A Computer Scientist Looks at the Energy Problem

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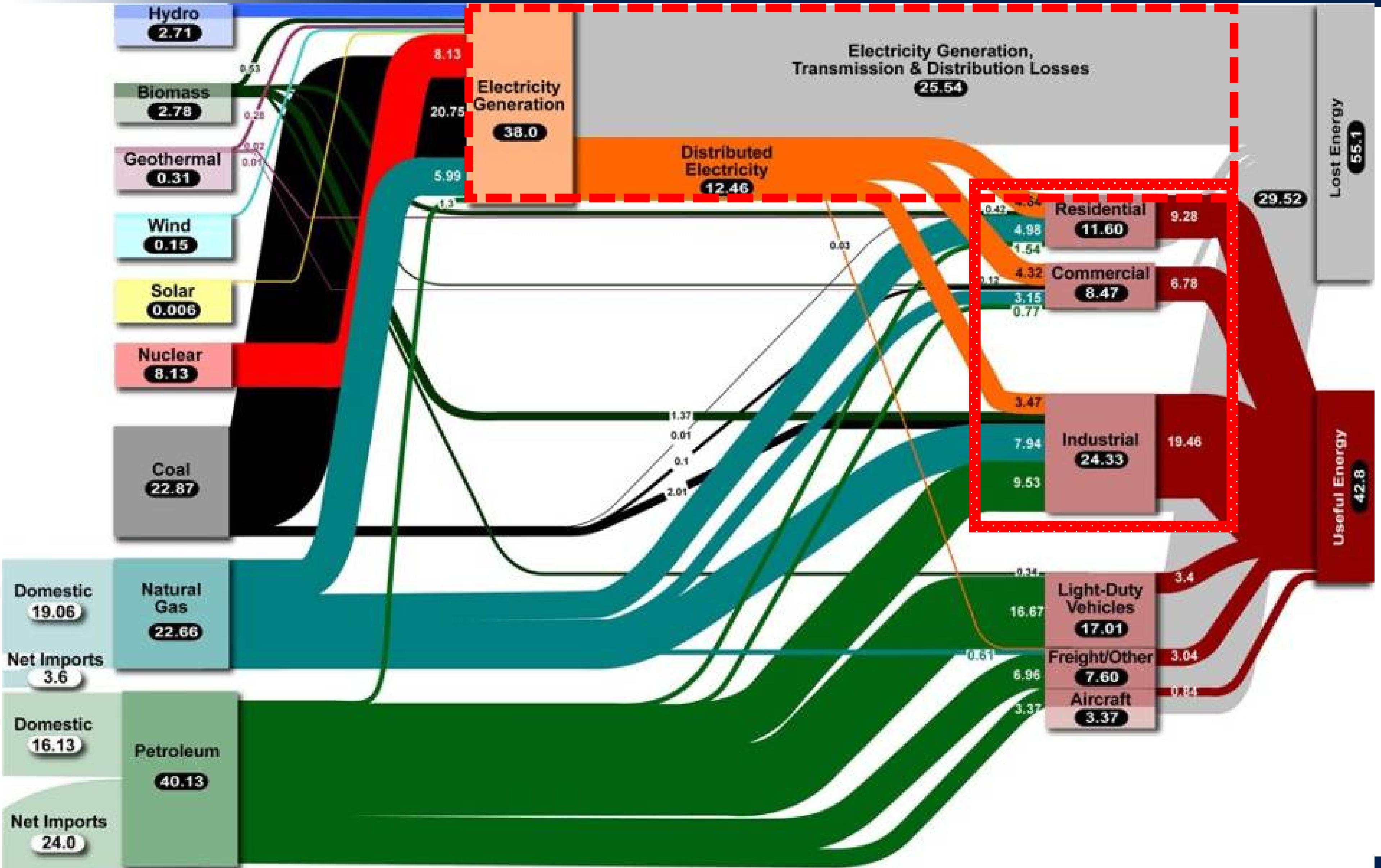
"Energy permits things to exist; information, to behave purposefully."
W. Ware, 1997

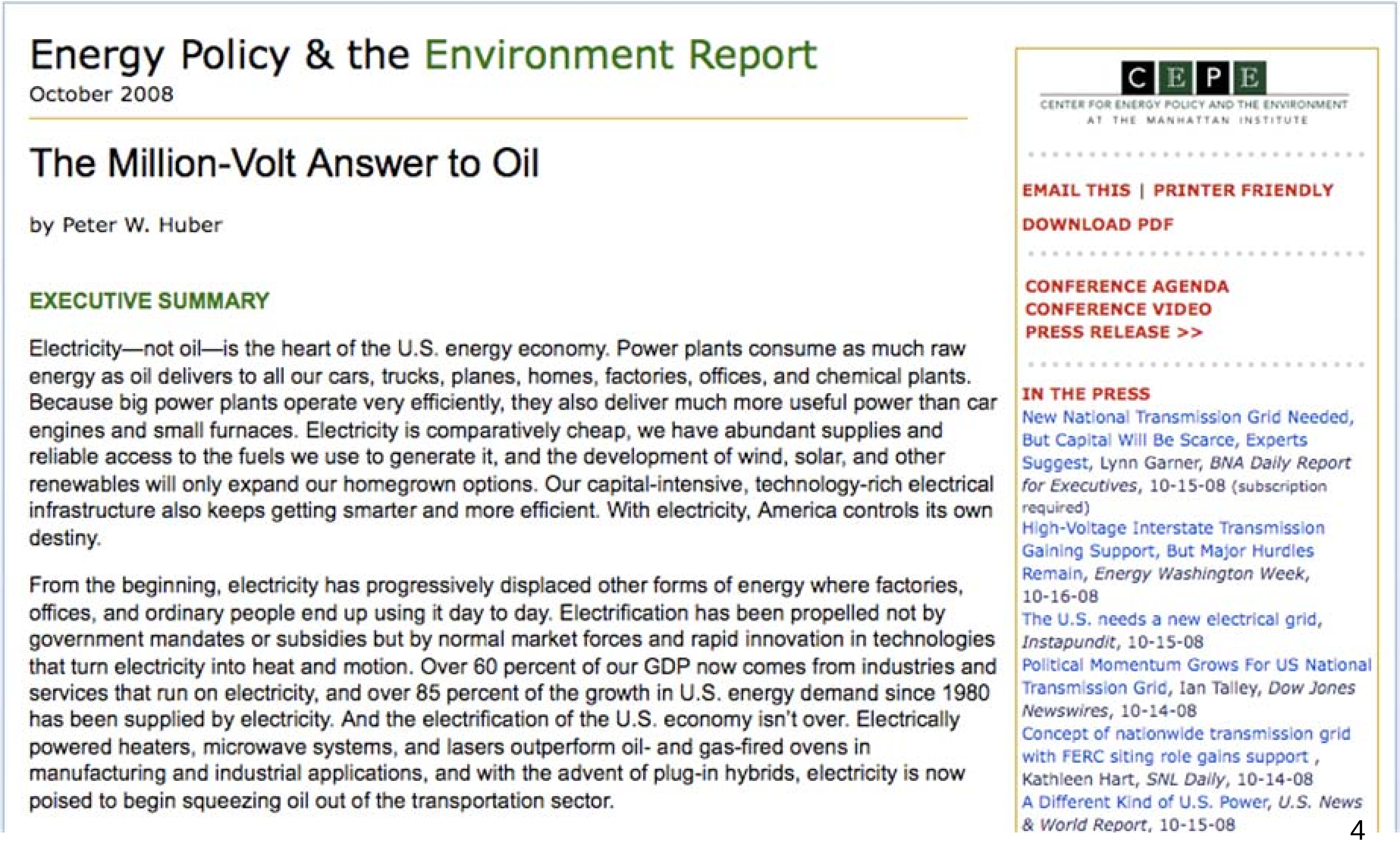
Agenda

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

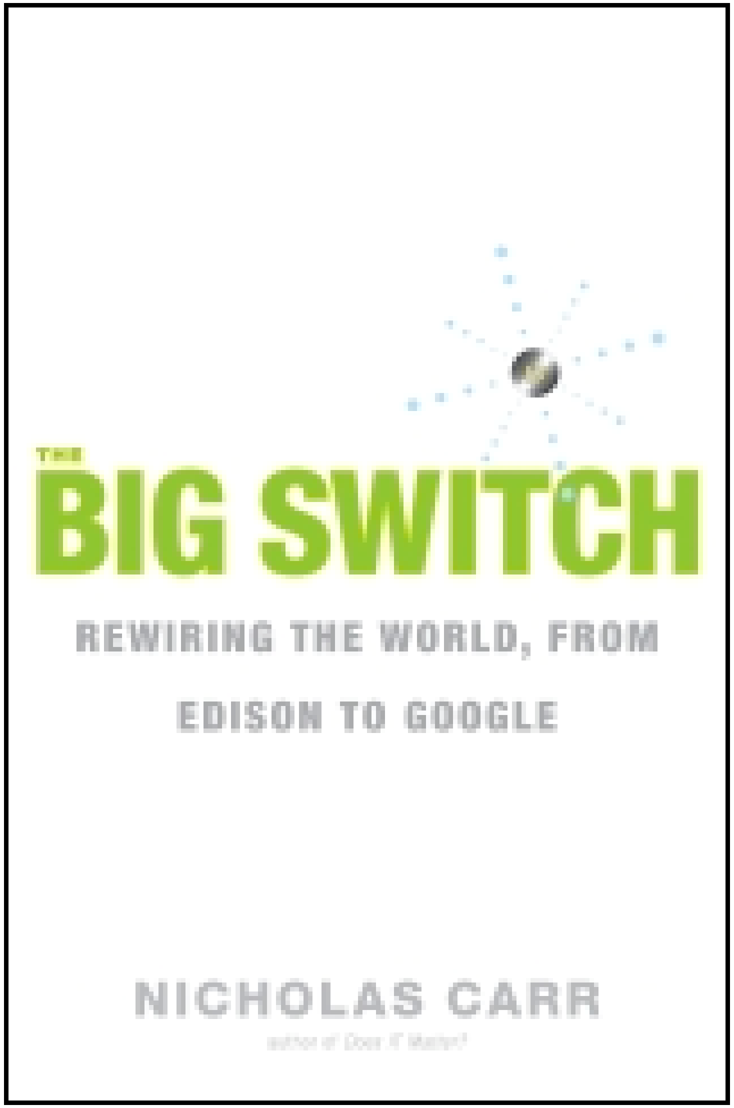
Energy "Spaghetti" Chart



Electricity is the Heart of the Energy Economy



“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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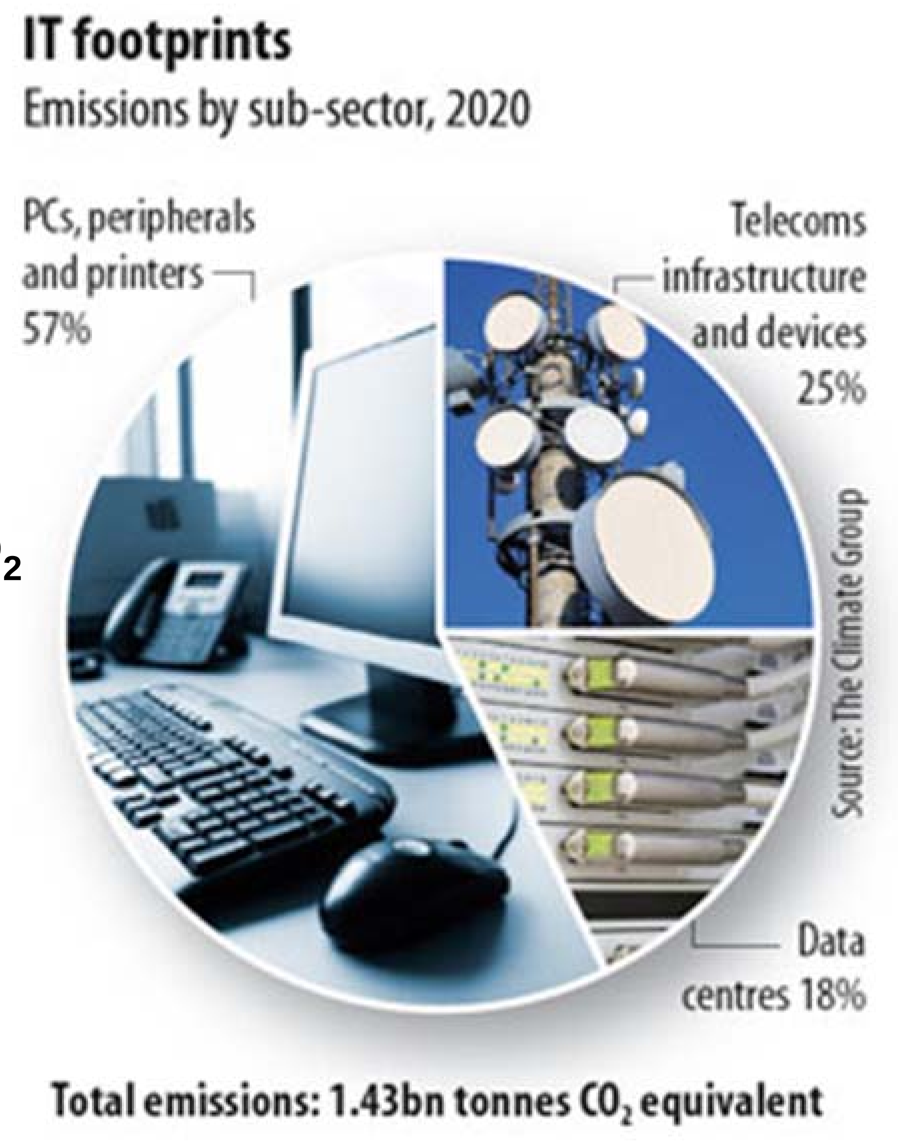
Start with IT: 2020 Carbon Footprint

820m tons CO_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



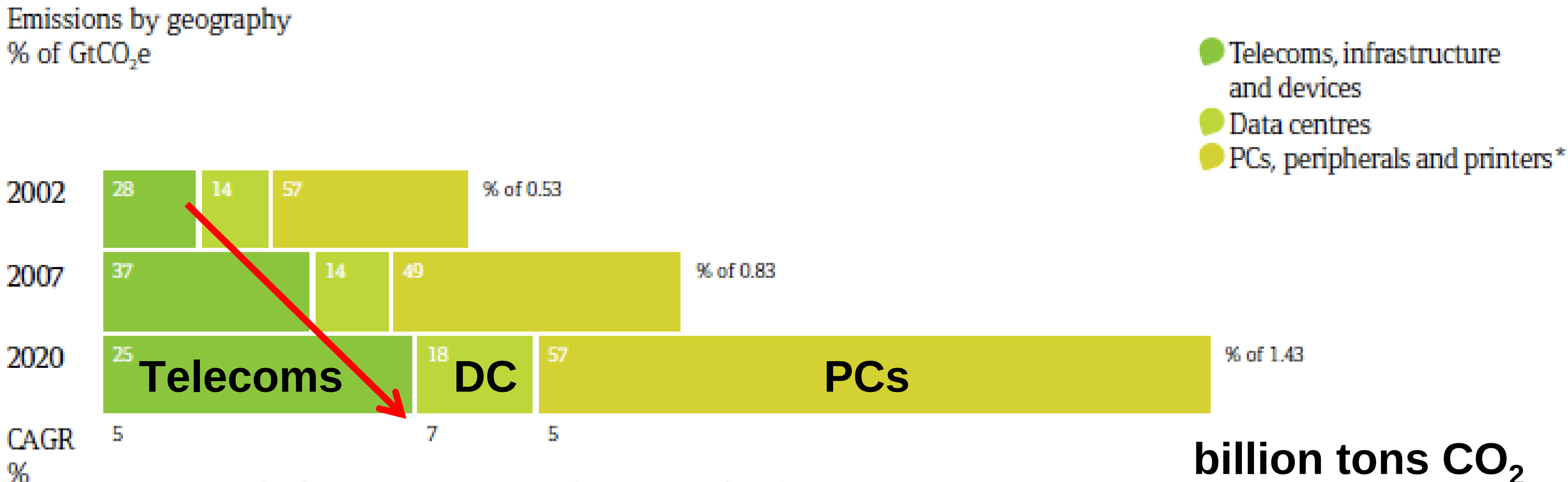
360m tons CO_2

260m tons CO_2

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



* Printers were 11% of the total ICT footprint in 2002, 8% in 2007 and will be 12% in 2020.

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

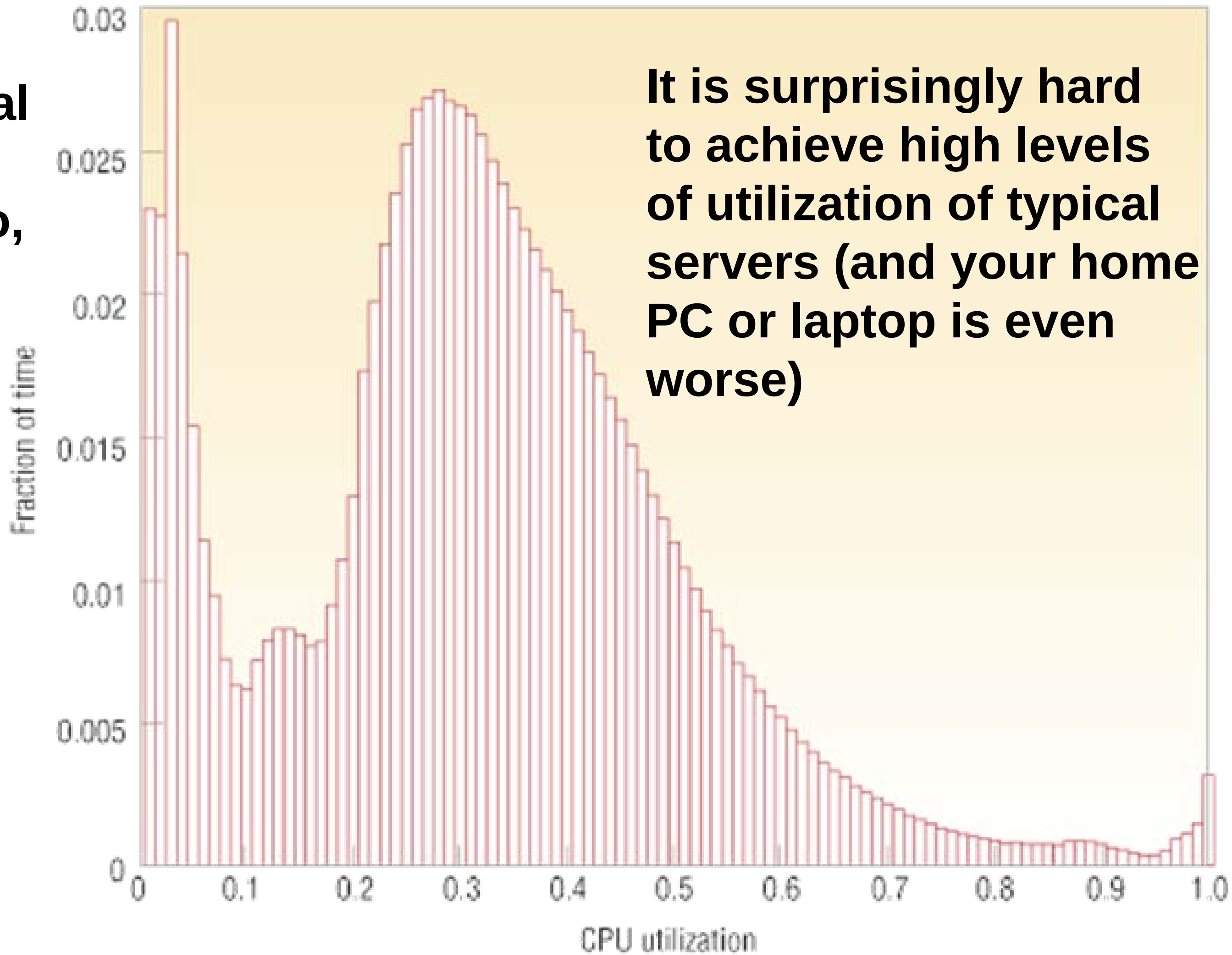


Figure 1. Average CPU utilization of more than 5,000 servers during a six-month period. Servers are rarely completely idle and seldom operate near their maximum utilization, instead operating most of the time at between 10 and 50 percent of their maximum

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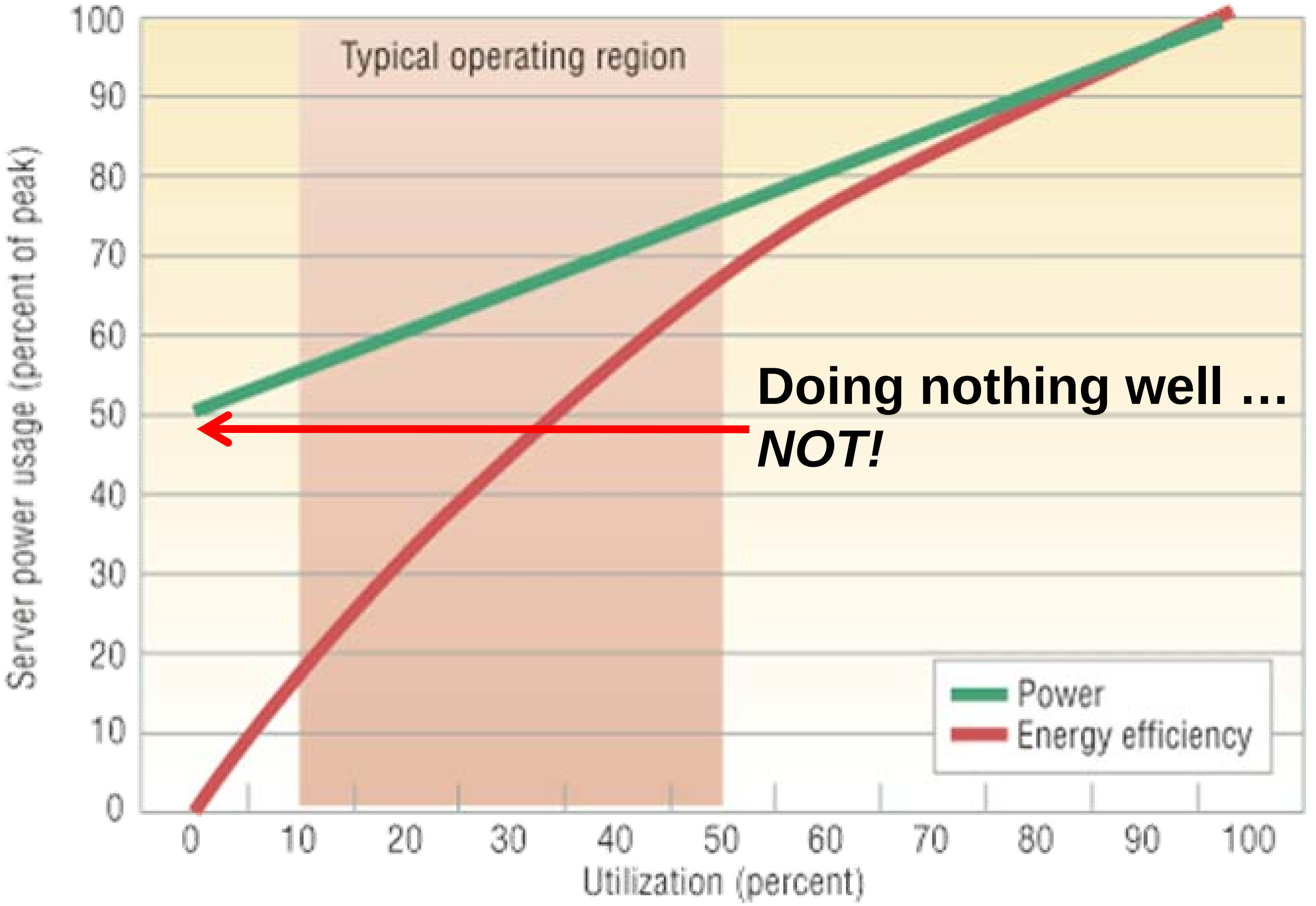

Energy Efficiency = Utilization/Power

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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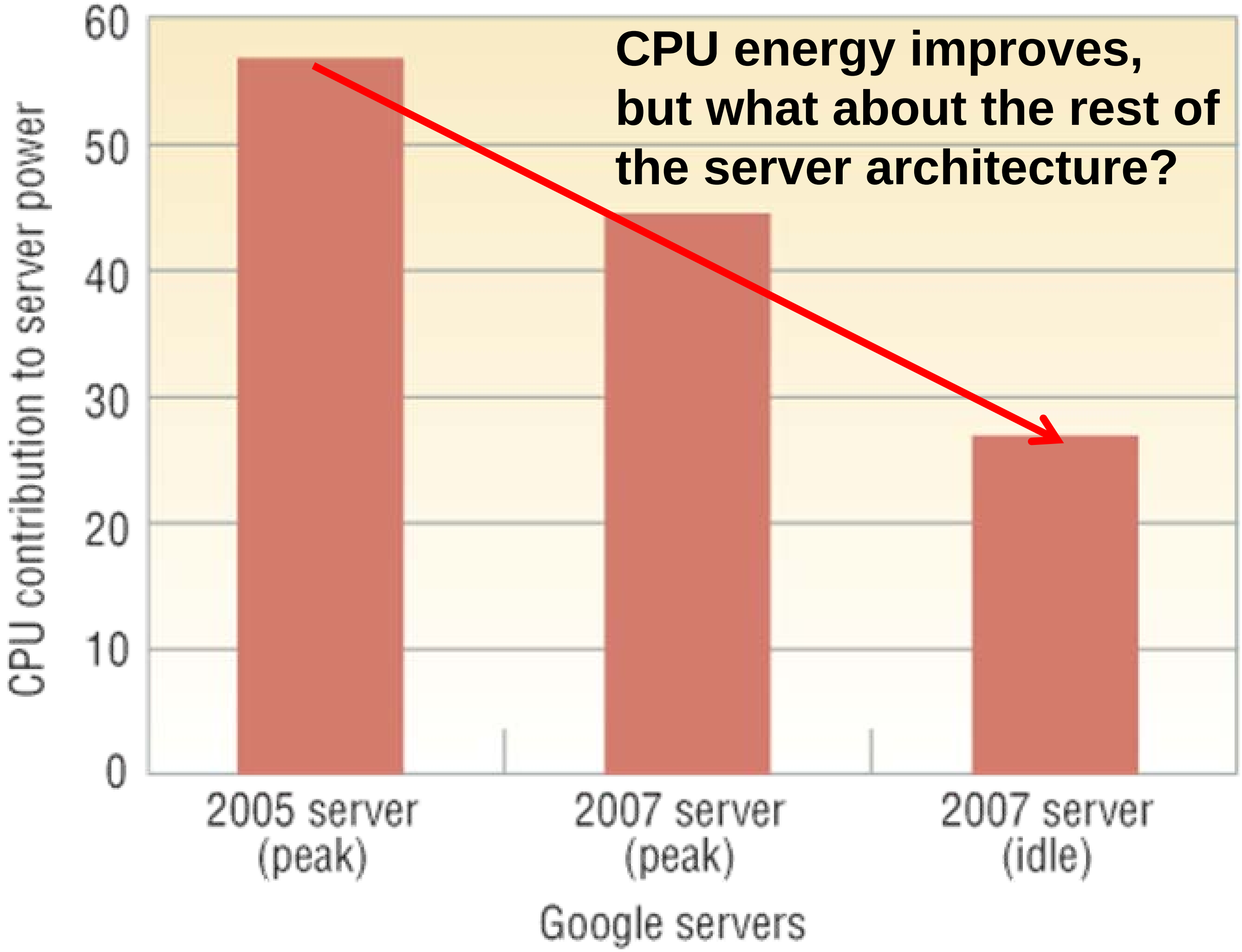
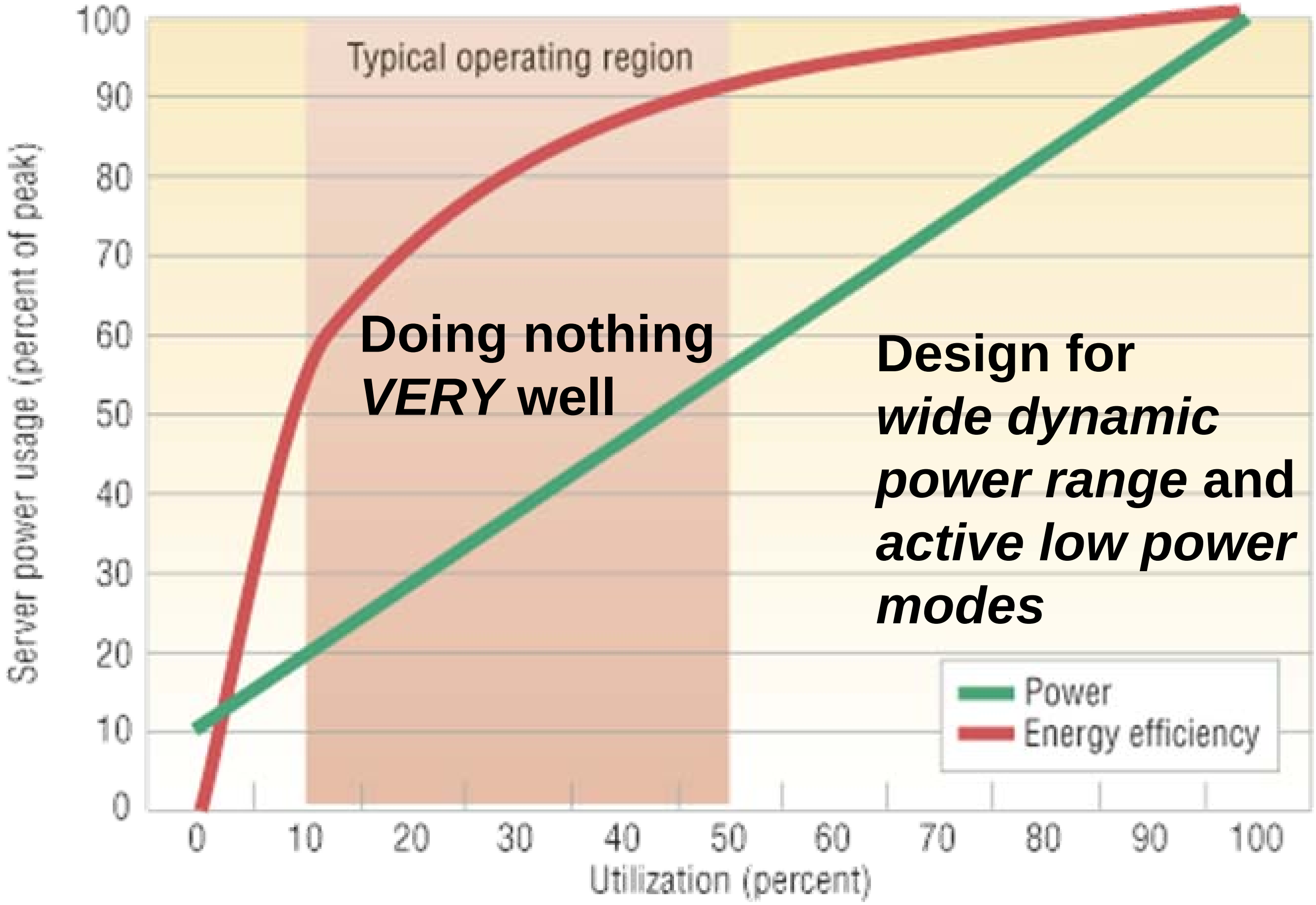


Memory?
Storage?
Network?

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).

Energy Proportional Computing

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



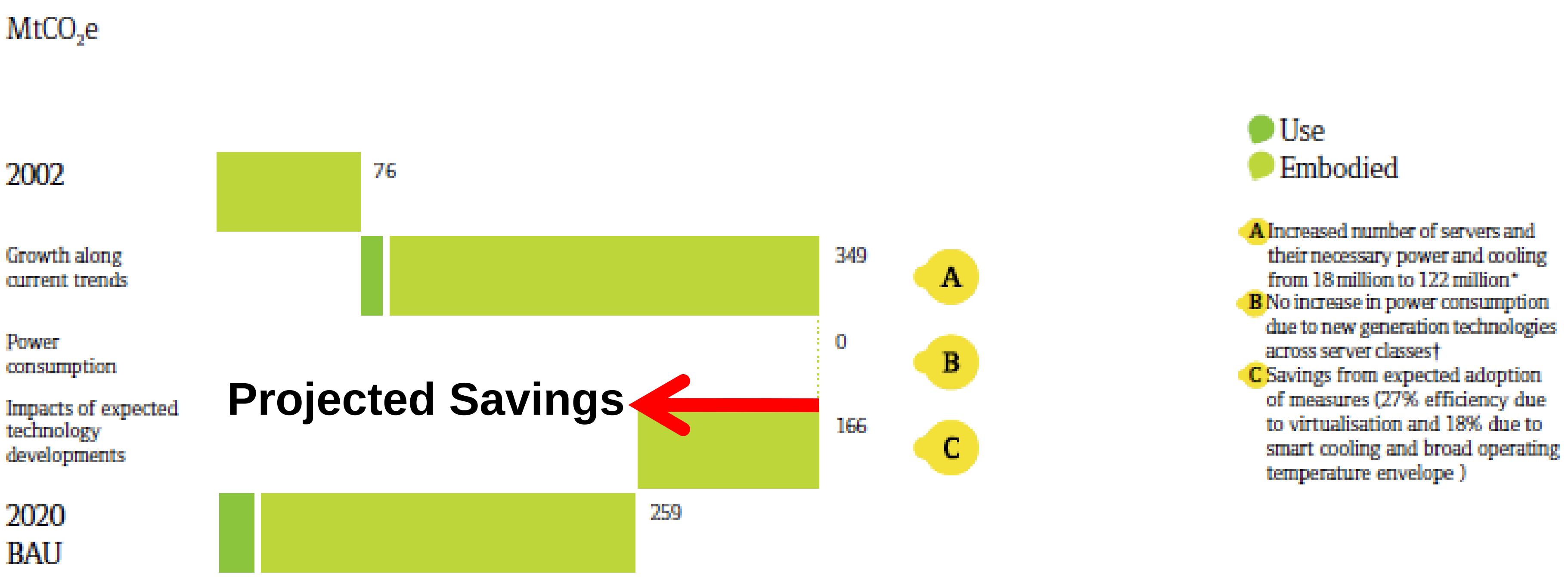
Energy Efficiency = Utilization/Power

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.

2020 IT Carbon Footprint

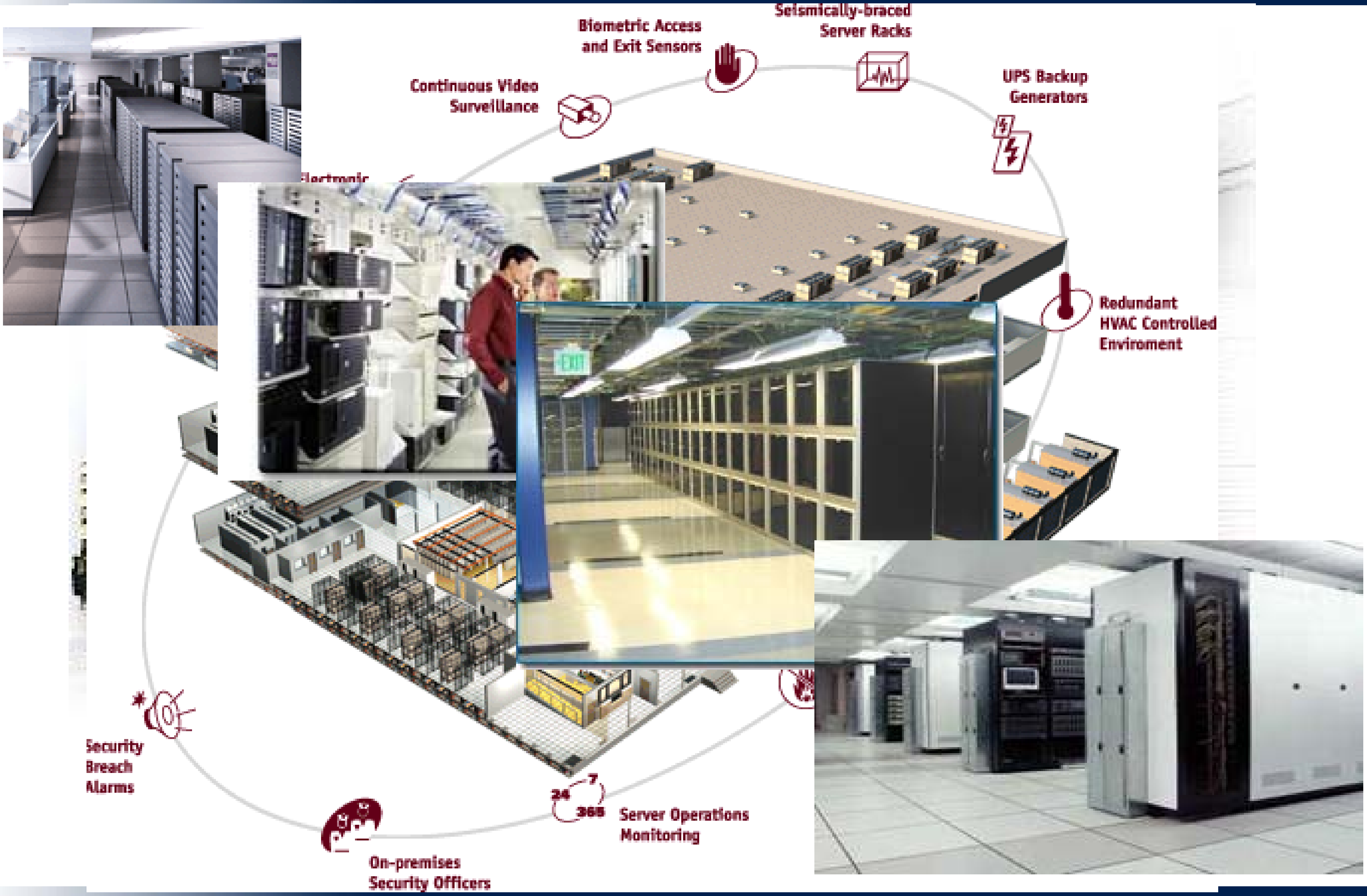
"SMART 2020: Enabling the Low Carbon Economy in the Information Age", The Climate Group

Fig. 4.1 The global data centre footprint

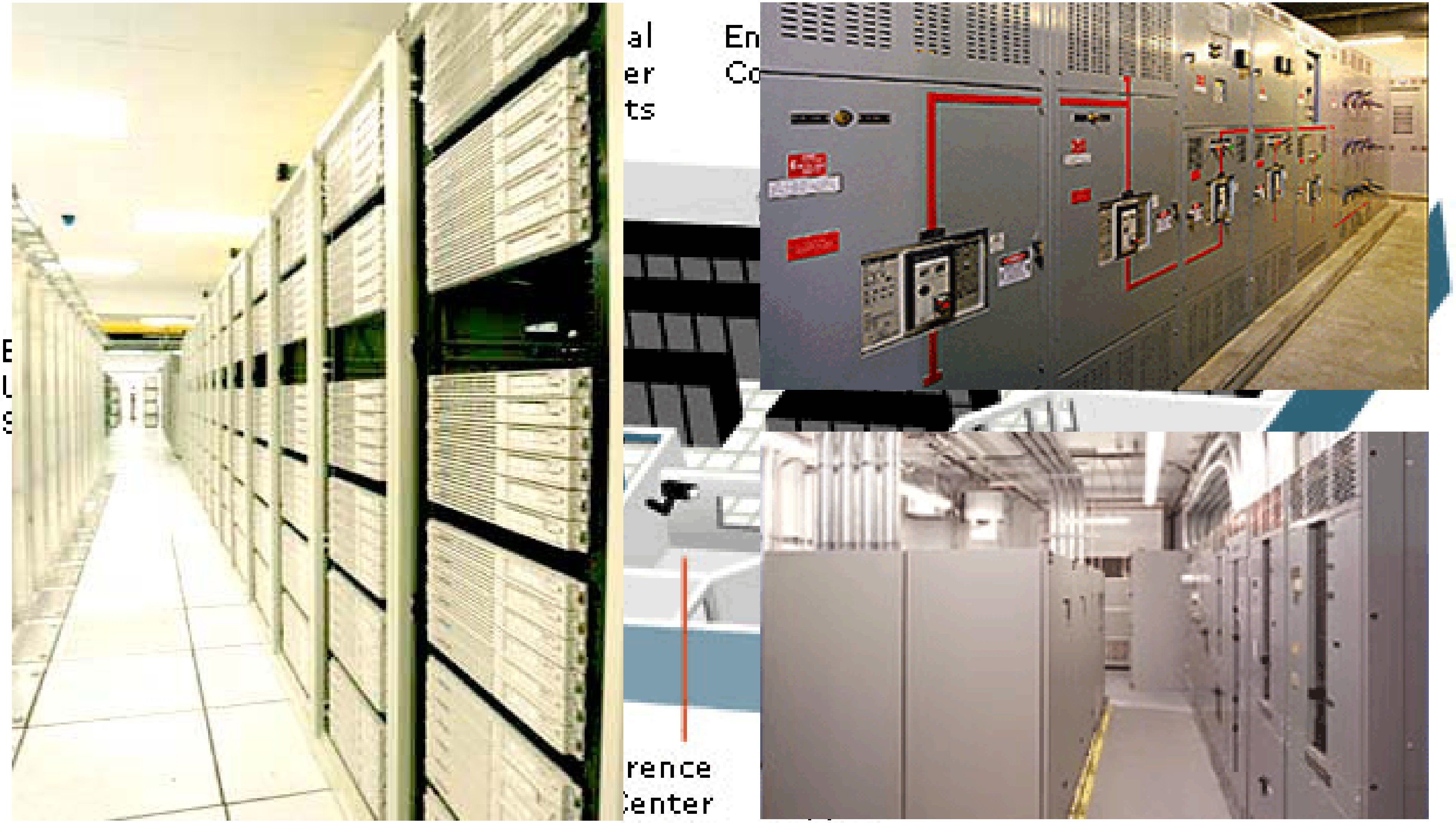


*Based on IDC estimates until 2011 and trend extrapolation to 2020, excluding virtualisation.
†Power consumption per server kept constant over time.

Internet Datacenters

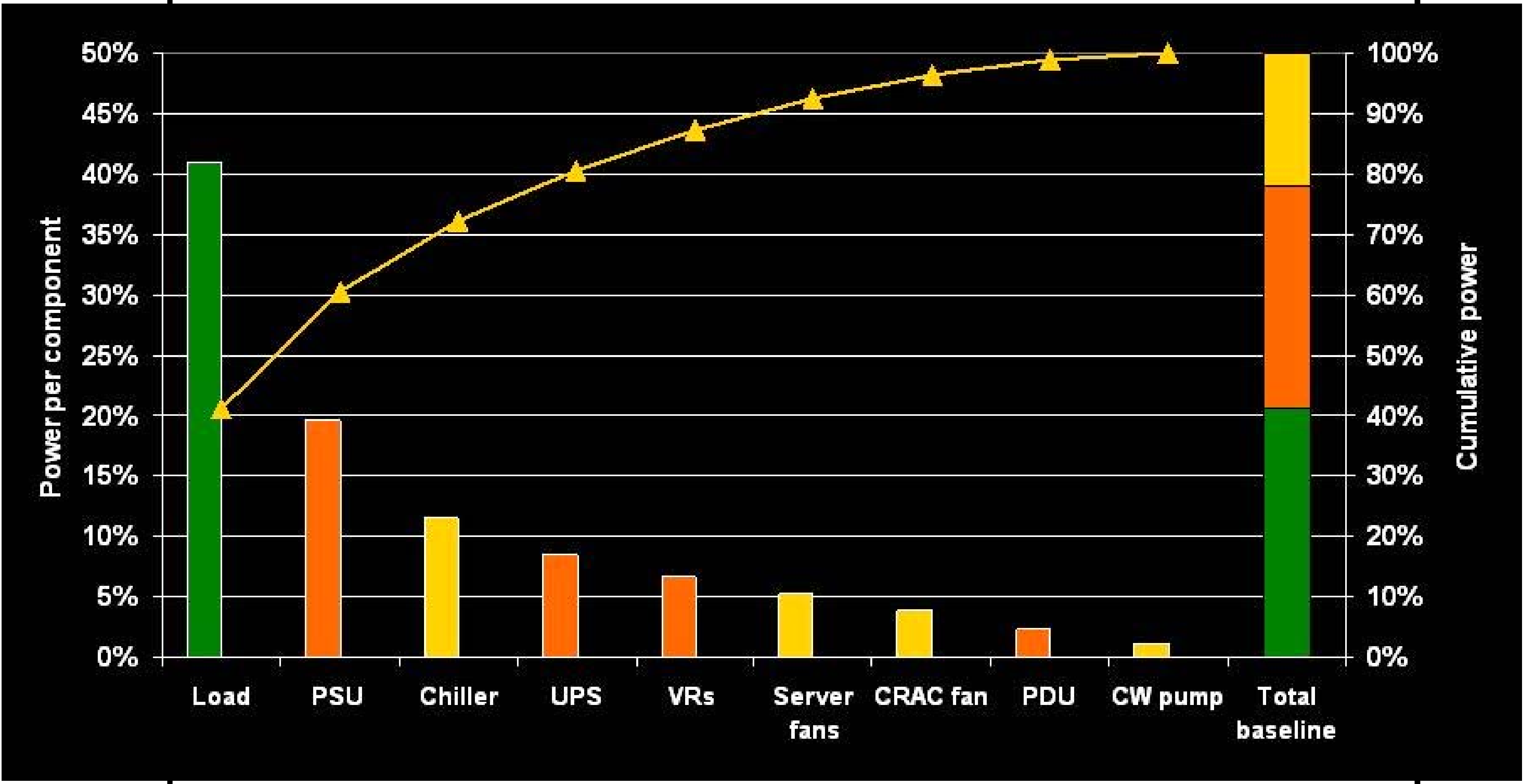


Computers + Net + Storage + *Power* + *Cooling*

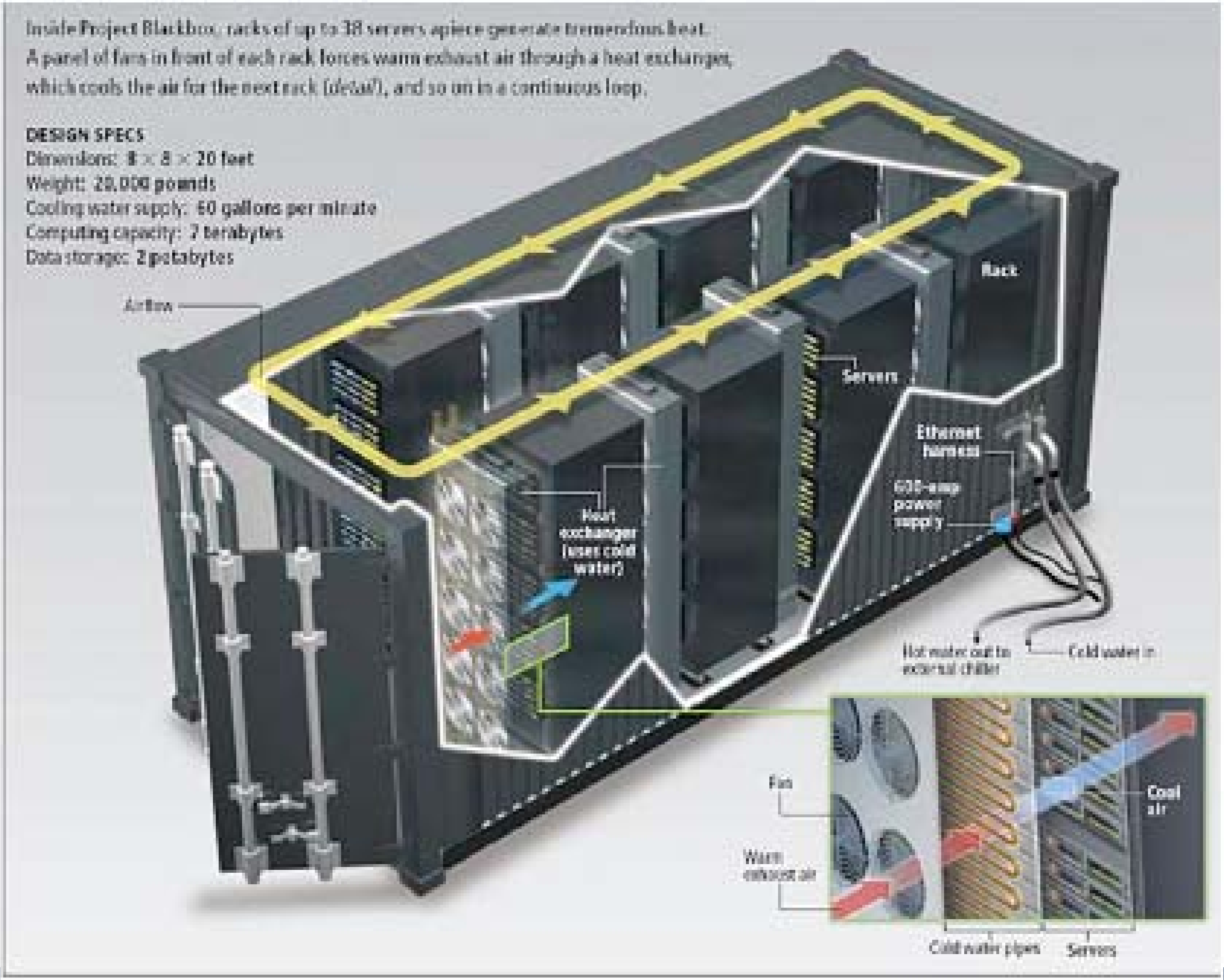


Energy Use In Datacenters

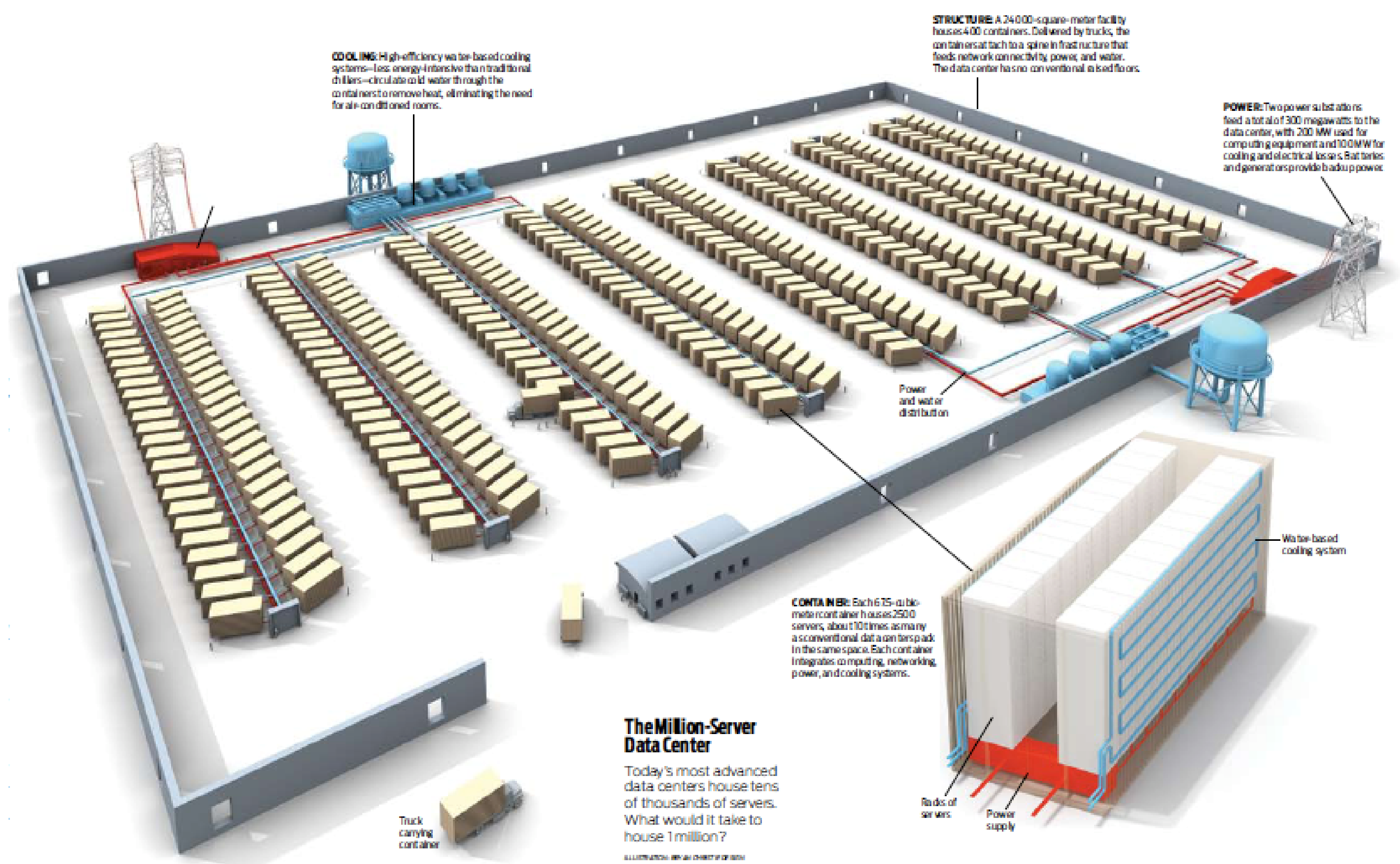
Electricity Flows in Data Centers



Containerized Datacenter Mechanical-Electrical Design



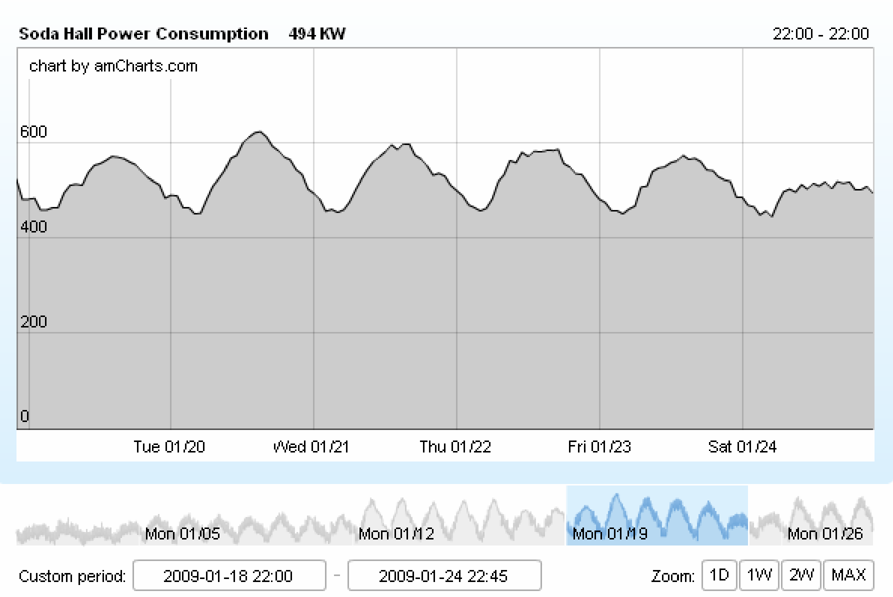
Microsoft's Chicago Modular Datacenter

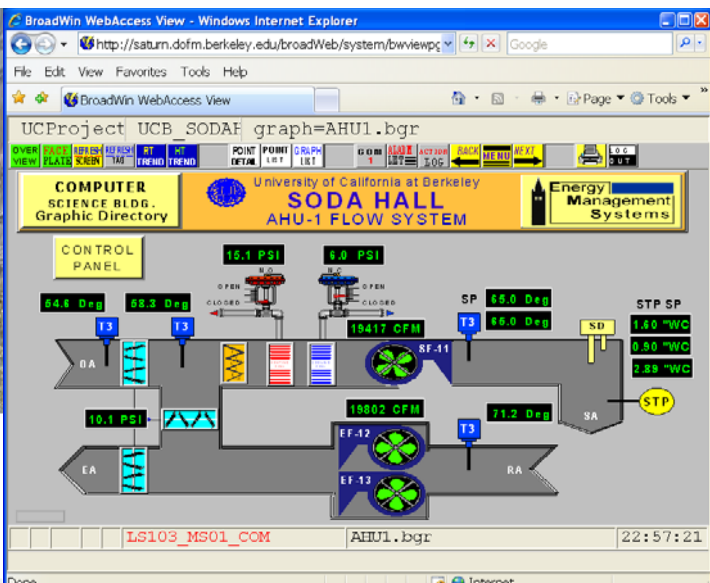


The Million Server Datacenter

- 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

Smart Buildings





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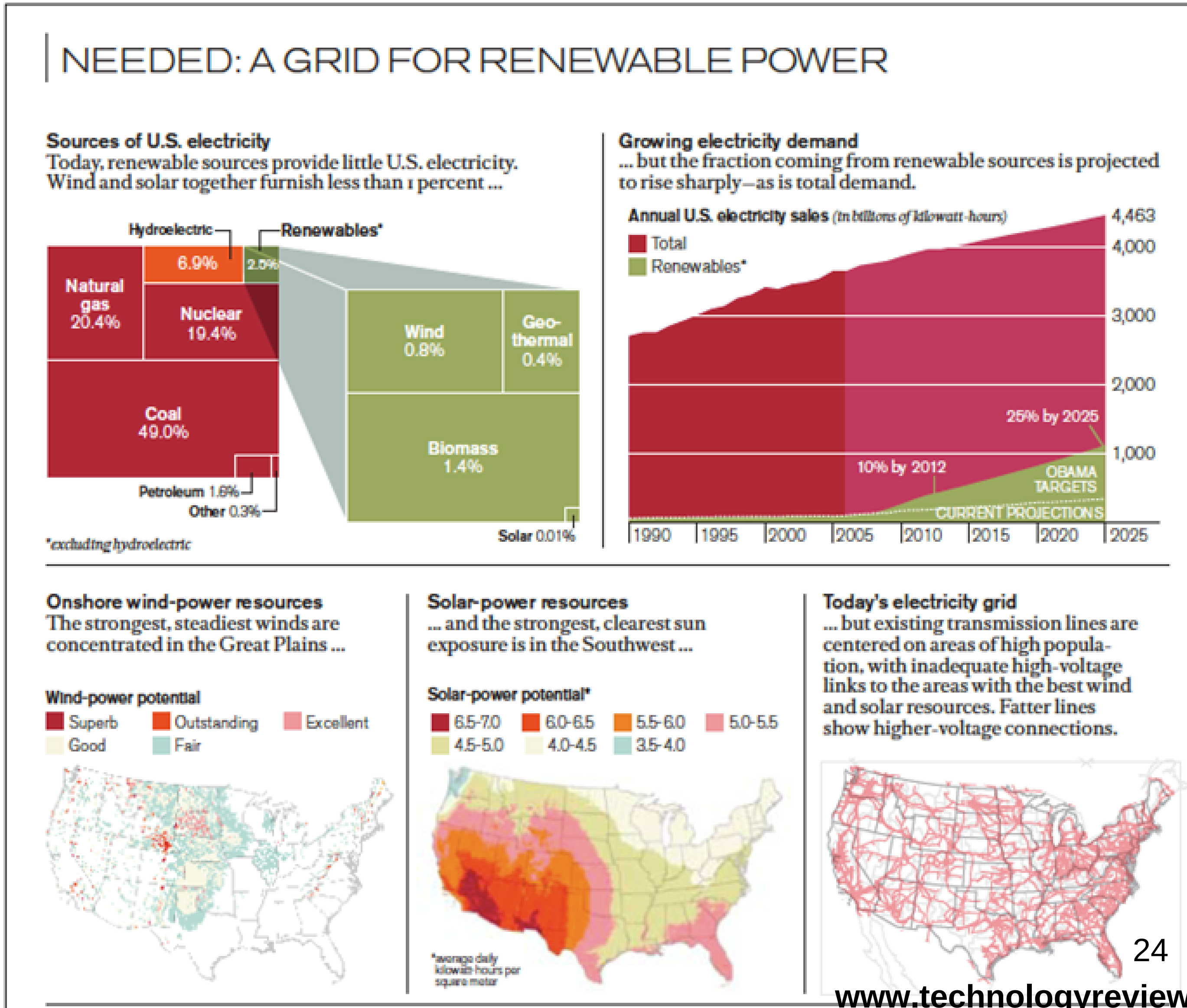
LoCal

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

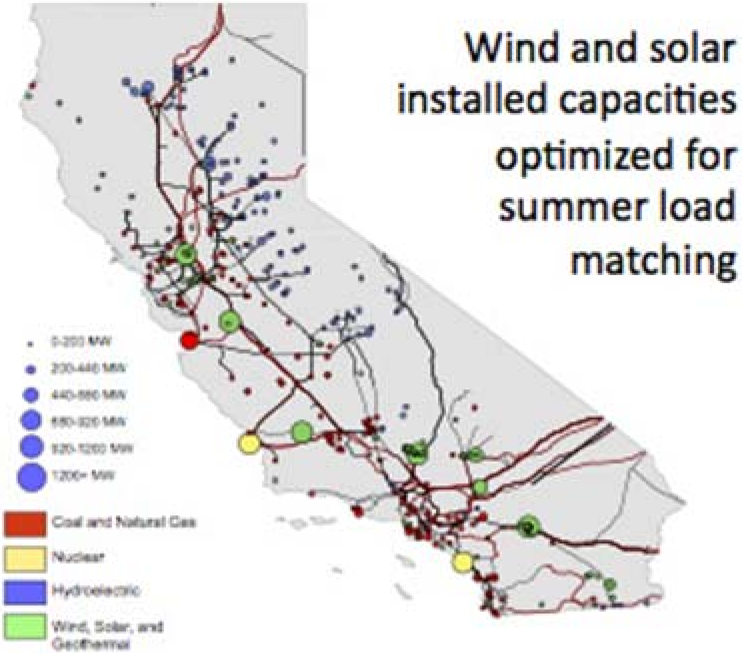
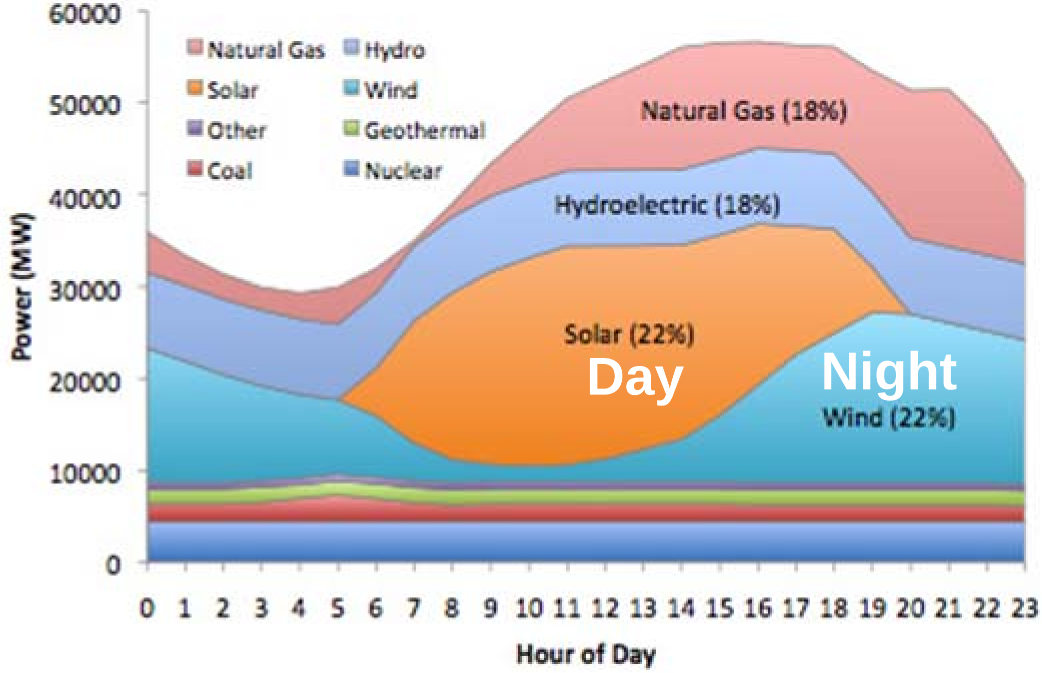


Figure 6. California power generation on July 2016 Day High-Renewable Penetration Case



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?

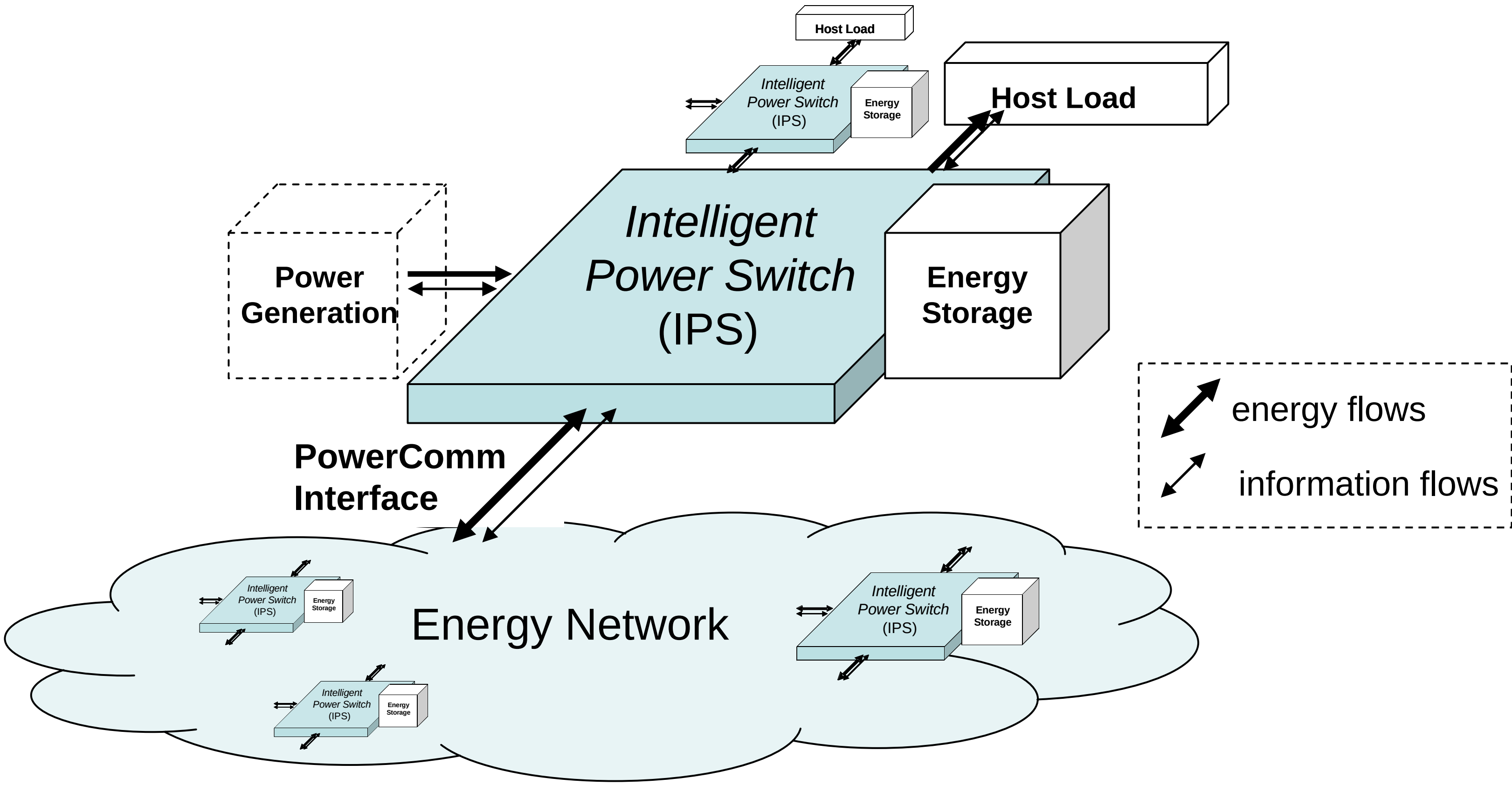
- Energy: *the* limited resource of the 21st Century
- Needed: Information Age approach to the Machine Age infrastructure
- Lower cost, more incremental deployment, suitable for developing economies
- Enhanced reliability and resilience to wide-area outages, such as after natural disasters

- *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

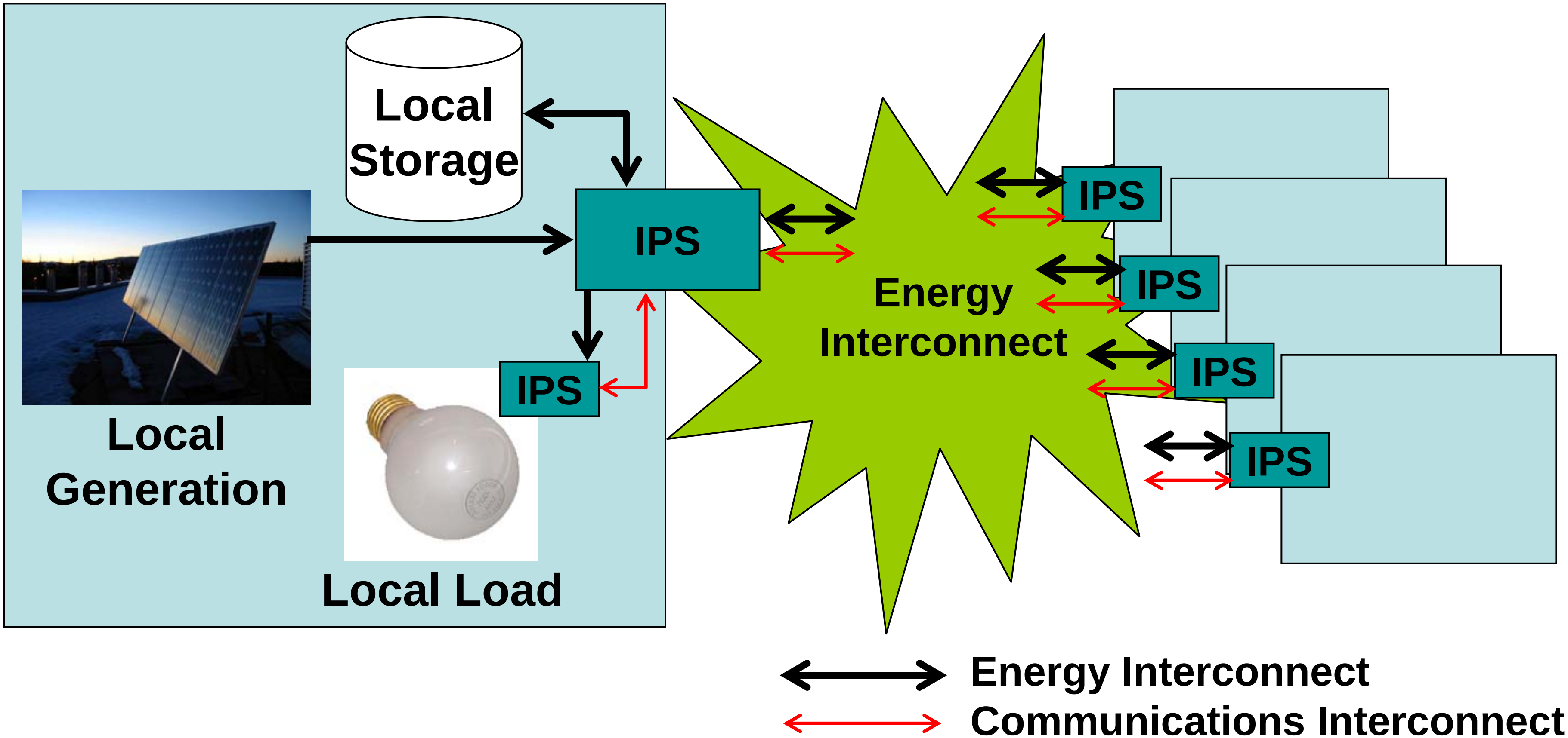


- PowerComm Interface: Network + Power connector
- Scale Down, Scale Out

"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

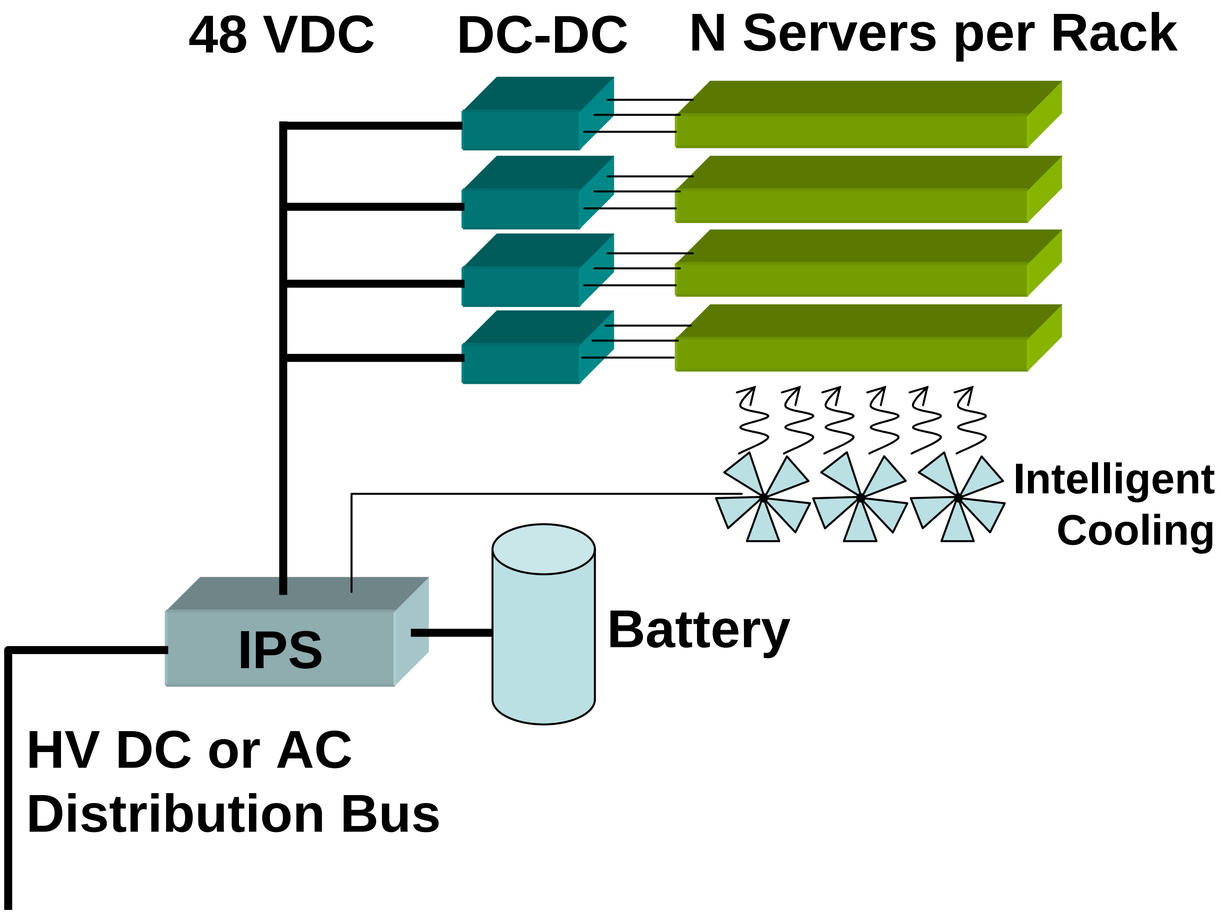


- Hierarchical aggregates of loads and IPSs
- Overlay on existing Energy Grid

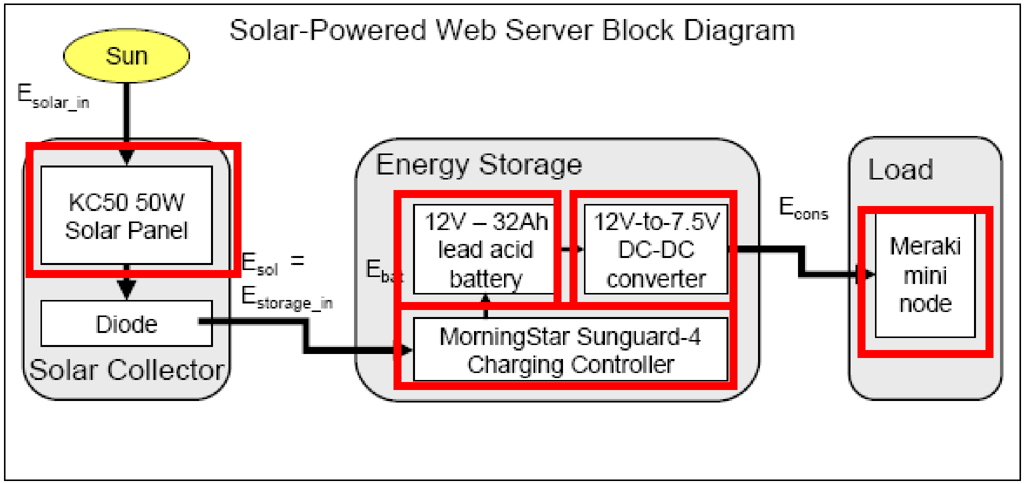
LoCal-ized Datacenter

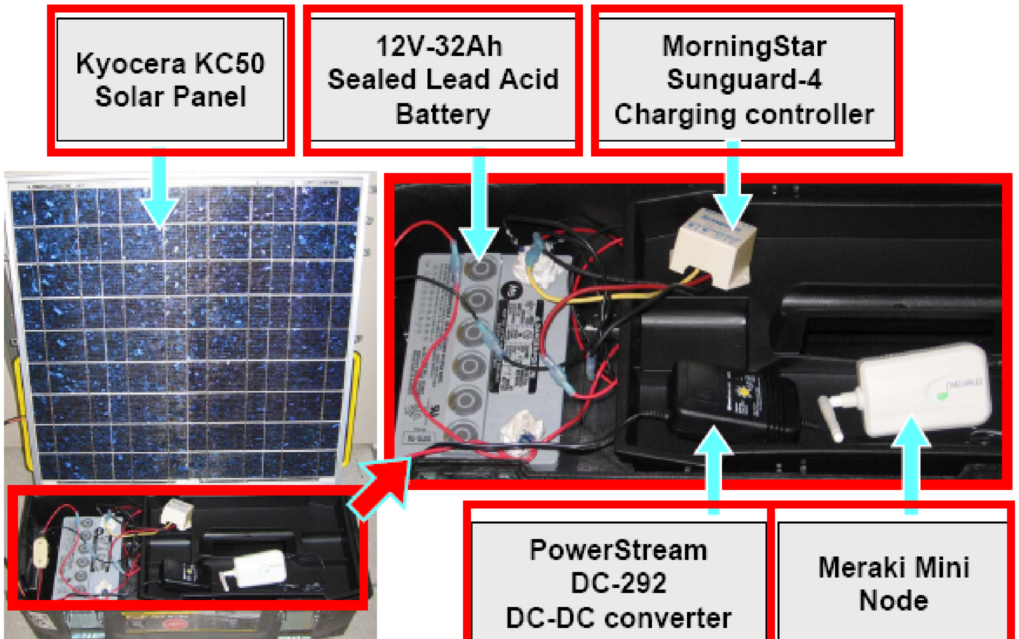
Rack Unit

- 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	**50W panel**
Input Regulator	**Efficiency 89%-97%**
Energy Storage	**12V-32Ah lead acid**
Output Regulator	**Efficiency 80%-82%**
Load	**2.25W average**

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

Thank You!