A Computer Scientist
Looks at the Energy Problem

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EECS BEARS Symposium
February 12, 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
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.
“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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2007 Worldwide IT carbon footprint: 2% = 830 m tons CO₂
Comparable to the global aviation industry

Expected to grow to 4% by 2020

IT footprints
Emissions by sub-sector, 2020

820m tons CO₂

360m tons CO₂

260m tons CO₂

Total emissions: 1.43bn tonnes CO₂ equivalent
“SMART 2020: Enabling the Low Carbon Economy in the Information Age”, The Climate Group

Datacenters: Owned by single entity interested in reducing opex

It is surprisingly hard to achieve high levels of utilization of typical servers (and your home PC or laptop is even worse).

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

Fig. 4.1 The global data centre footprint

MtCO$_2$e

Projected Savings

*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 + \textit{Power} + \textit{Cooling}
Energy Use In Datacenters

Electricity Flows in Data Centers

- Local distribution lines to the building, 480 V
- HVAC system for lights, office space, etc.
- UPS PDU for computer racks
- Backup diesel generators

Electricity flows in data centers

- Power per component
- Cumulative power

- Load
- PSU
- Chiller
- UPS
- VRs
- Server fans
- CRAC fan
- PDU
- CW pump
- Total baseline

Michael Patterson, Intel
LBNL
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 (detail), 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: 2 terabytes
- Data storage: 2 petabytes
Microsoft’s Chicago Modular Datacenter

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

**Structure:** A 24,000-square-meter facility houses 4,000 containers. Delivered by trucks, the containers at The Chicago site are infrastructure that feeds network connectivity, power, and water.

**Power:** Two power substations feed a total of 200 megawatts to the data center, with 200 kW used for computing equipment and 150 MW for the cooling and electrical systems. Batteries and generators provide backup power.

**Containers:** Each 40-foot container houses 2500 servers, about 10 times smaller than a conventional data center. In the same space, four container integrations computing, networking, power, and cooling systems.

**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?
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

Soda Hall Power Consumption - 494 kW

Custom period: 2008-01-18 22:00 - 2008-01-24 22:45

Locality

[Image of a building and a chart showing power consumption]

[Image of a map with electrical components and a graphic of a building with solar panels]
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Machine Age Energy Infrastructure
Accommodate 21\textsuperscript{st} Century Renewable Energy Sources
Sun and wind aren’t where the people – and the current grid – are located!
California as a Testbed

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
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

Diagram:
- 48 VDC
- DC-DC
- N Servers per Rack
- HV DC or AC Distribution Bus
- Battery
- Intelligent Cooling

IPS
LoCal-ized Web Server

Solar-Powered Web Server Block Diagram

<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>KC50 50W Solar Panel</td>
<td>50W panel</td>
</tr>
<tr>
<td>12V-32Ah Sealed Lead Acid Battery</td>
<td>Efficiency 89%-97%</td>
</tr>
<tr>
<td>Energy Storage</td>
<td>12V-32Ah lead acid battery</td>
</tr>
<tr>
<td>MorningStar Sunguard-4 Charging controller</td>
<td>12V-to-7.5V DC-DC converter</td>
</tr>
<tr>
<td>Load</td>
<td>Efficiency 80%-82%</td>
</tr>
<tr>
<td>Meraki mini node</td>
<td>2.25W average</td>
</tr>
</tbody>
</table>

PowerStream DC-292 DC-DC converter

Meraki Mini Node
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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
• 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!