A Computer Scientist Looks at the Energy Problem

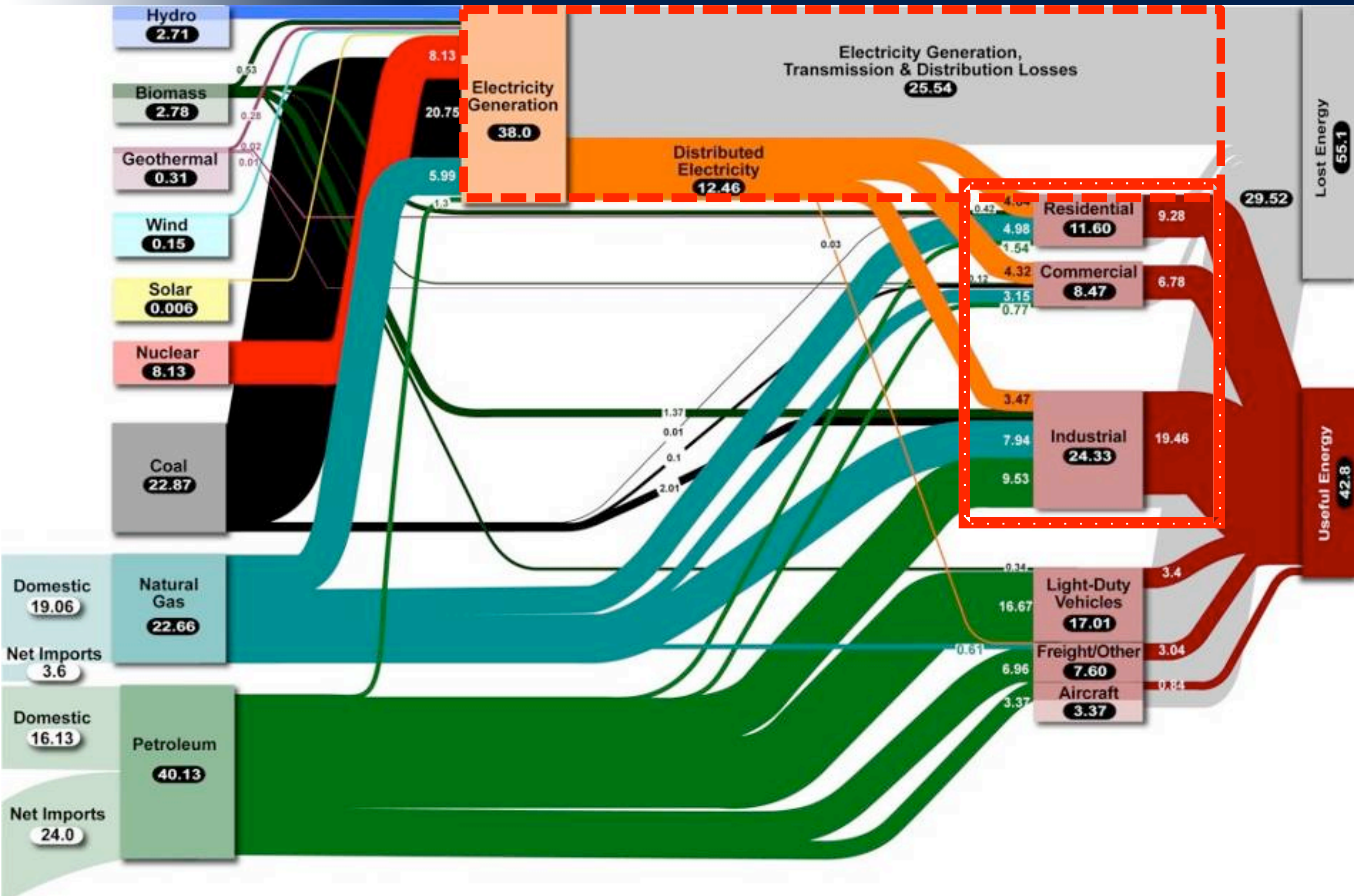
David Culler, Randy H. Katz
University of California, Berkeley
CITRIS Symposium
October 7, 2009

"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.

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

LoCal 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

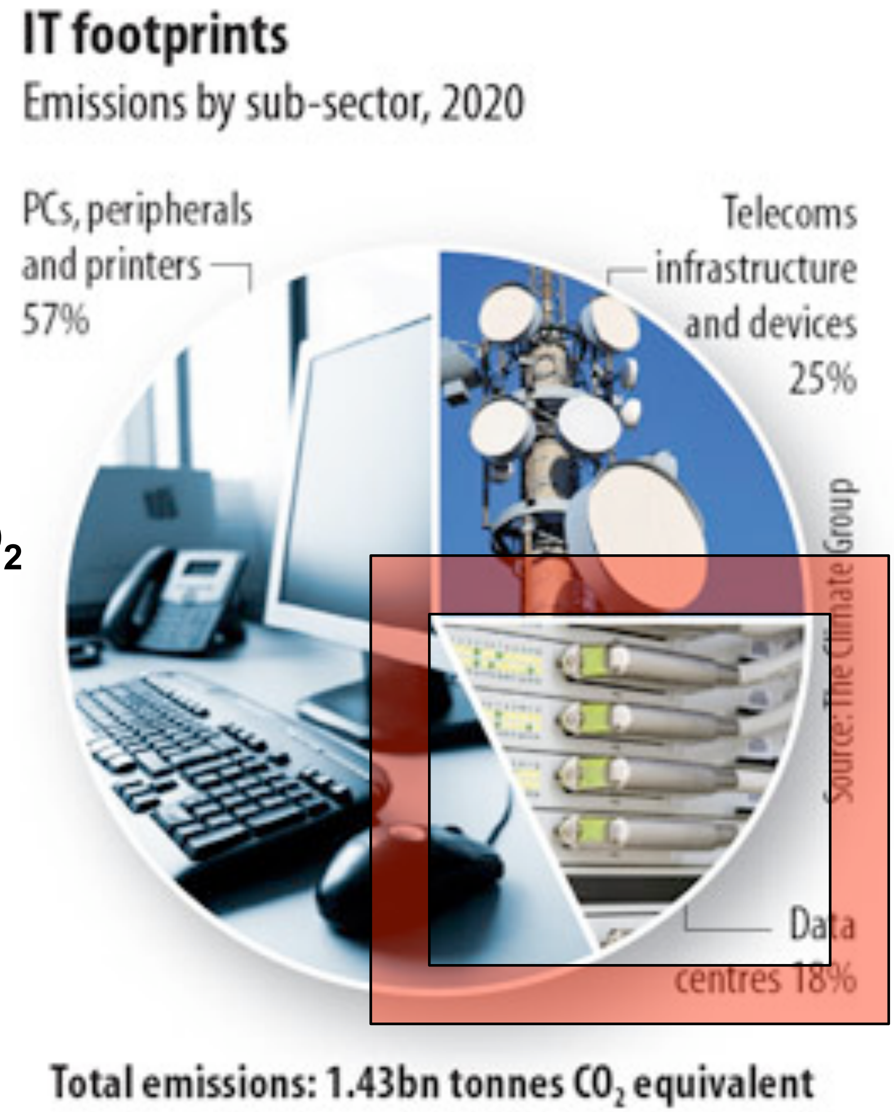
820m tons CO_2

360m tons CO_2

260m tons CO_2

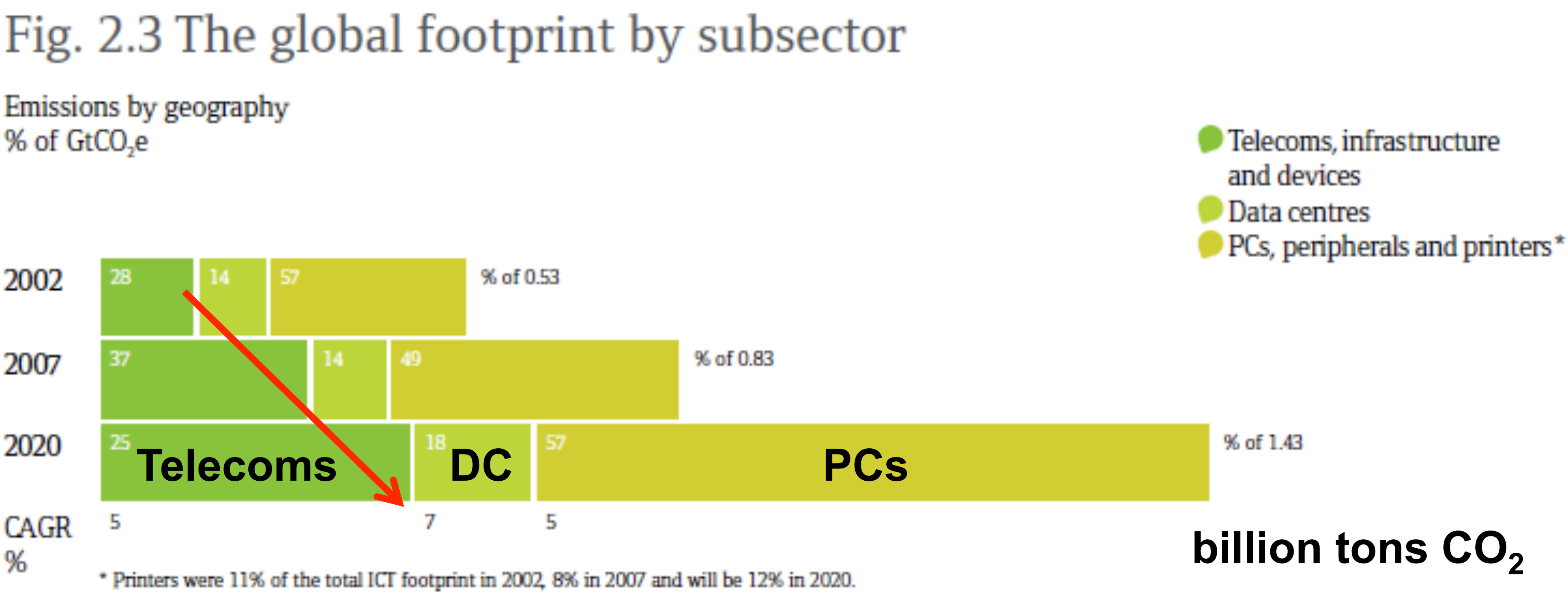
2007 Worldwide IT carbon footprint: 2% = 830 m tons CO_2 Comparable to the global aviation industry

Expected to grow to 4% by 2020



2020 IT Carbon Footprint

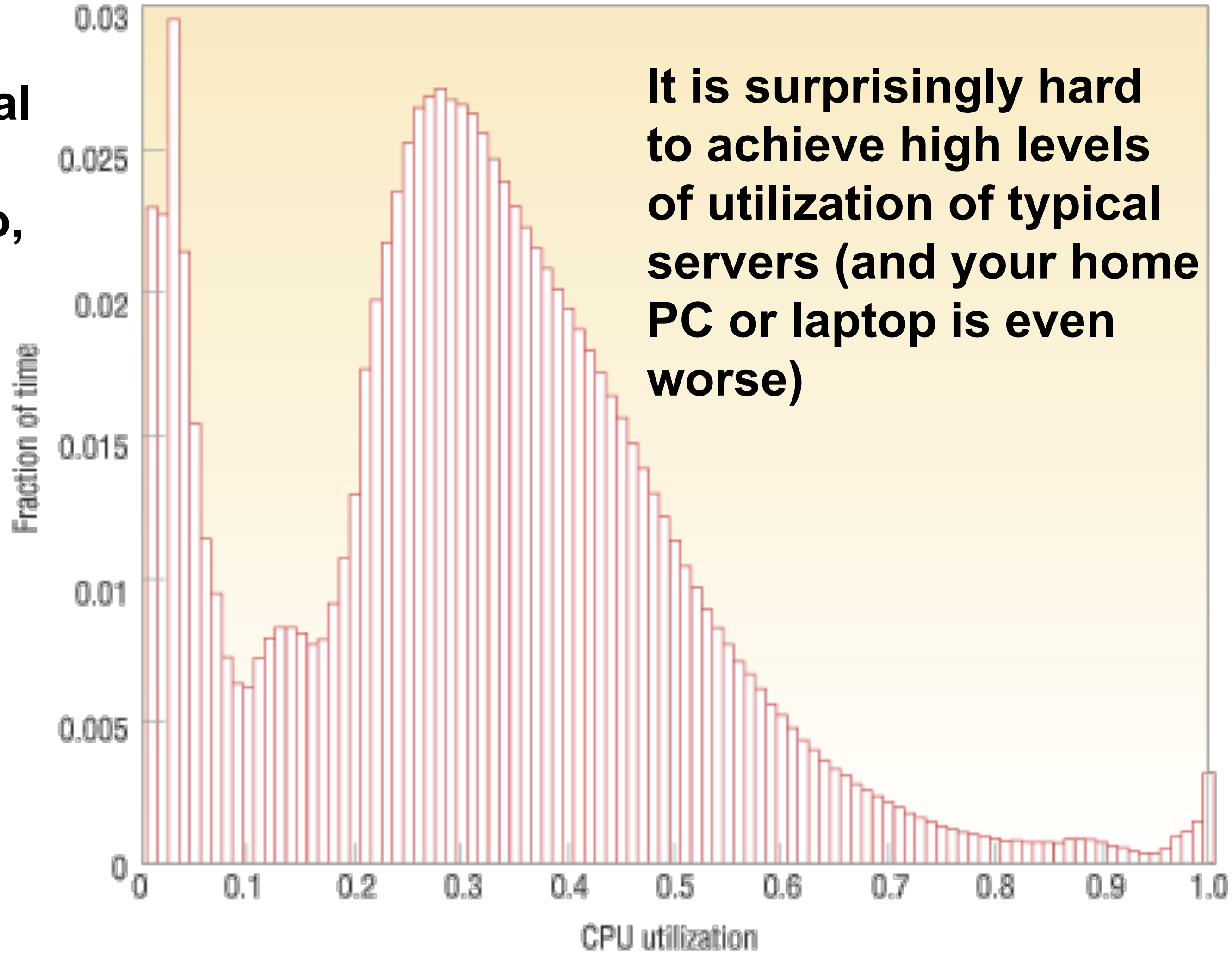
"SMART 2020: Enabling the Low Carbon Economy in the Information Age", The Climate Group



Datacenters: Owned by single entity interested in reducing opex

Energy Proportional Computing

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



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

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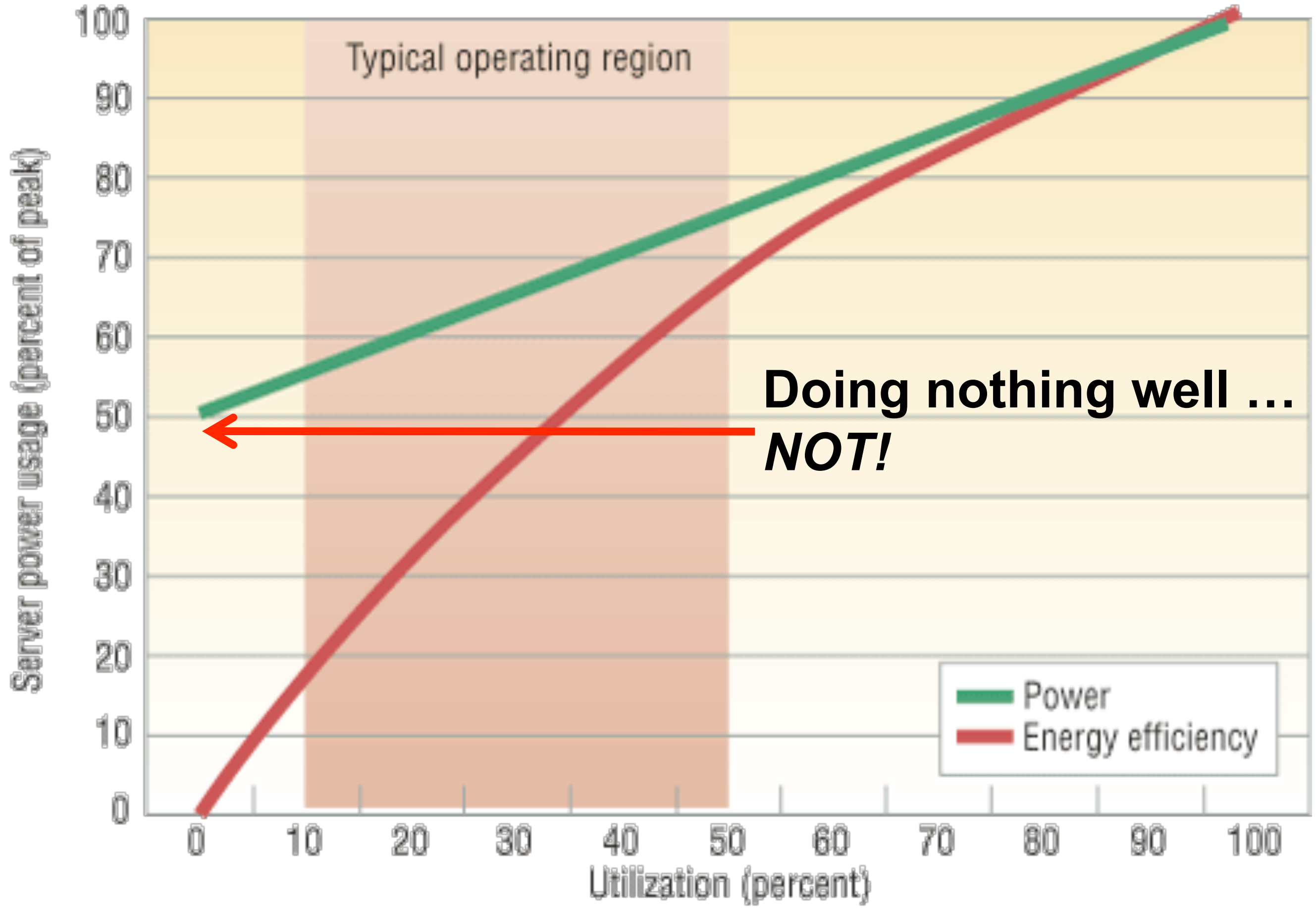

Energy Efficiency = Utilization/Power

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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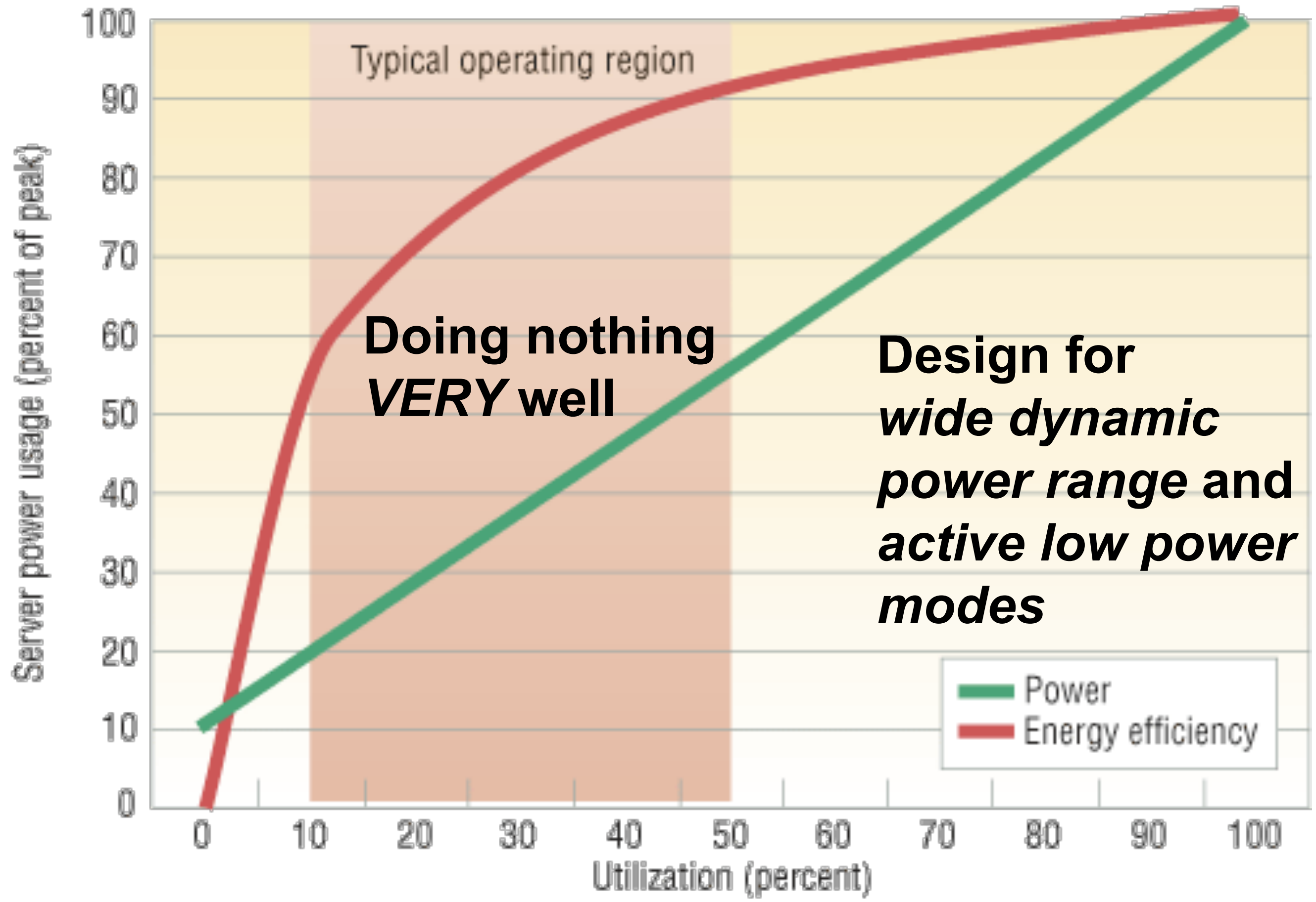


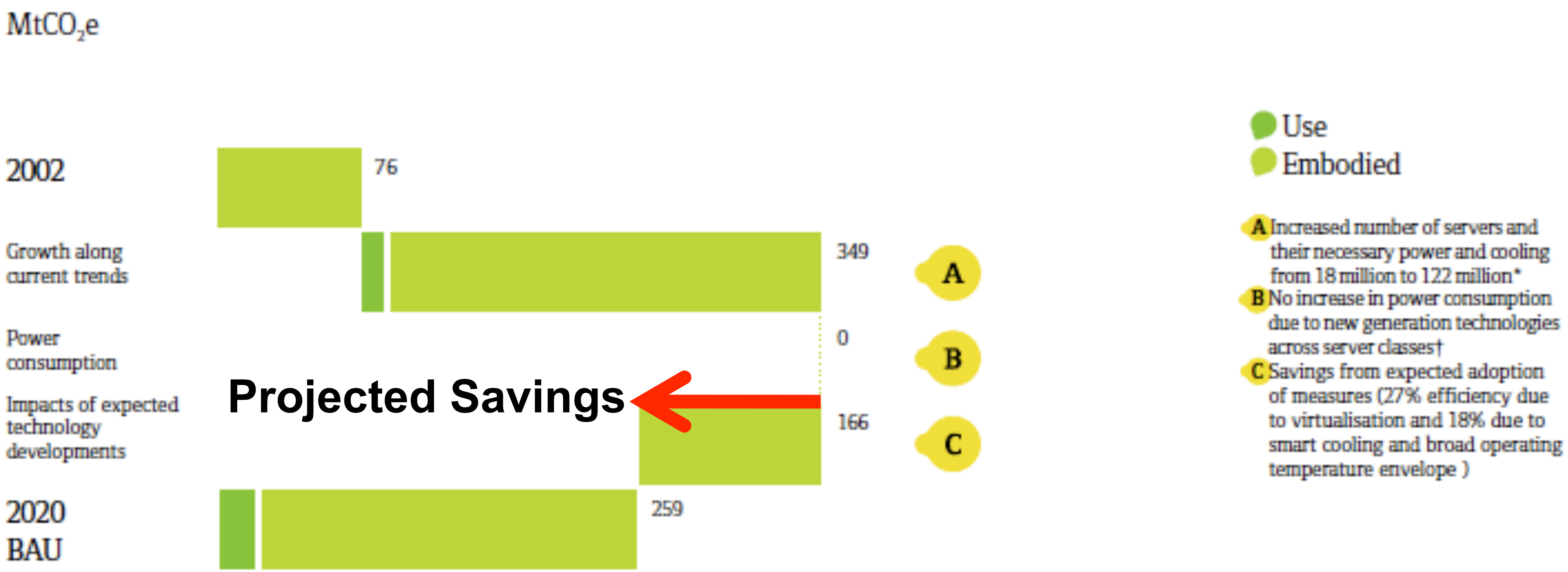
Energy Efficiency = Utilization/Power

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

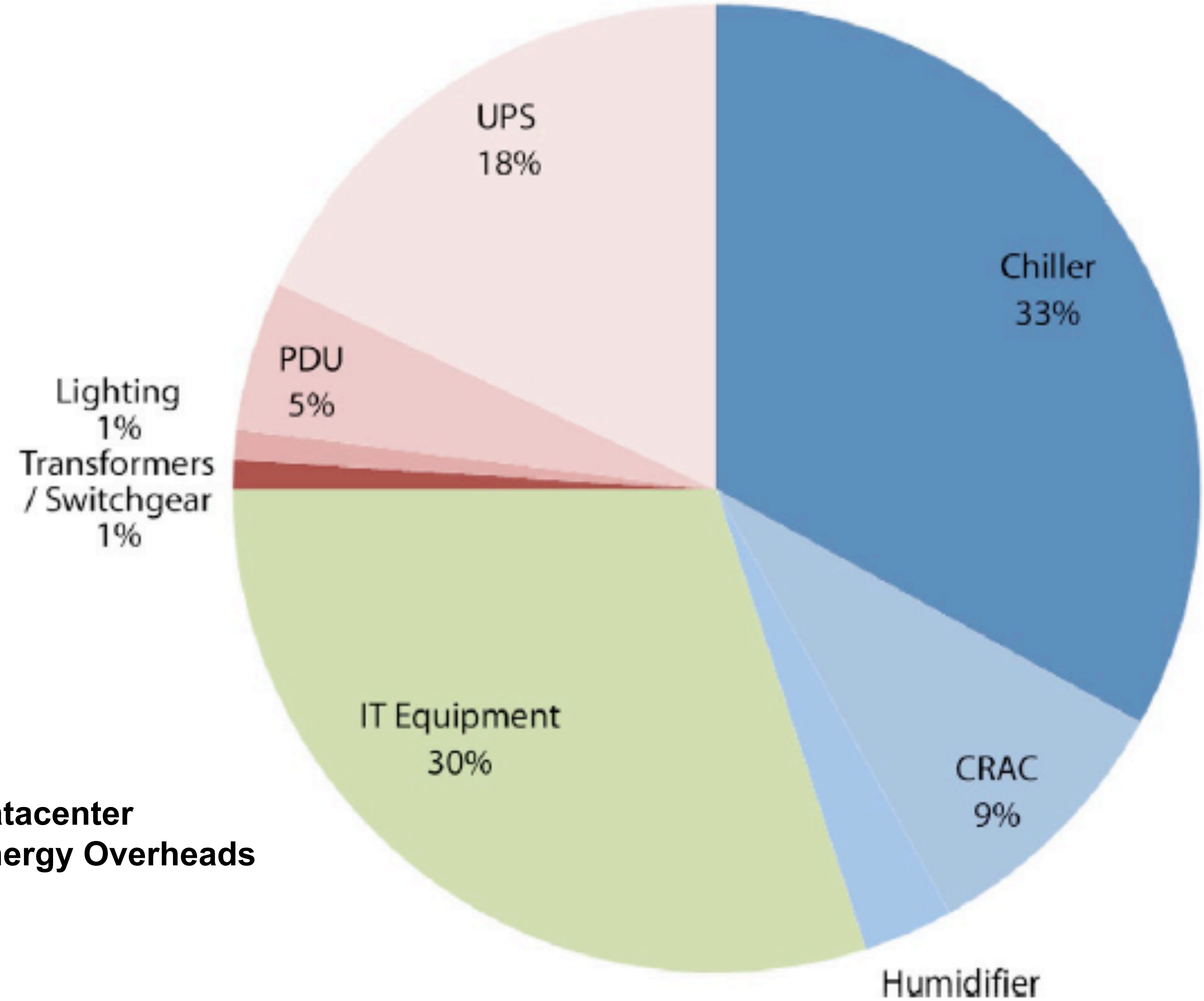
Fig. 4.1 The global data centre footprint



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

Internet Datacenters

Energy Use In Datacenters

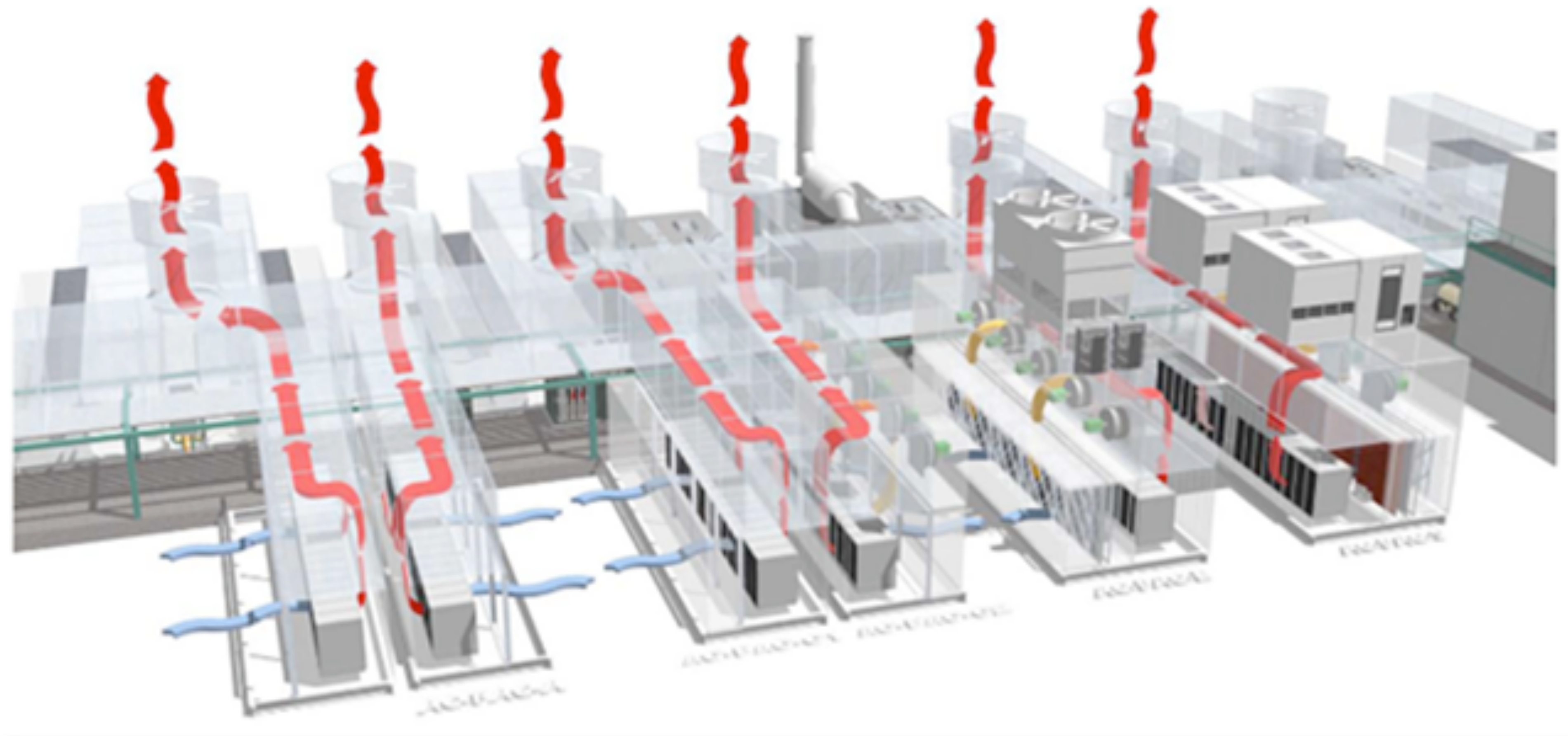


Datacenter Energy Overheads

BNL

DC Infrastructure Energy Efficiencies

Cooling (Air + Water movement) + Power Distribution



Containerized Datacenter Mechanical-Electrical Design

Go
Co
Dat

Microsoft Chicago Datacenter

Power Usage Effectiveness Rapidly Approaching 1!

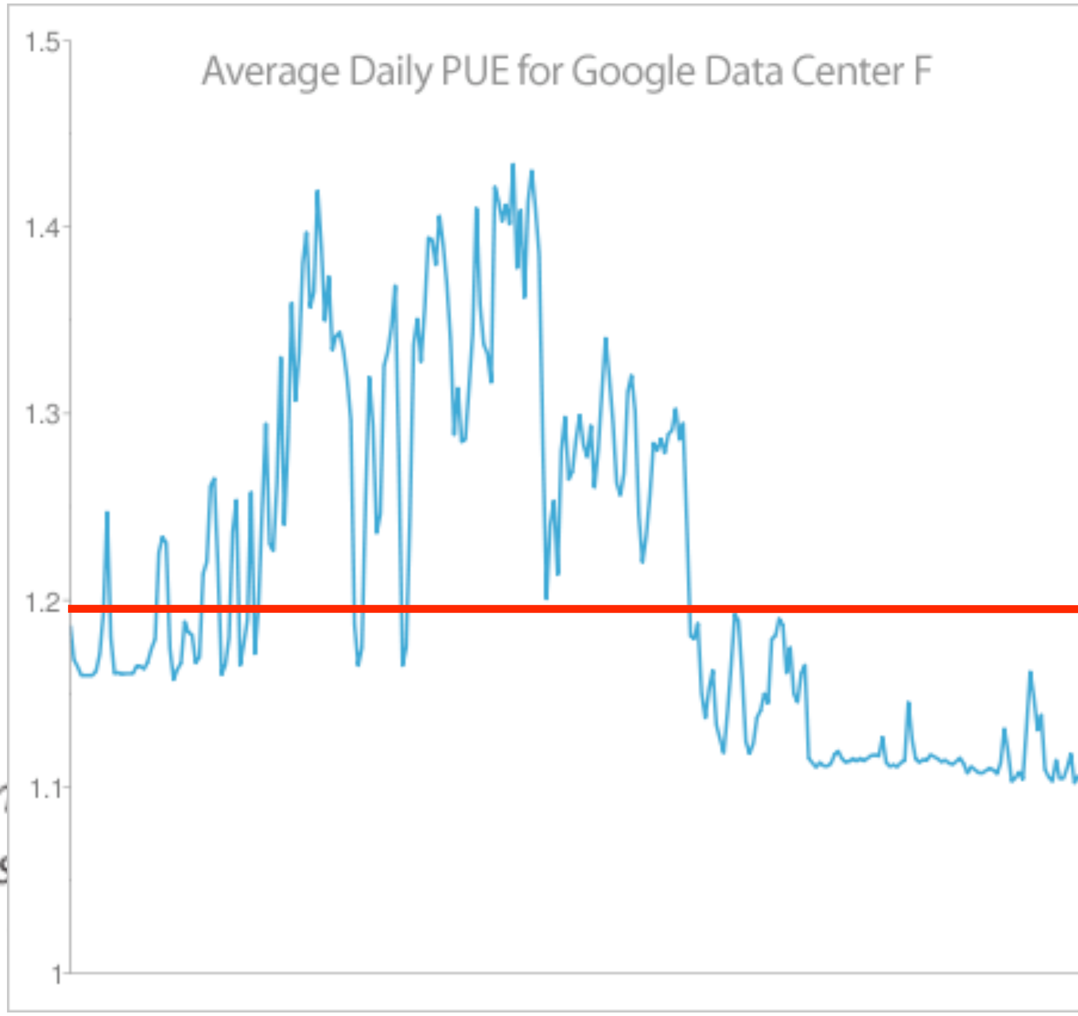
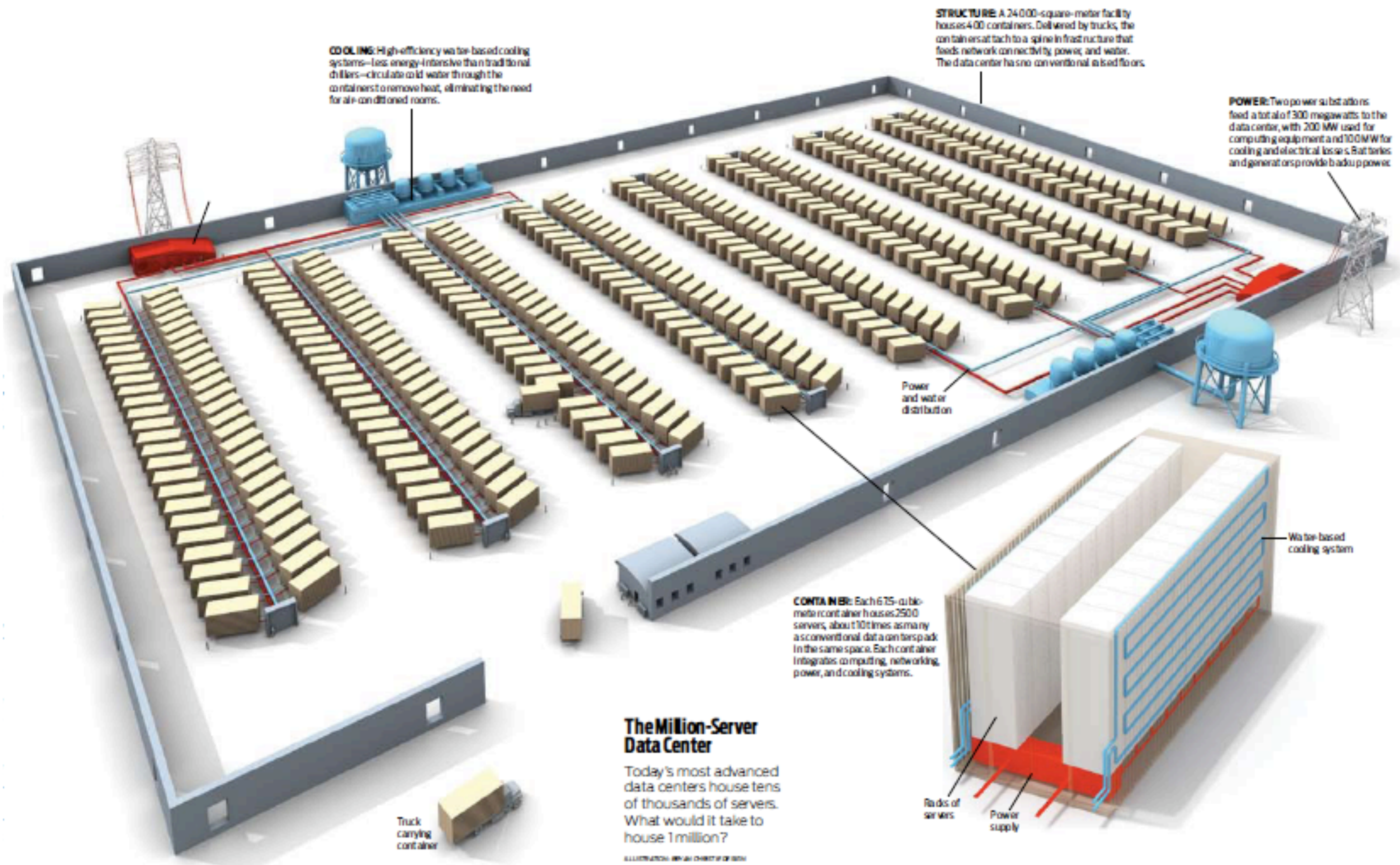


Figure 4. Our Sar … hieved a PUE of
1.28, which trans … ed to a target
datacenter built

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

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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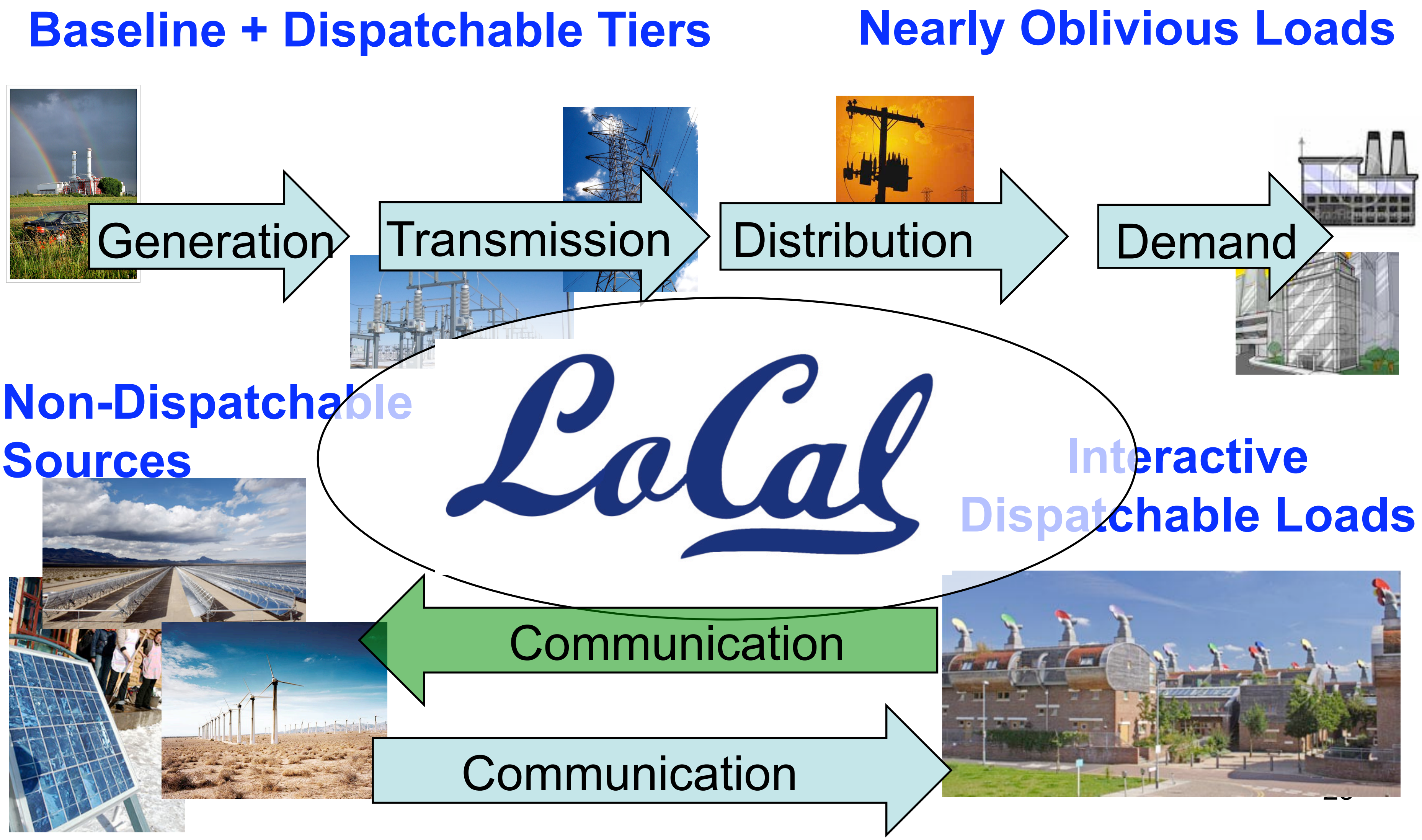
Machine Age Energy Infrastructure

The Grid: Marvel of Industrial Age Design

- Deliver high quality low-cost power
- To millions of customers over thousands of miles
- Synchronized to 16 ms cycle (60 Hz)
- With no orders, no forecasts, no plans
- No inventory anywhere in the supply chain
- To enable rapid economic & industrial growth through oblivious consumption

Accommodate 21st Century Renewable Energy Sources

Towards an "Aware" Energy Infrastructure

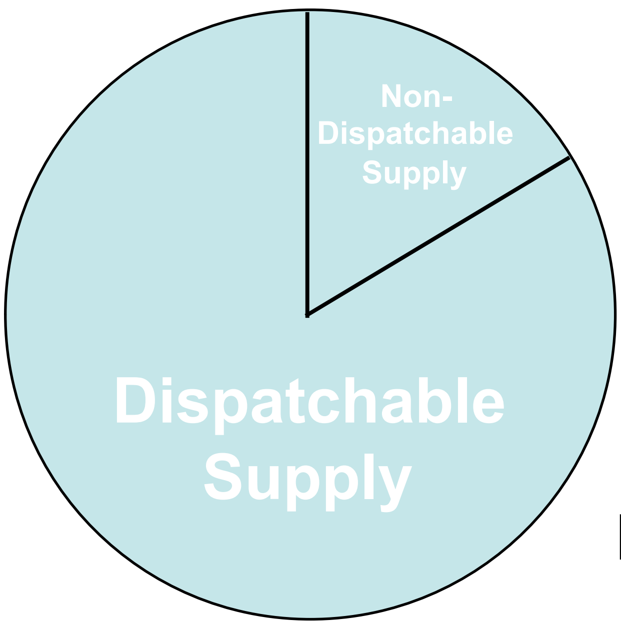


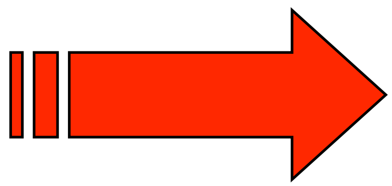
Energy Reduction and Support for Renewables thru Information

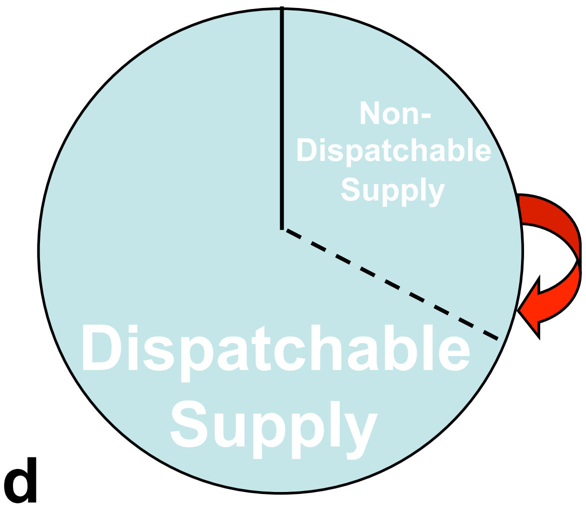
Doing Nothing Well

Scheduling

Storage







Reduce Demand

Increase Effectiveness of Non-Dispatchable Supply

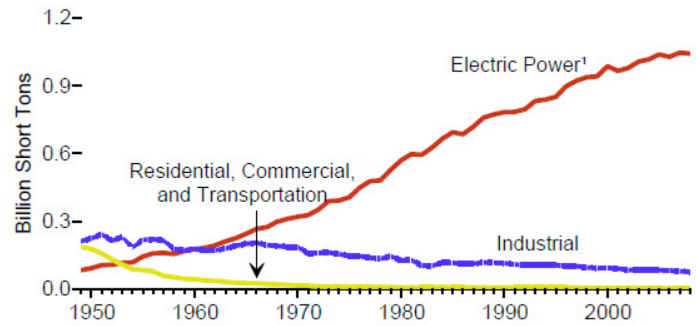
LoCal Energy Network Architecture

- Information exchanged whenever energy is transferred
- Loads are "Aware" and sculptable
  - Forecast demand, adjust according to availability / price, self-moderate
- Supplies negotiate with loads
- Storage, local generation, demand response are intrinsic

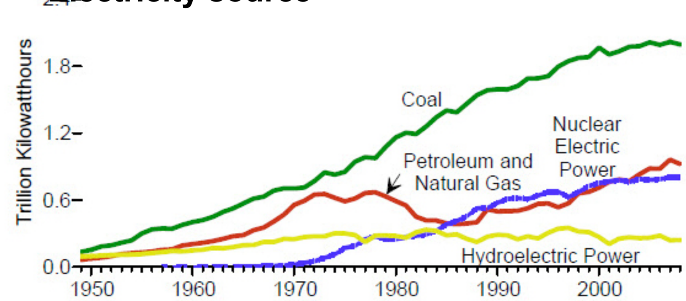
Where to Focus?

- Buildings …
- 72% of electrical consumption, 40% of total consumption, 42% of GHG footprint
- 370 B$ in US annual utility bill
- 9.5% of GDP in bldg construction/renovation
- Primarily Coal generation
- Primary opportunity for renewable supplies

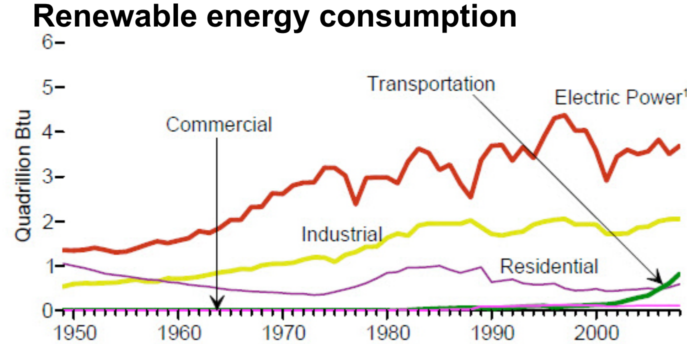
Coal consumption by sector



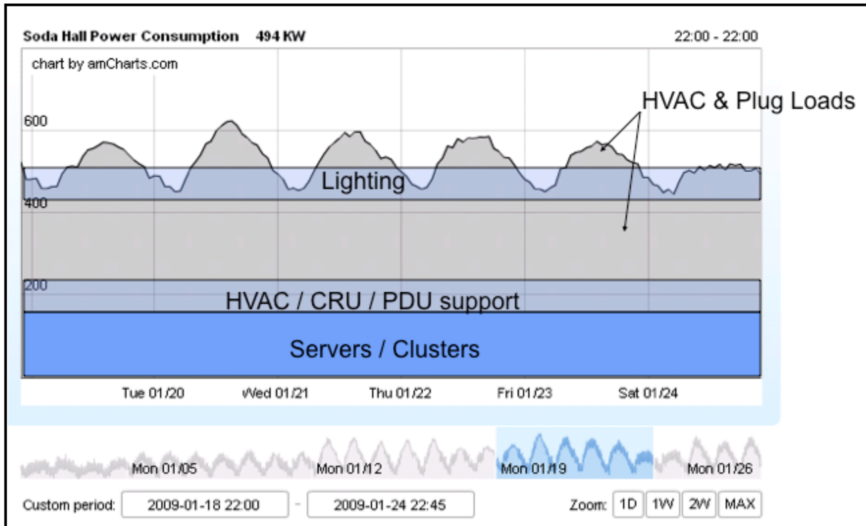
Electricity source

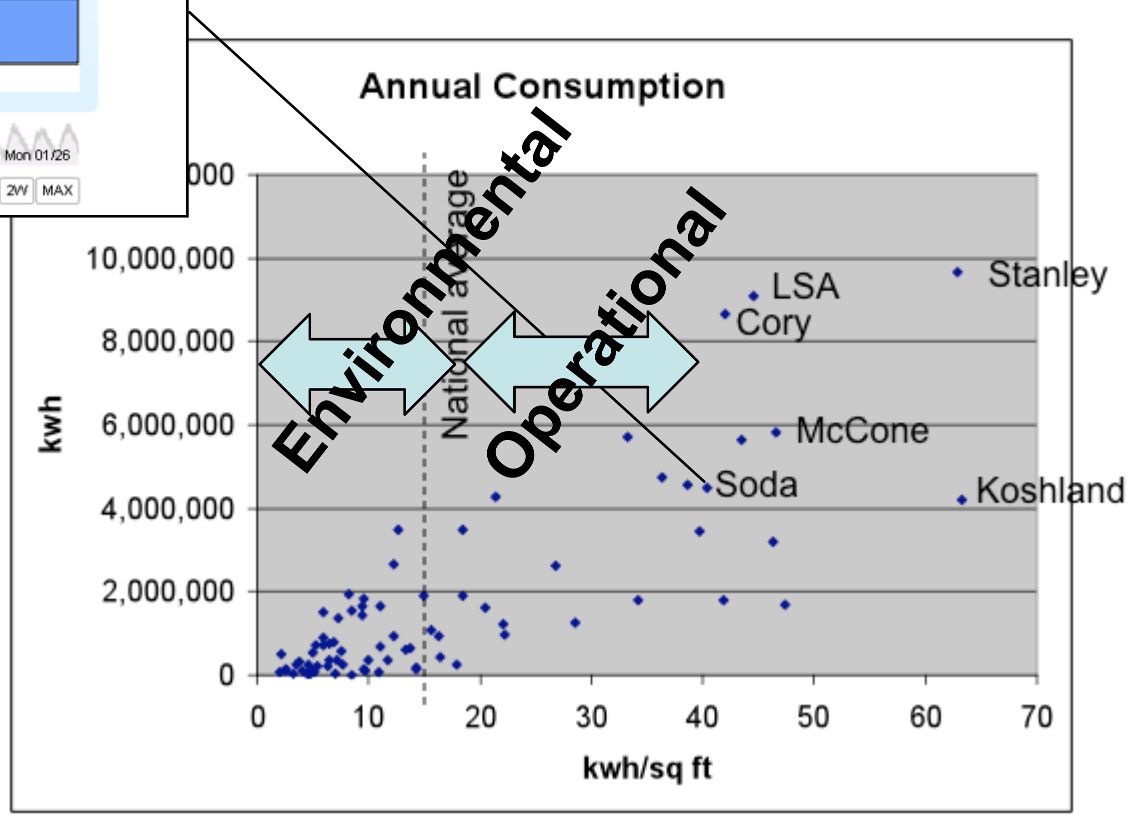


Renewable energy consumption



Our Buildings





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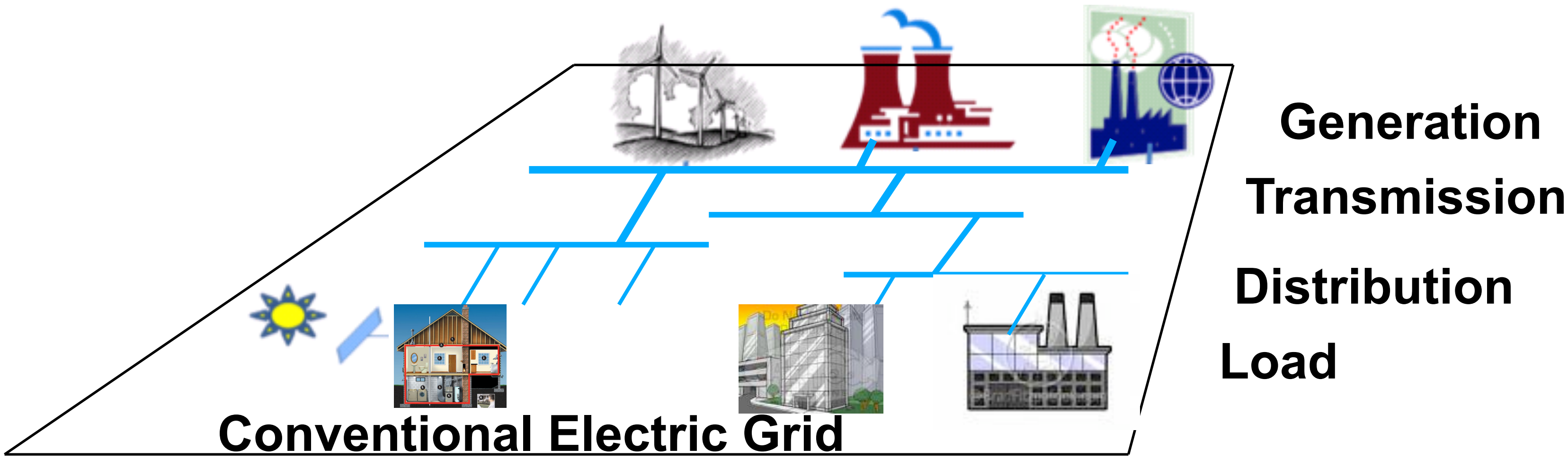
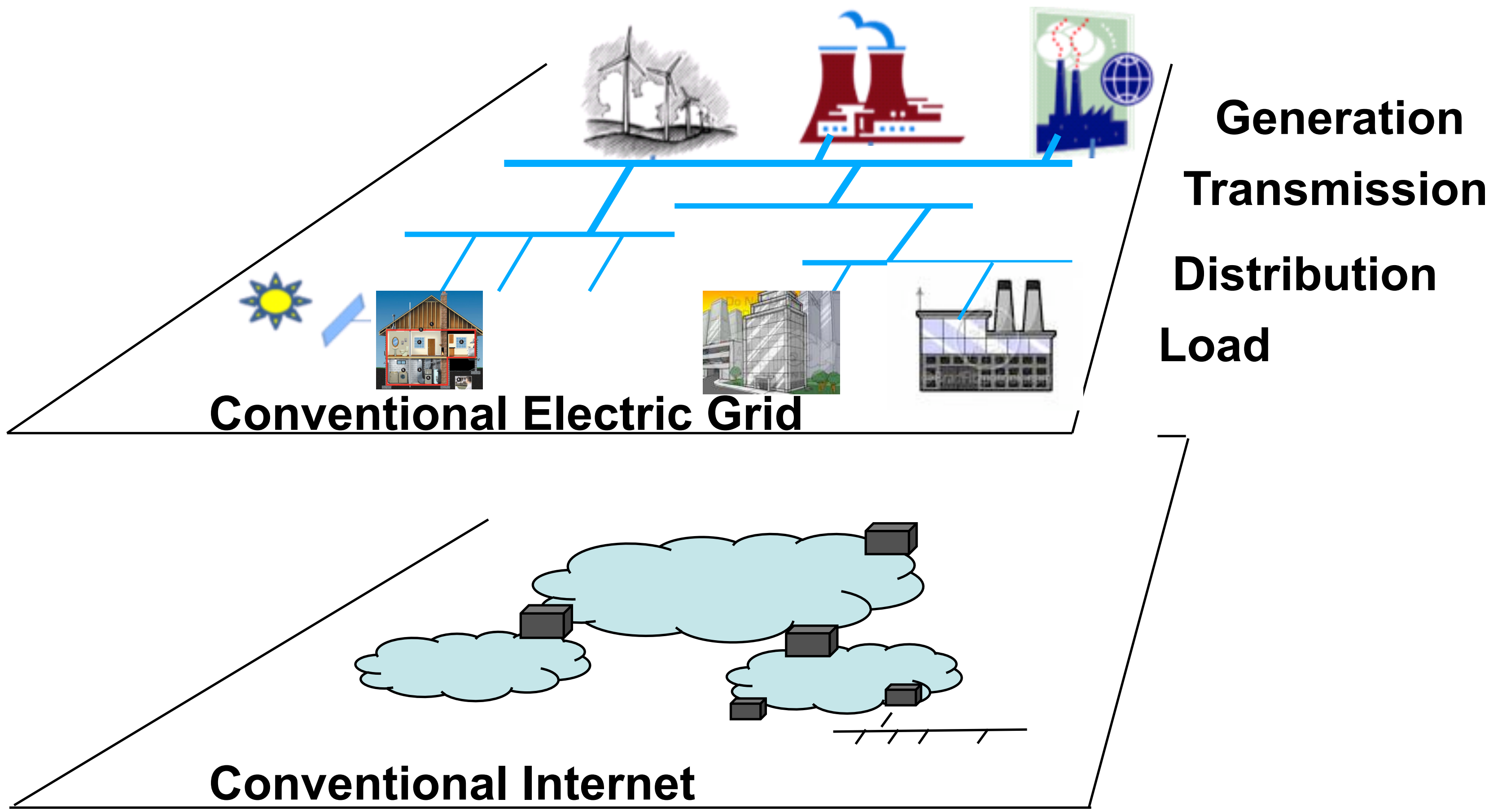
Start from Scratch?

- No!

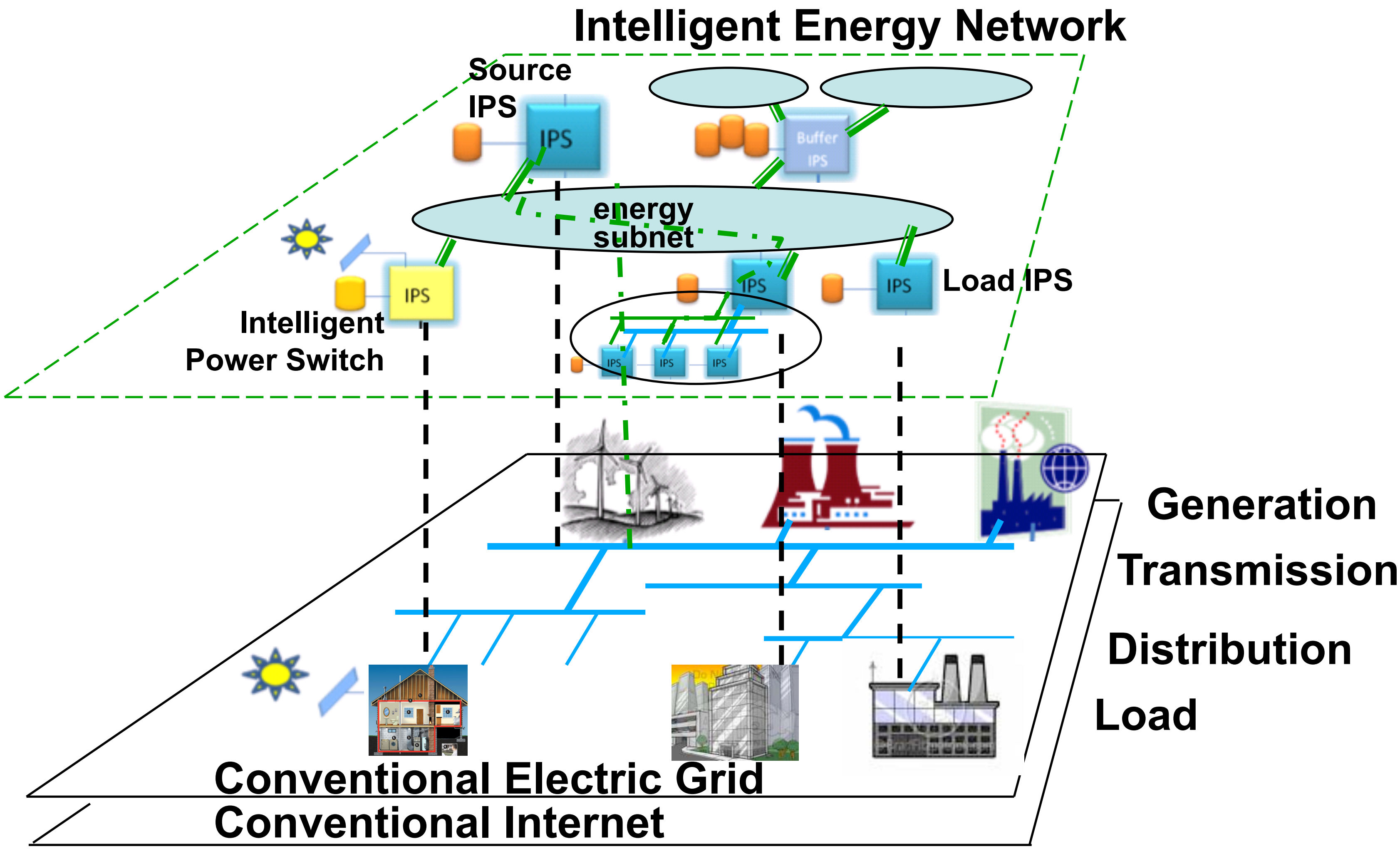
Grid Exists


Generation
Transmission
Distribution
Load
Conventional Electric Grid

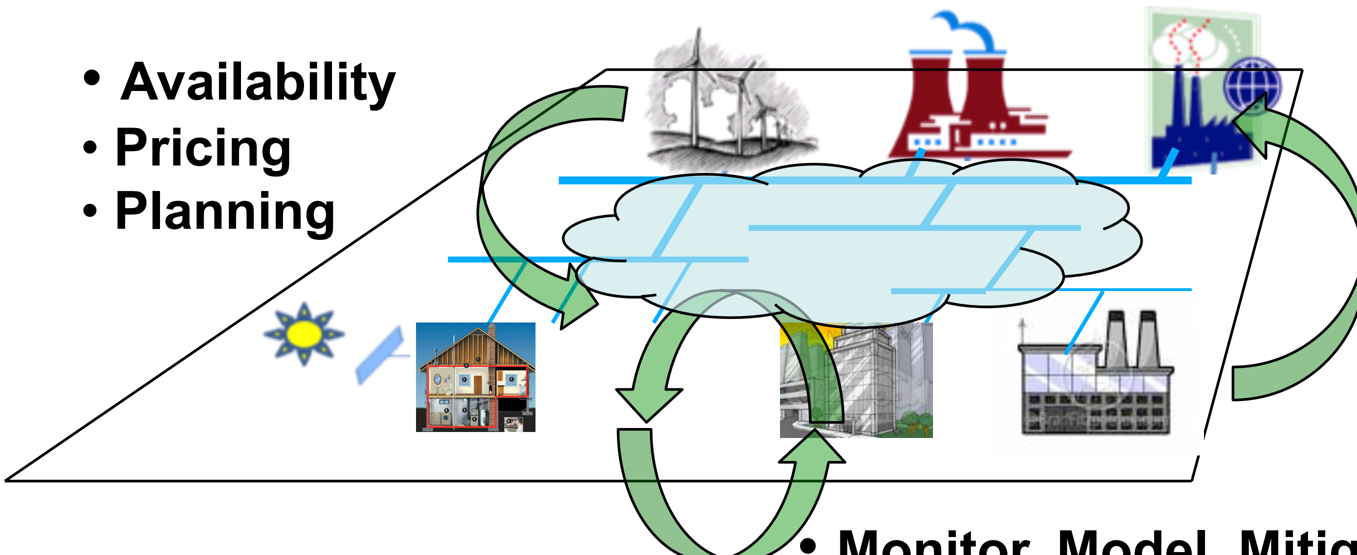
Internet Exists



Intelligent Energy Network as Overlay on Both



Aware Co-operative Grid

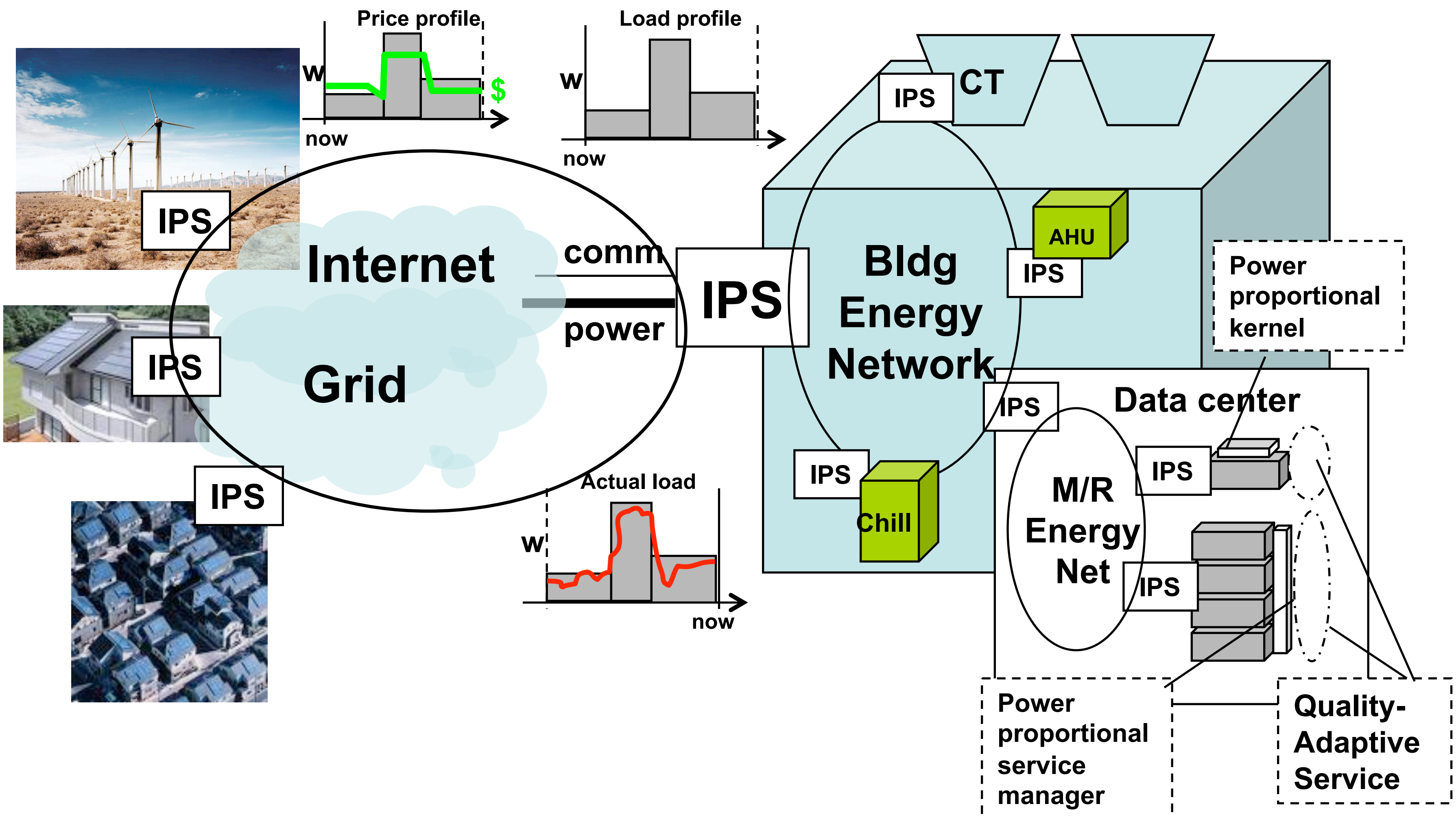


- Availability
- Pricing
- Planning

- Forecasting
- Tracking
- Market

- Monitor, Model, Mitigate
  - Deep instrumentation
  - Waste elimination
  - Efficient Operation
- Shifting, Scheduling, Adaptation

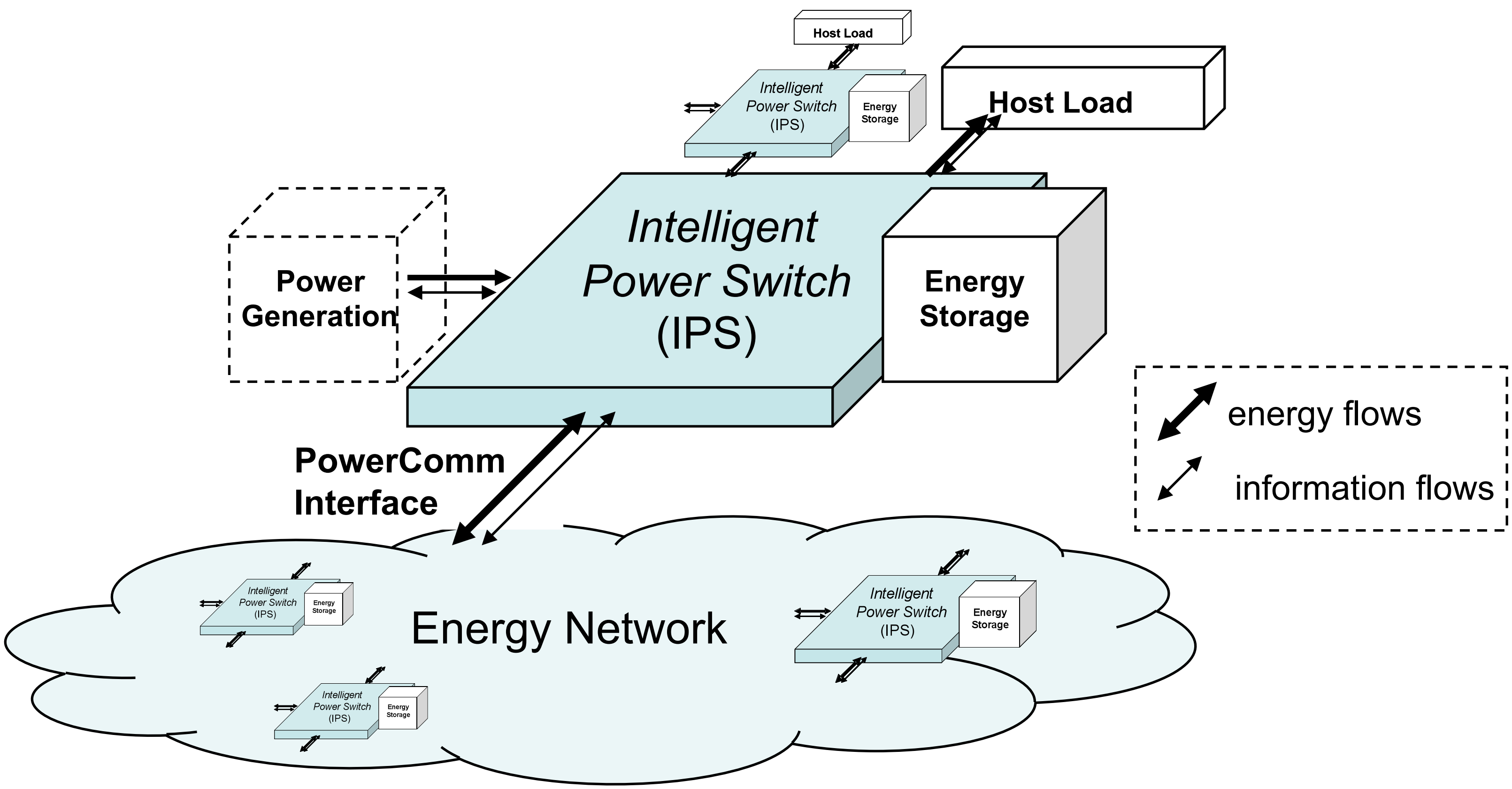
LoCal Energy Nets in Action



Questions…

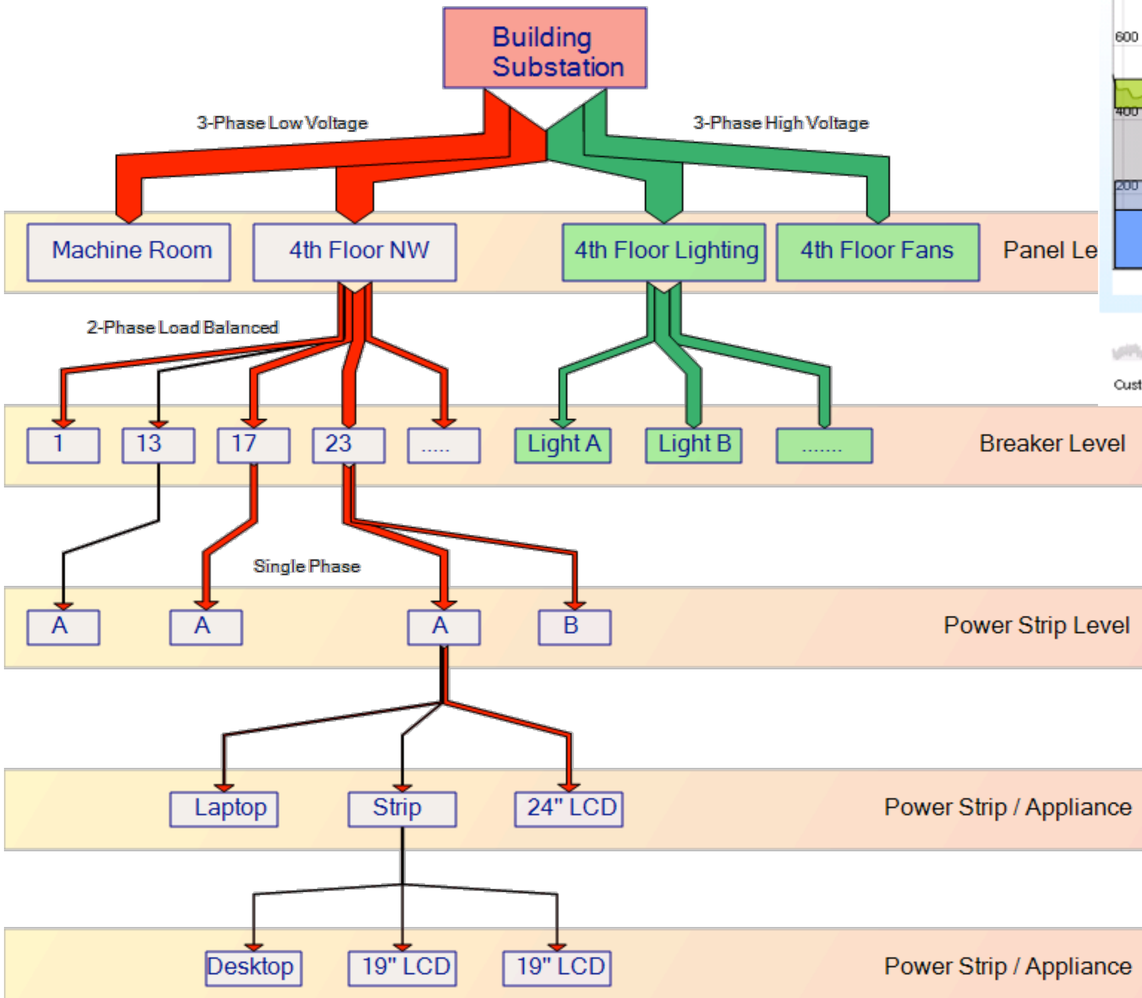
- Where does the energy go?
  - how much is wasted? => do nothing well
  - how can the rest be optimized?
- How much demand slack is there?
  - Can it be exercised through shifting?
  - Energy storage?   Electrical Storage?
- What limits renewable penetration?
  - vs storage, scheduling, cooperation
- What are the protocols involved?
- System and network design
- …

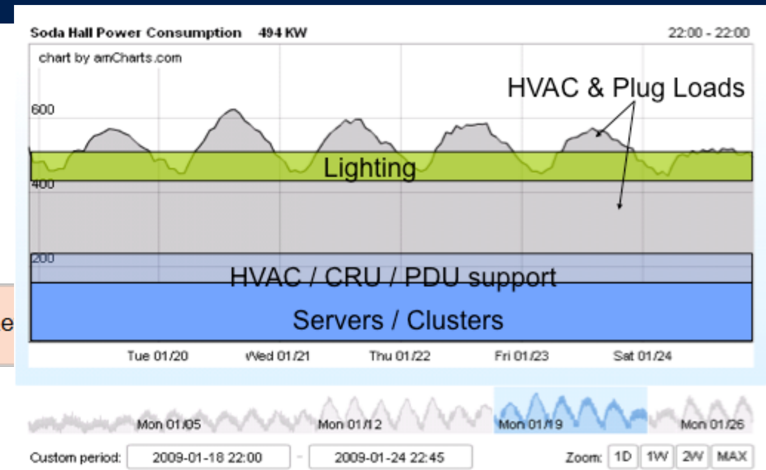
Intelligent Power Switch

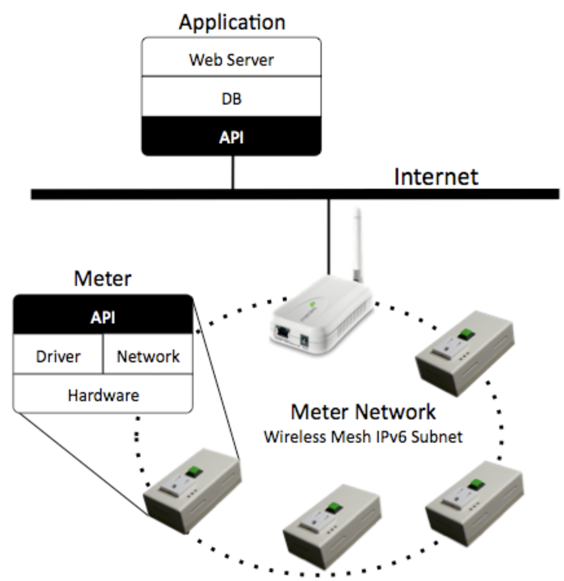


- PowerComm Interface: Network + Power connector
- Scale Down, Scale Out

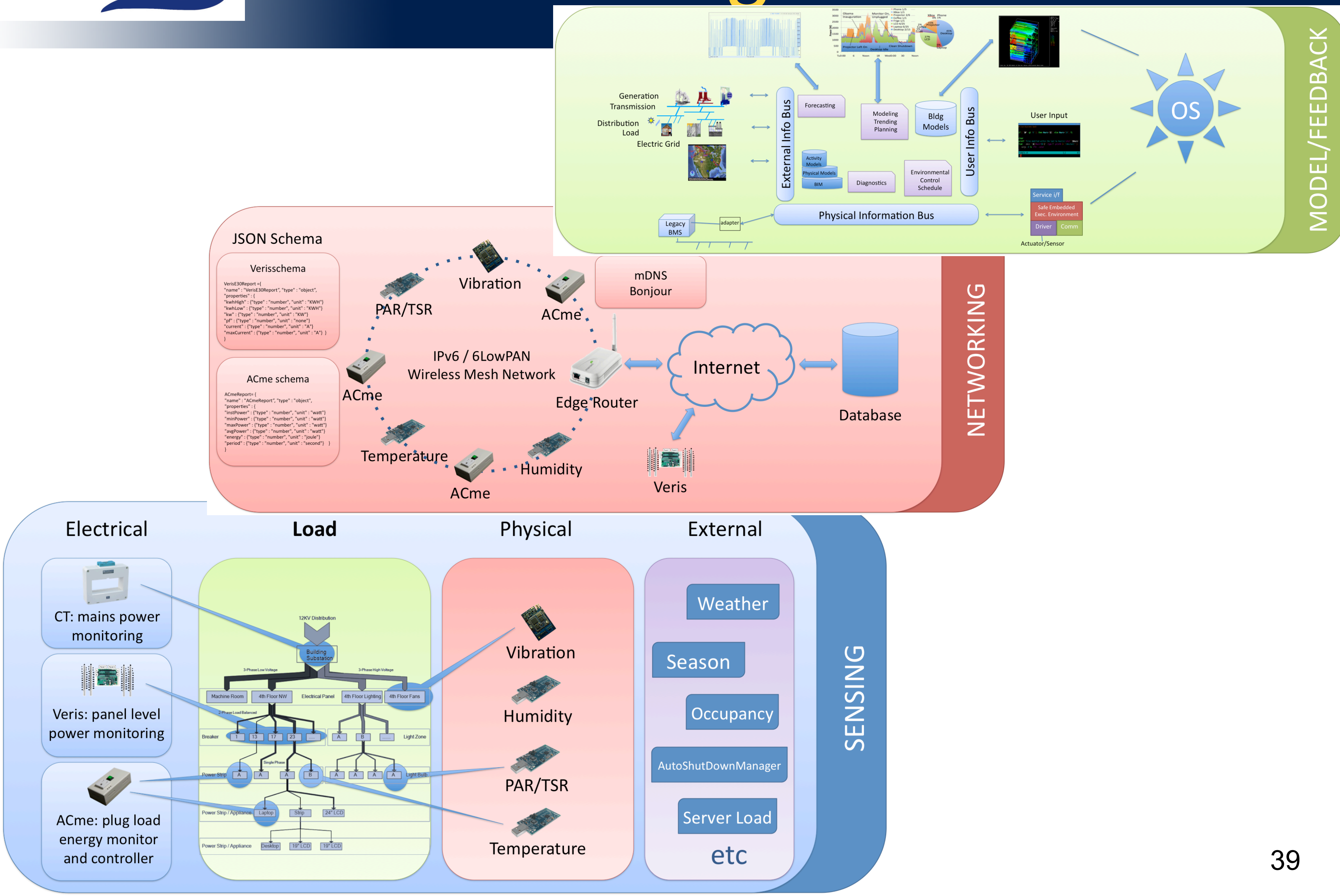
Understanding Diverse Load



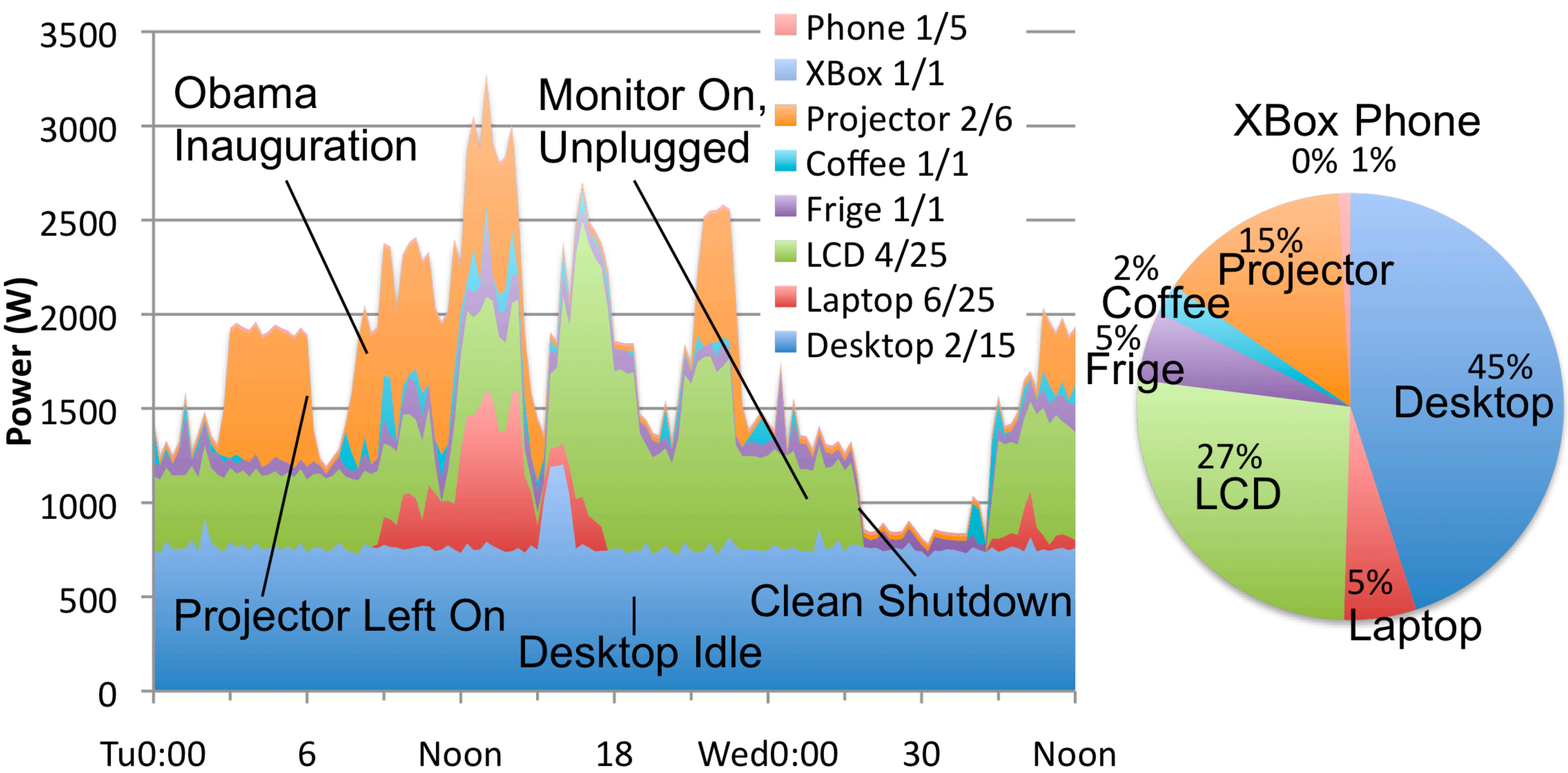




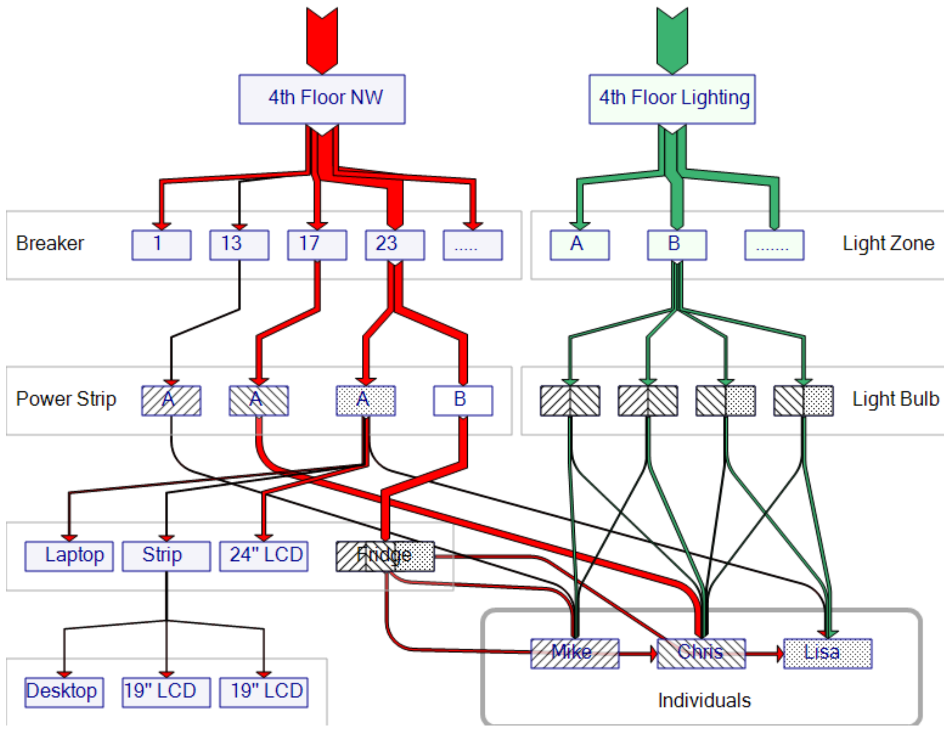
Monitoring Architecture

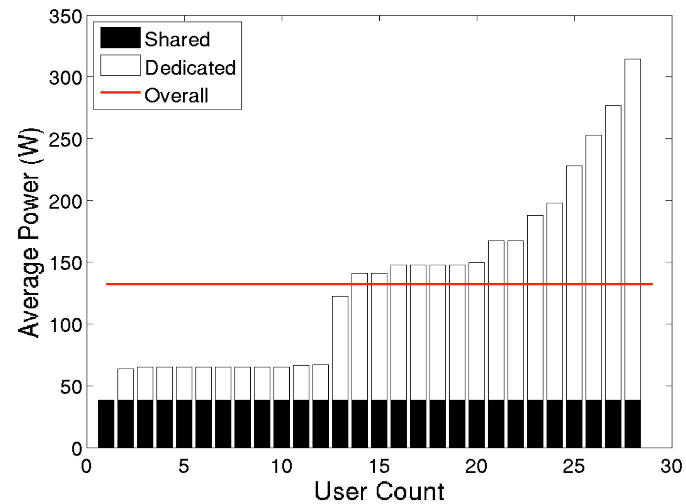


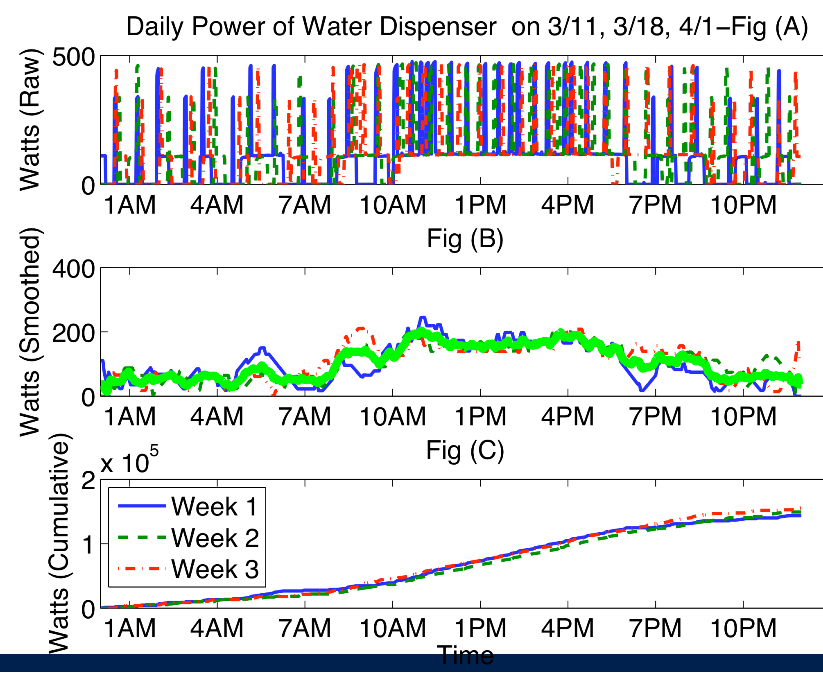
Energy Consumption Breakdown



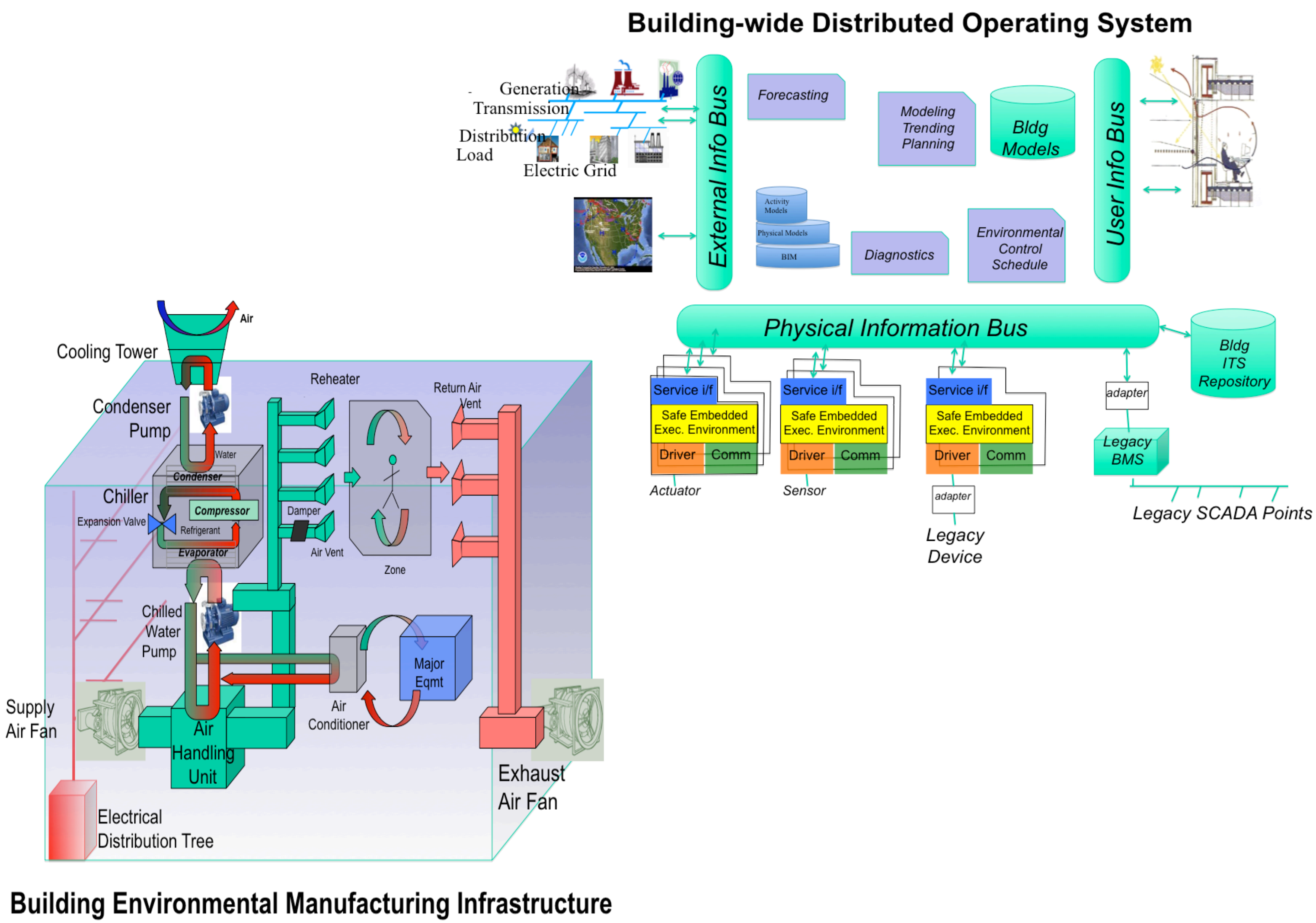
Re-aggregation to Purpose



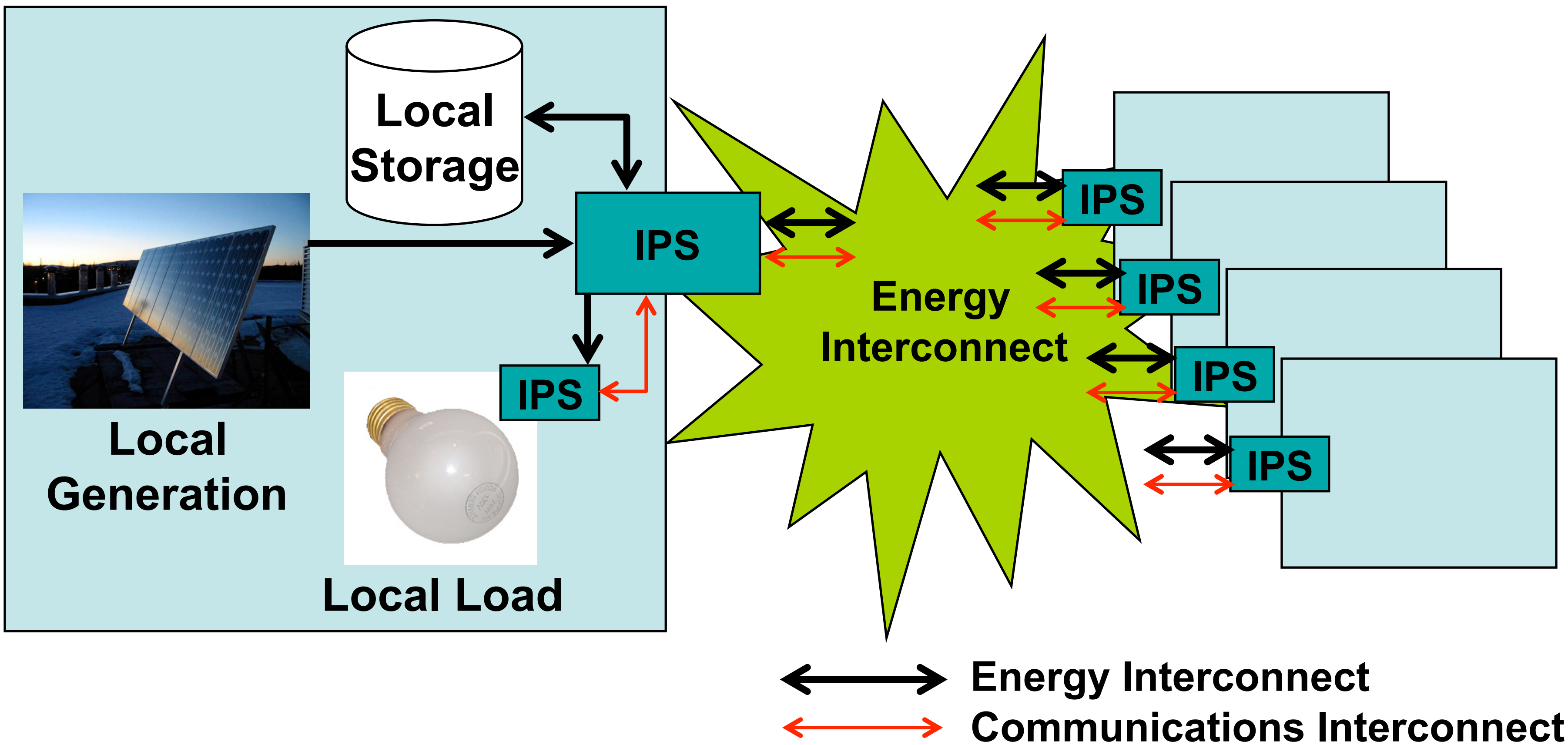




OS for Building, Datacenter, Grid, …



Scaling Energy Cooperation



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

“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
- … to the Grid

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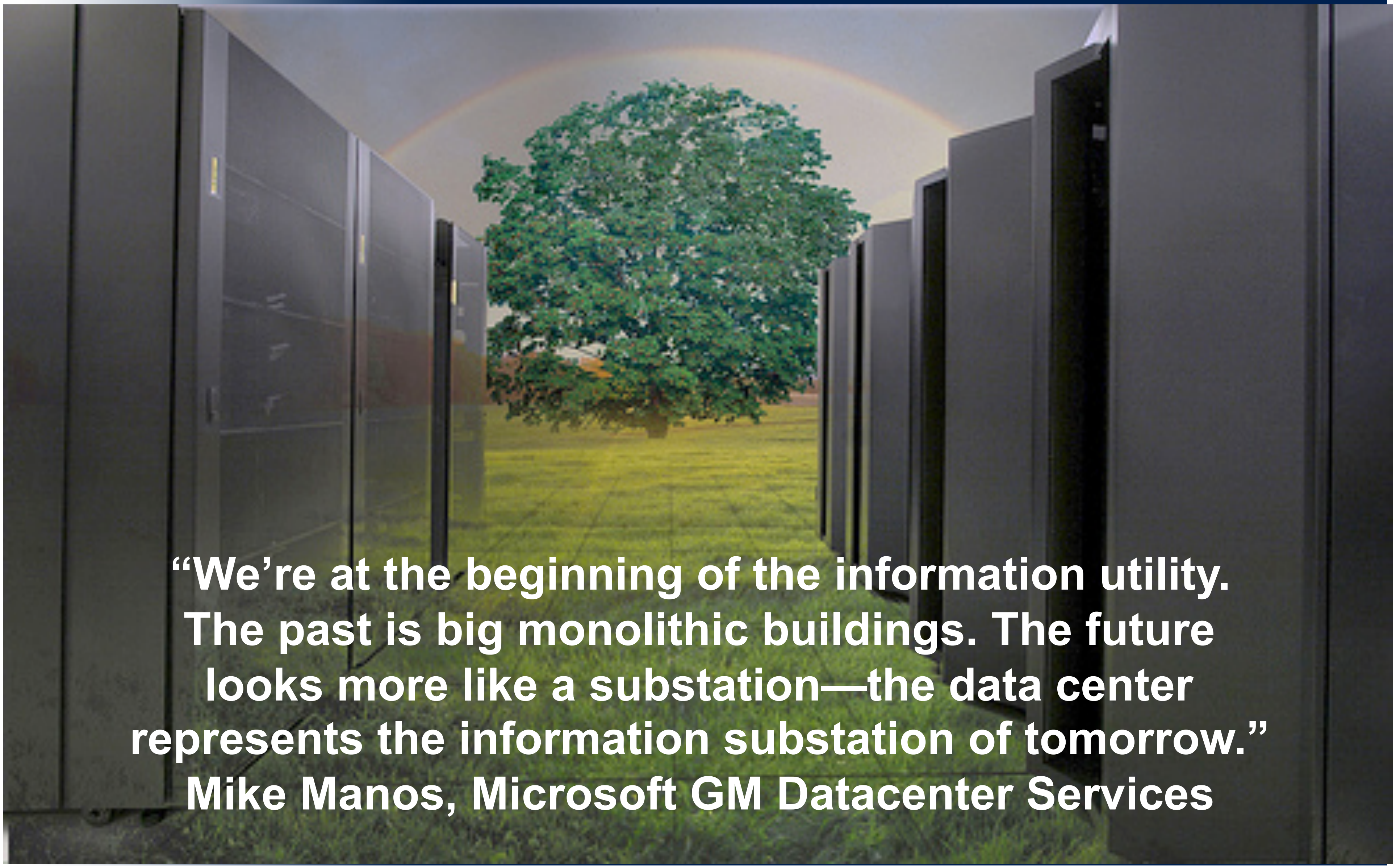
Summary and Conclusions

- 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!



"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