: A GRID FOR RENEWABLE POWER

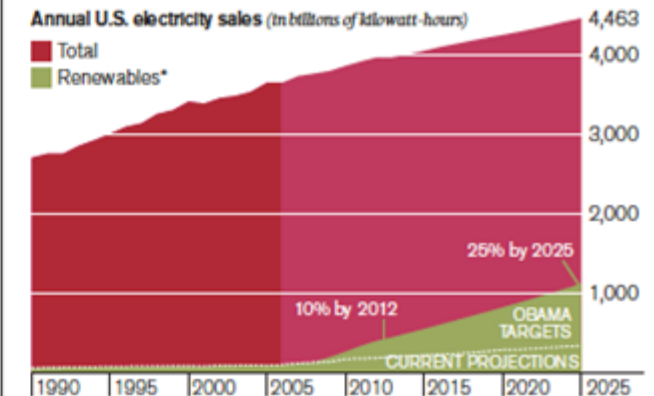
### Sources of U.S. electricity

Today, renewable sources provide little U.S. electricity. Wind and solar together furnish less than 1 percent ...



### Growing electricity demand

... but the fraction coming from renewable sources is projected to rise sharply—as is total demand.



### Onshore wind-power resources

The strongest, steadiest winds are concentrated in the Great Plains ...

#### Wind-power potential

Superb Outstanding Excellent  
Good Fair



### Solar-power resources

... and the strongest, clearest sun exposure is in the Southwest ...

#### Solar-power potential\*

6.5-7.0 6.0-6.5 5.5-6.0 5.0-5.5  
4.5-5.0 4.0-4.5 3.5-4.0



### Today's electricity grid

... but existing transmission lines are centered on areas of high population, with inadequate high-voltage links to the areas with the best wind and solar resources. Fatter lines show higher-voltage connections.



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

# California as a Testbed

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

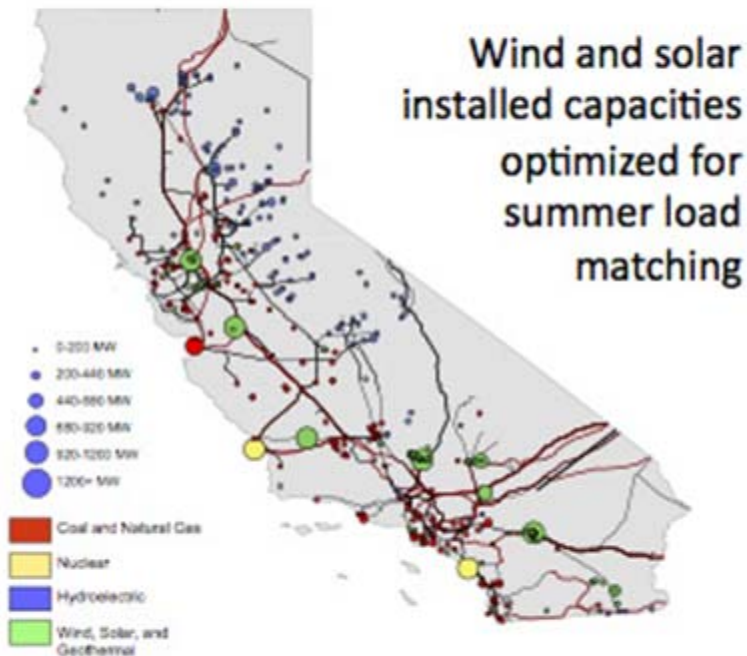
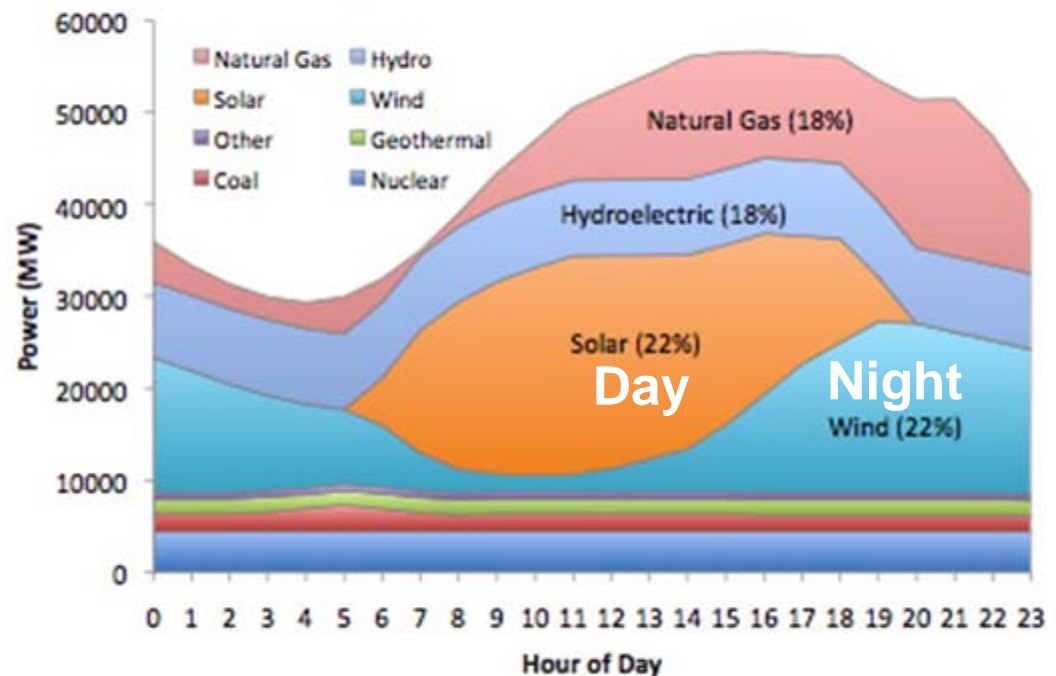


Figure 6. California power generation on July 2016 Day High-Renewable Penetration Case



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



# What if the Energy Infrastructure were Designed like the Internet?

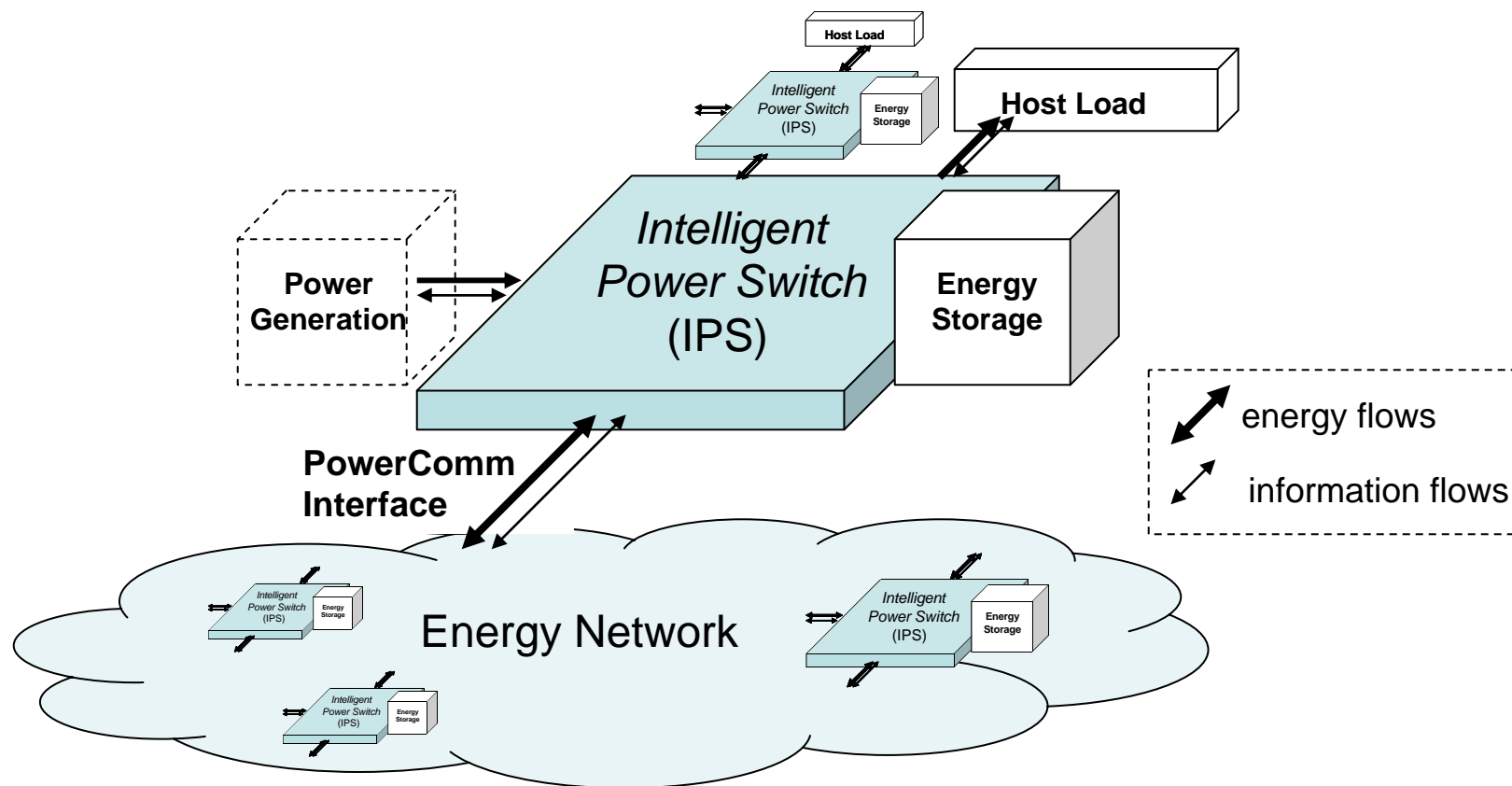
- Energy: *the* limited resource of the 21st Century
- Needed: Information Age approach to the Machine Age infrastructure
- Lower cost, more incremental deployment, suitable for developing economies
- Enhanced reliability and resilience to wide-area outages, such as after natural disasters
- *Packetized Energy*: discrete units of energy locally generated, stored, and forwarded to where it is needed; enabling a market for energy exchange



# Intelligent Power Switch

- *Interconnects* load to power sharing infrastructure
- *Bundles* communications with energy interconnection -- PowerComm interface
- Enables *intelligent* energy exchange
- Optionally incorporates energy *generation* and *storage*
  - Scale-down to individual loads, e.g., light bulb, refrigerator
  - Scale-up to neighborhoods, regions, etc.
- Overlay on the existing power grid

# Intelligent Power Switch



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



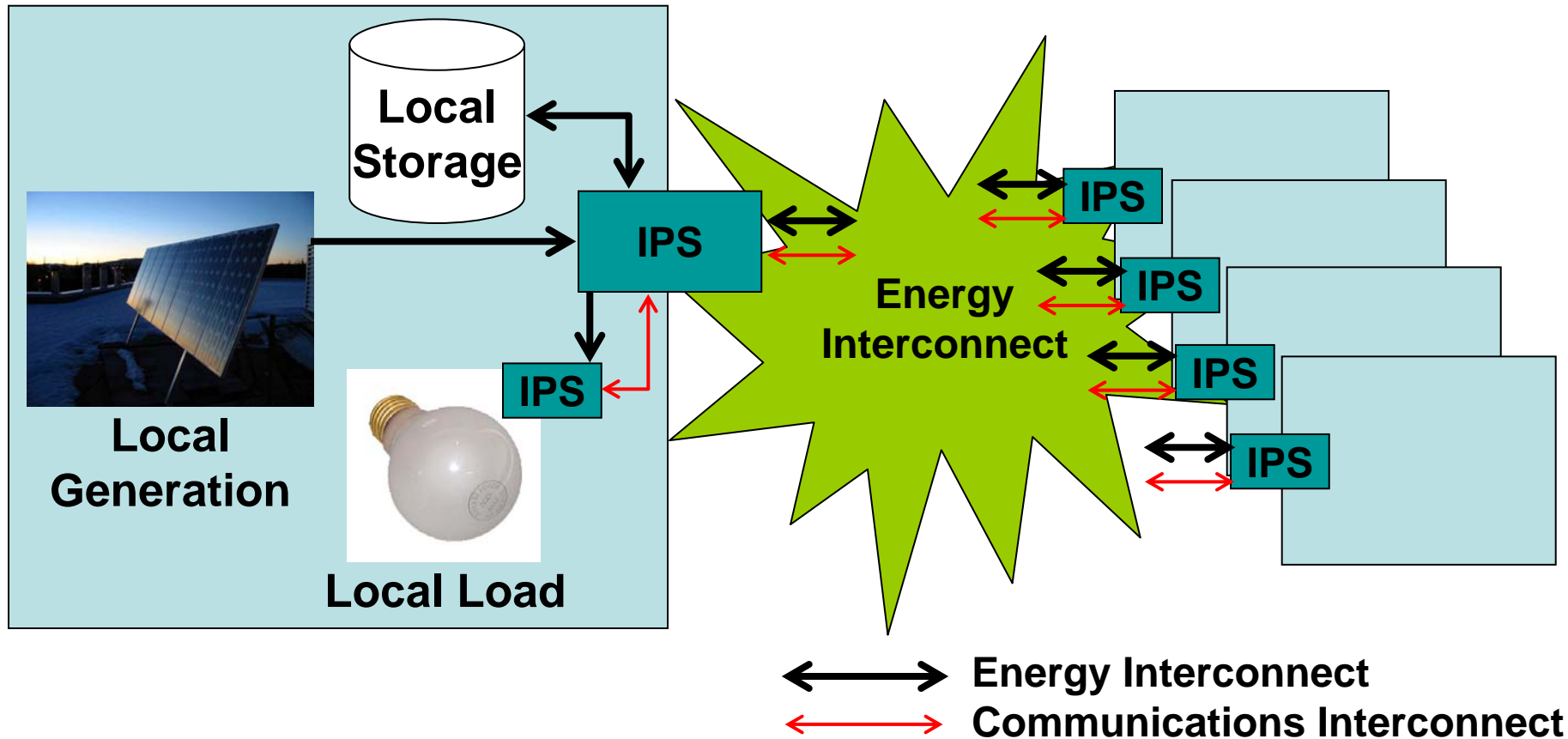


# “Doing Nothing Well”

## Existing Systems Sized for Peak

- Exploit huge gap in IT equipment peak-to-average processing/energy consumption
- Demand response
  - Challenge “always on” assumption for desktops and appliances
  - Realize potential of energy-proportional computing
- Better fine-grained idling, faster power shutdown/restoration
- Beyond architecture/hardware: pervasive support in operating systems and applications

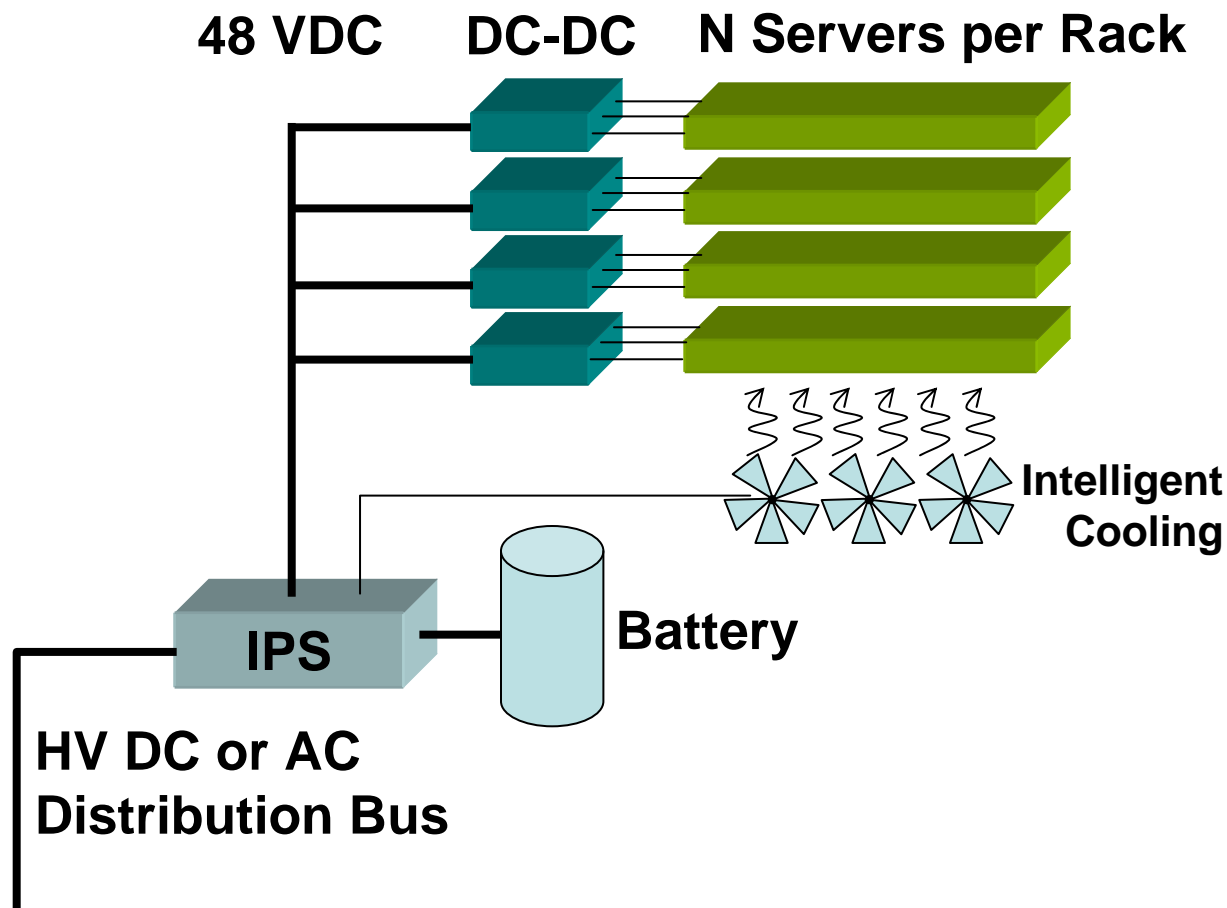
# Energy Markets



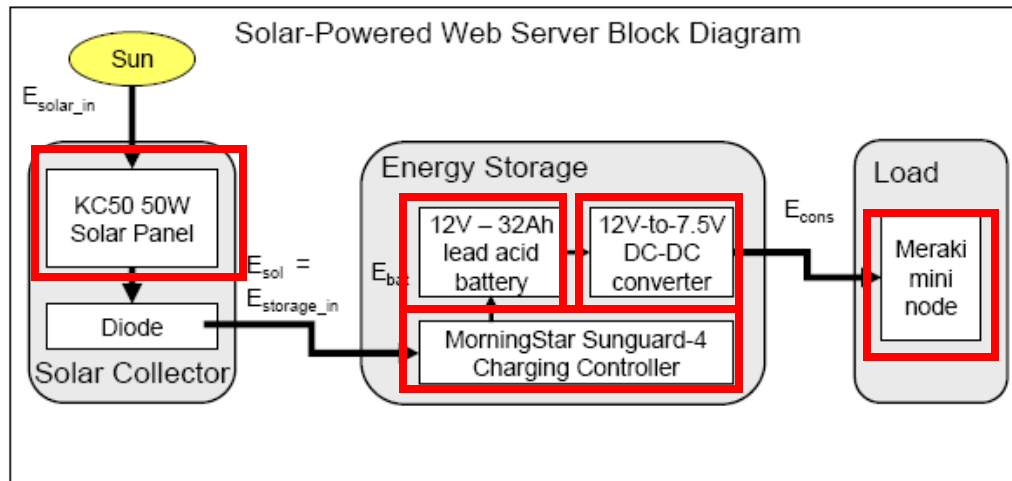
- Hierarchical aggregates of loads and IPSs
- Overlay on existing Energy Grid

## Rack Unit

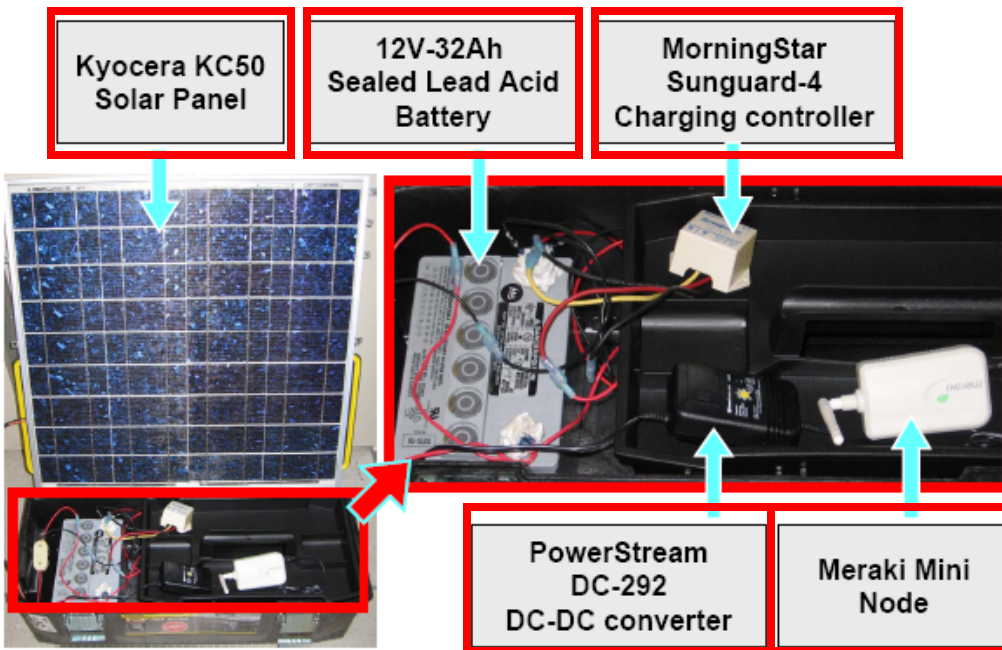
- Replace AC power supply in servers with DC-DC converters to generate required voltages
- Battery capacity per rack to simplify design of the DC-DC converter, centralizing the charge controller and energy sharing function in the IPS
- Distributed DC-DC converters provide regulation at the load



## LoCal-ized Web Server



|                  | Description               |
|------------------|---------------------------|
| Solar Panel      | <b>50W panel</b>          |
| Input Regulator  | <b>Efficiency 89%-97%</b> |
| Energy Storage   | <b>12V-32Ah lead acid</b> |
| Output Regulator | <b>Efficiency 80%-82%</b> |
| Load             | <b>2.25W average</b>      |







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- 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 sharing marketplace at small, medium, large scale
- Demand response: doing nothing well
- Testbeds: smart buildings, e.g., datacenters

