



Efficient Supply-Following Loads: The Key to a Cooperative Grid

David E. Culler

University of California, Berkeley



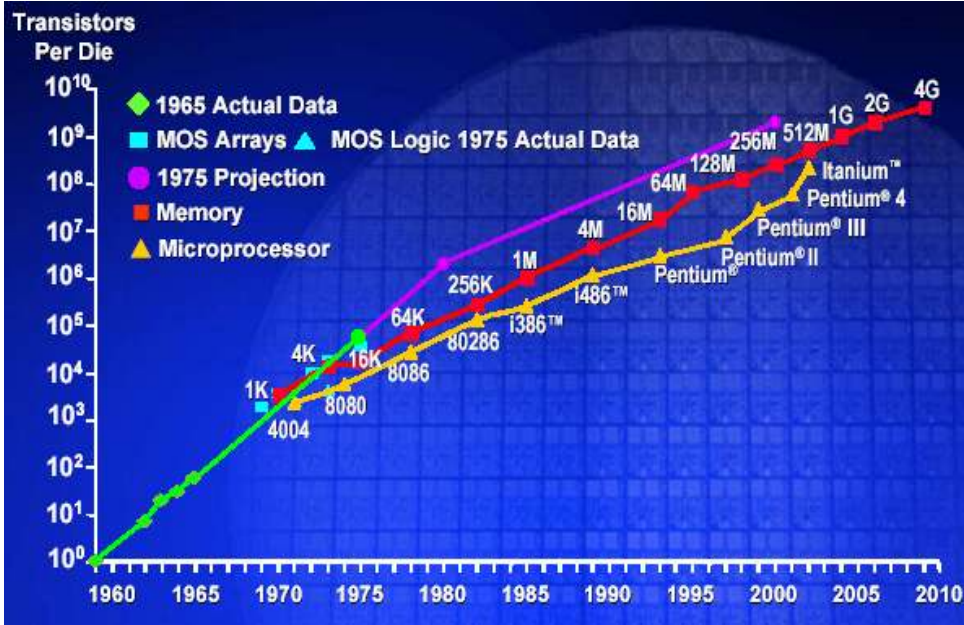
The Philomathia Foundation Symposium at Berkeley:
Pathways to a Sustainable Energy Future

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



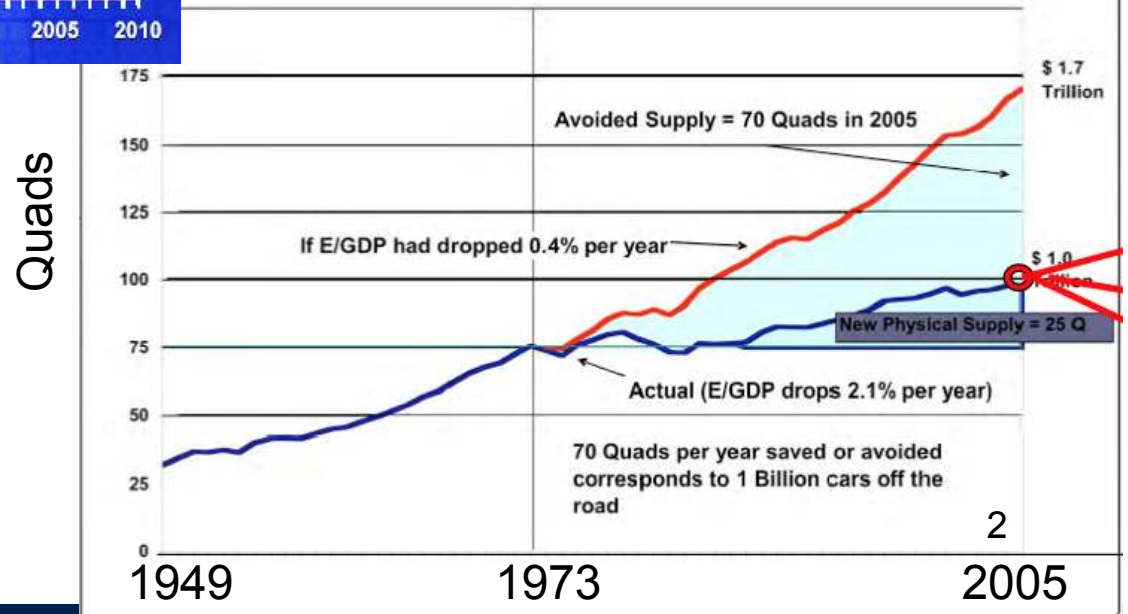


A Computer Scientist meets the Energy Problem



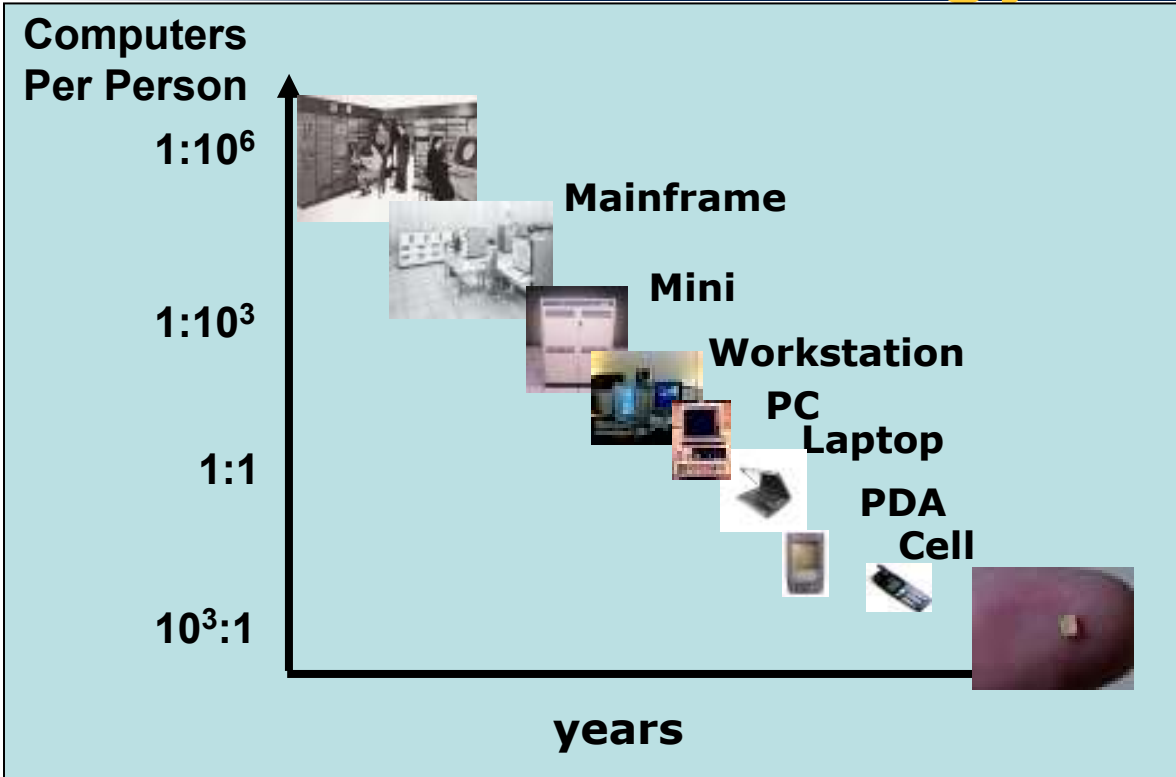
Moore's Law

Energy Consumption in the United States 1949 - 2005



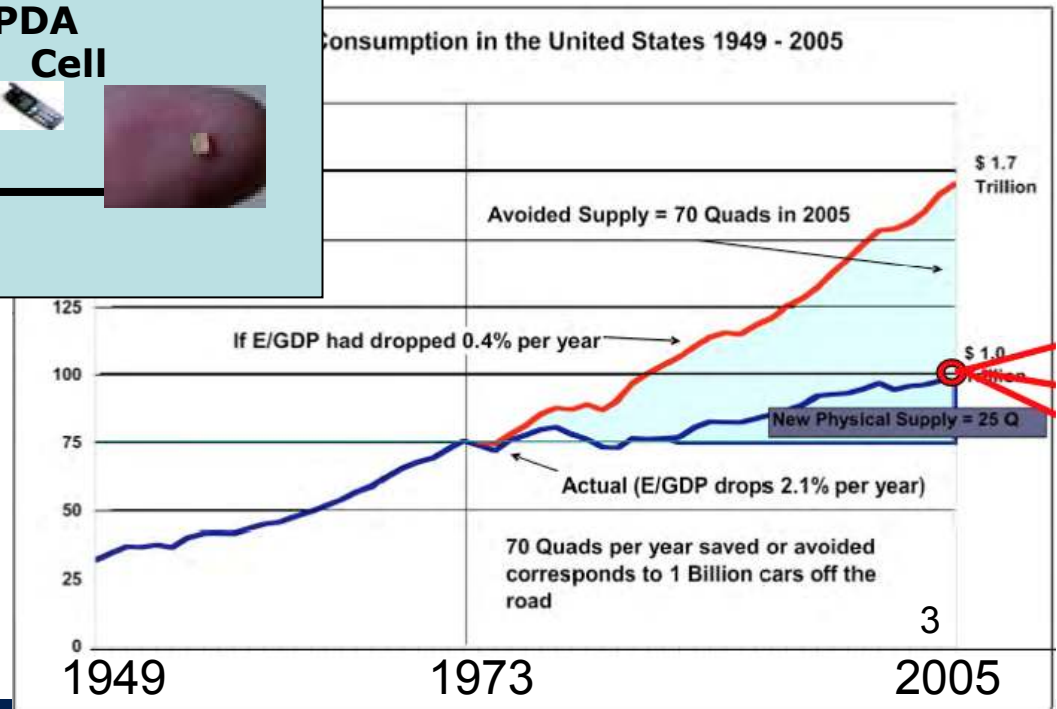


A Computer Scientist meets the Energy Problem



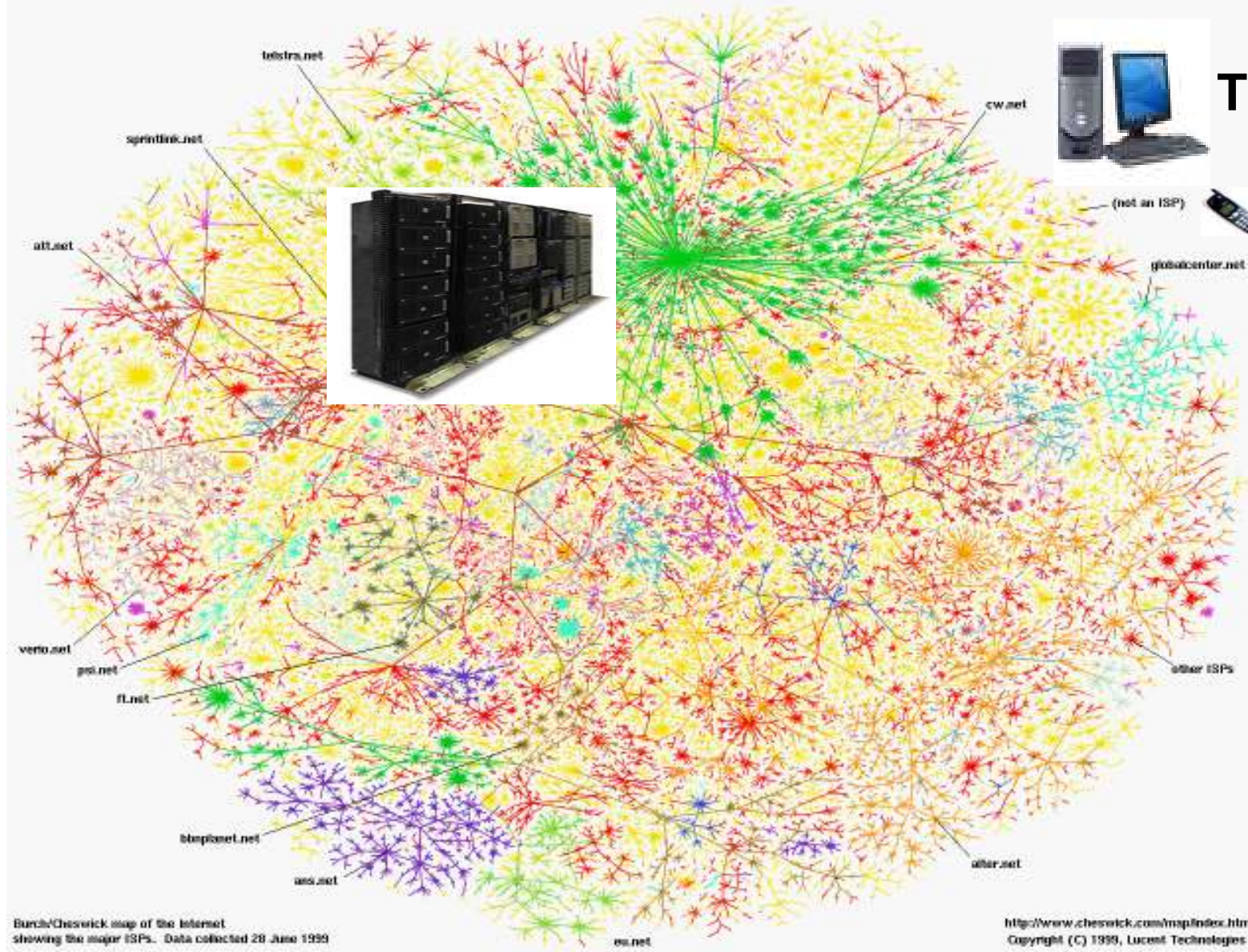
Bell's Law

Qua

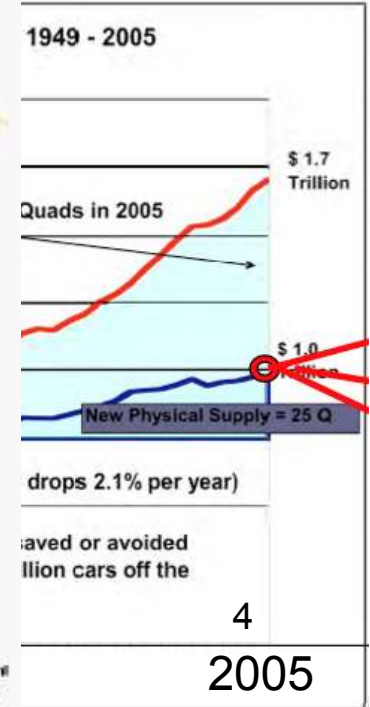




A Computer Scientist meets the Energy Problem



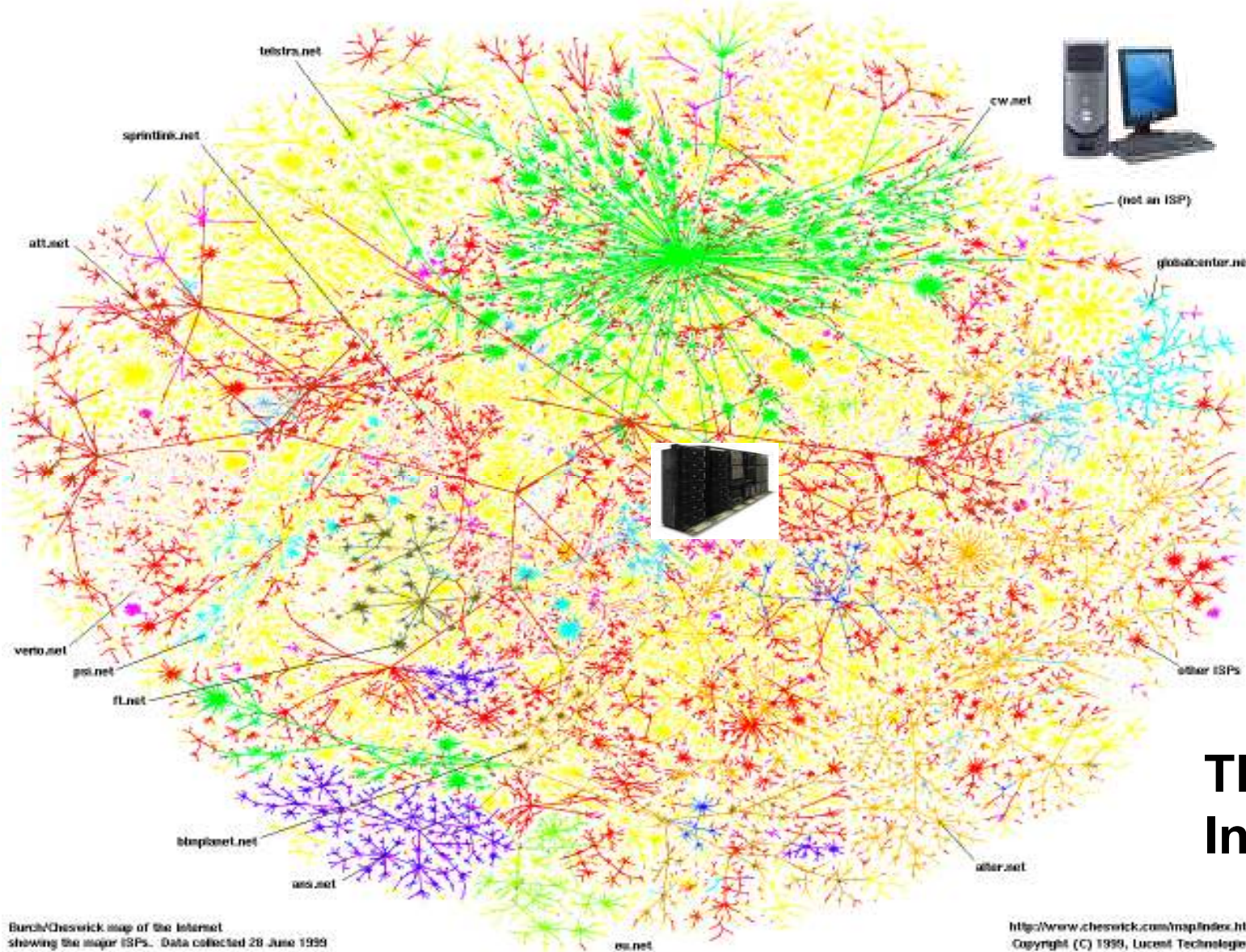
The Internet



Lolal



A Computer Scientist meets the Energy Problem



(not an ISP)



Burch/Cheswick map of the Internet showing the major ISPs. Data collected 28 June 1999

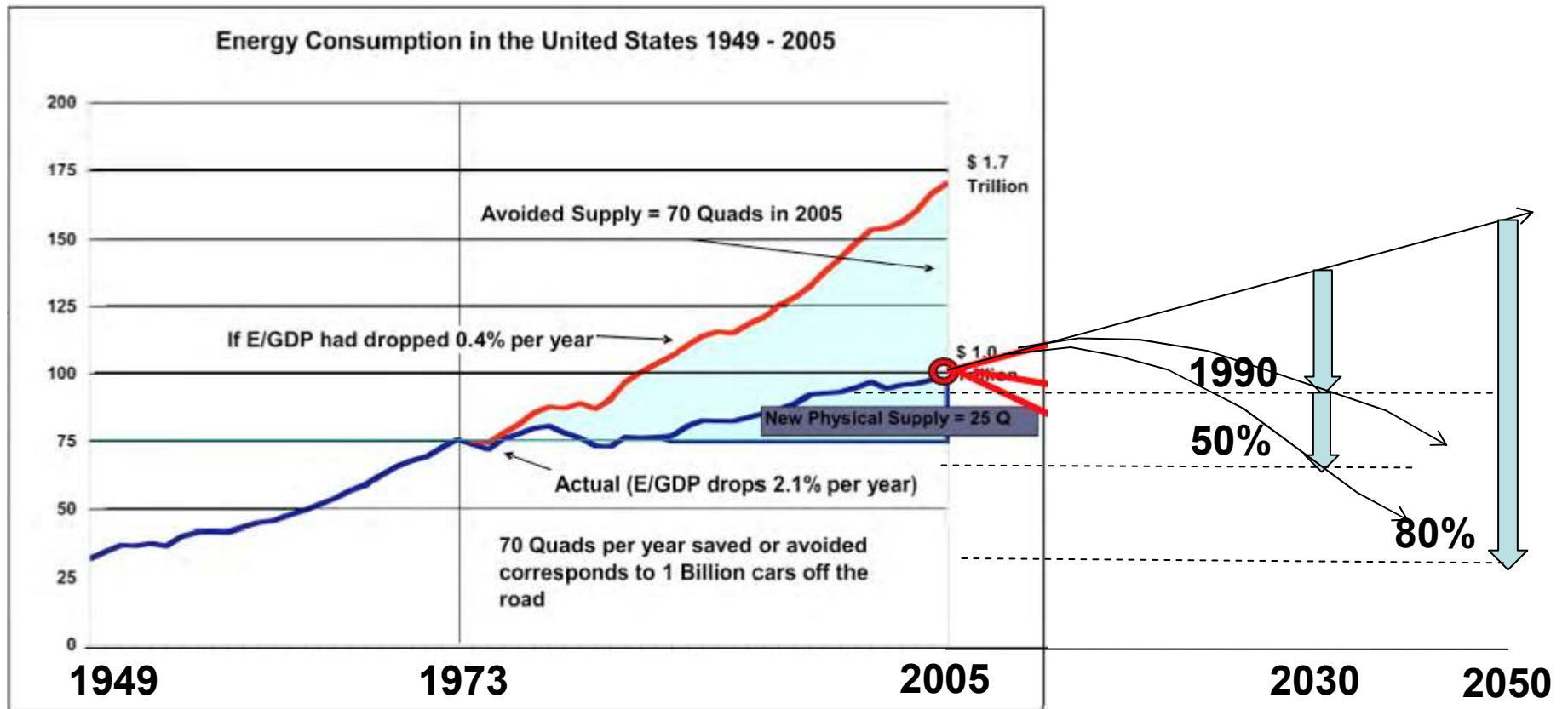
<http://www.cheswick.com/map/index.html>
Copyright (C) 1999, Lucent Technologies

The Physical Internet

5
2005



A Computer Scientist meets the Energy Problem





The Industrial Age Grid

Baseline + Dispatchable Tiers

Oblivious Loads



LaCal



Towards an "Aware" Energy Infrastructure

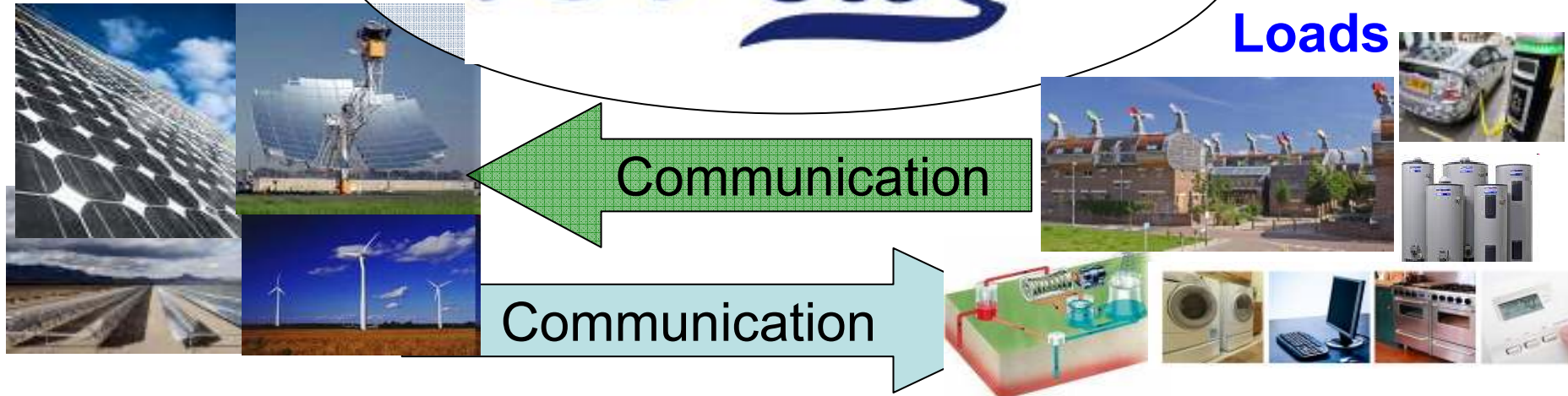
Baseline + Dispatchable Tiers

Oblivious Loads



Non-Dispatchable Sources

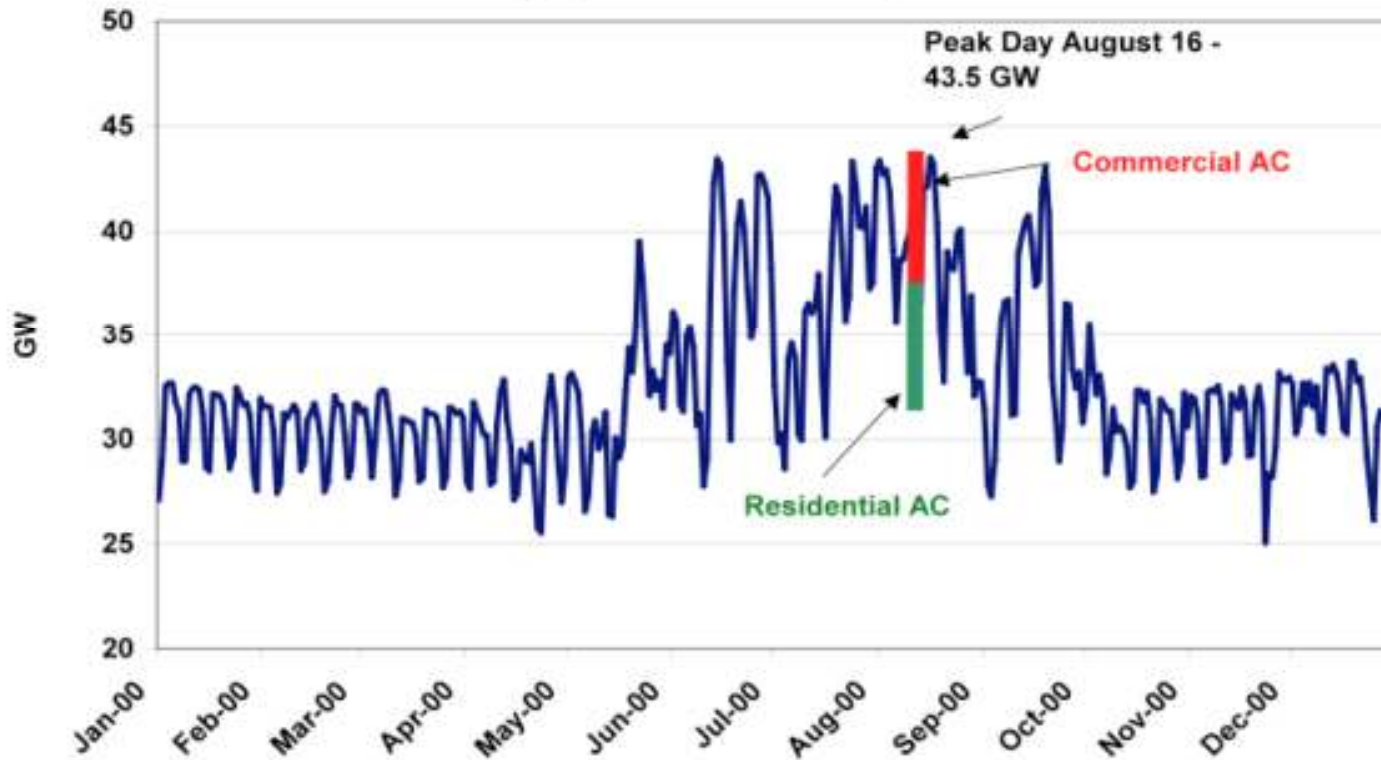
Aware Interactive Loads





Load-following Supply

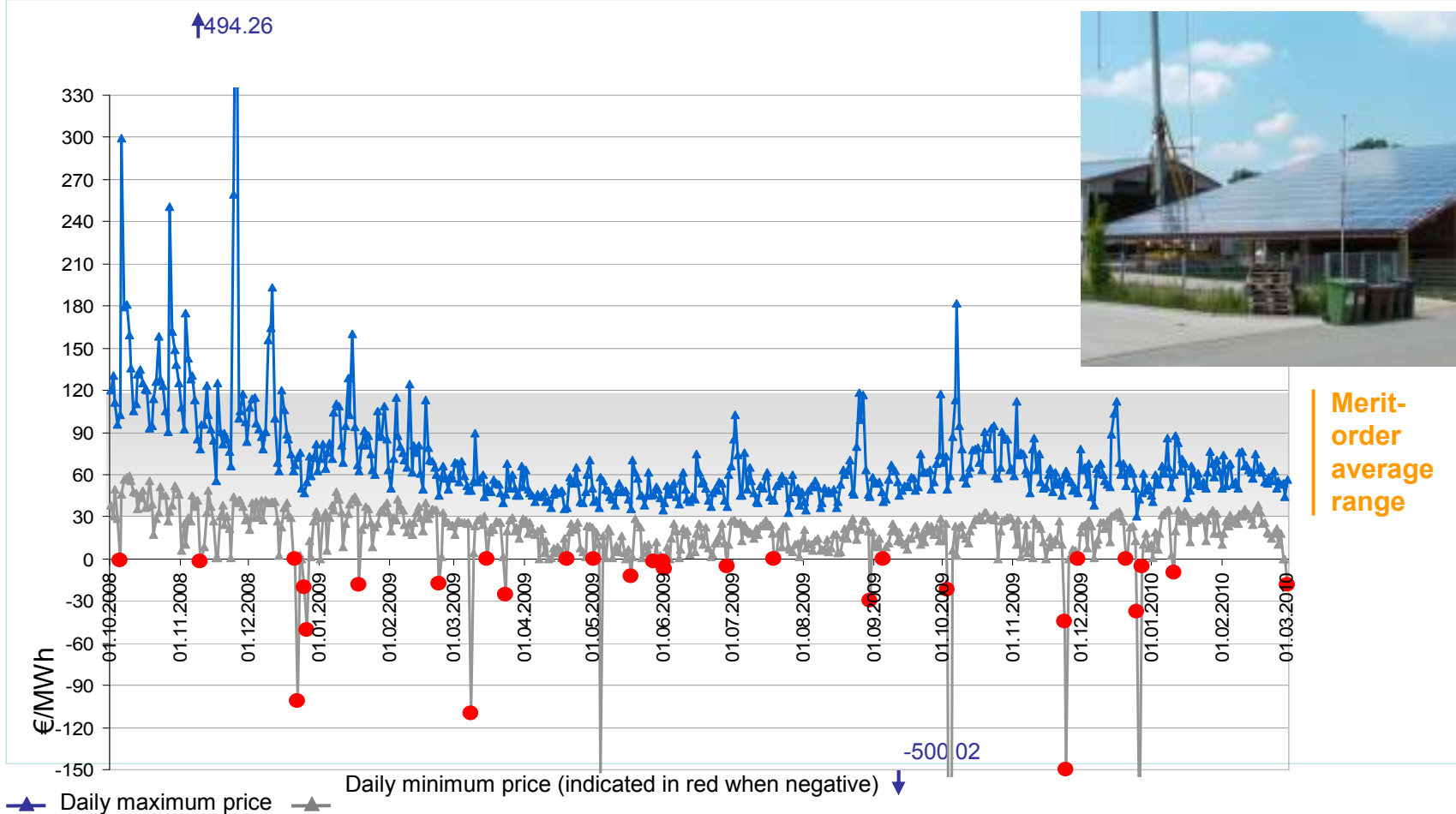
Cal ISO Daily Peak Loads
January 1, 2000 - December 31, 2000





Load-following Supply (?)

Growing proportion of renewables leads to higher price volatility. October 2008 to March 2010:
>90 hours with negative prices; highest price reached: +€500/MWh, lowest -€500/MWh

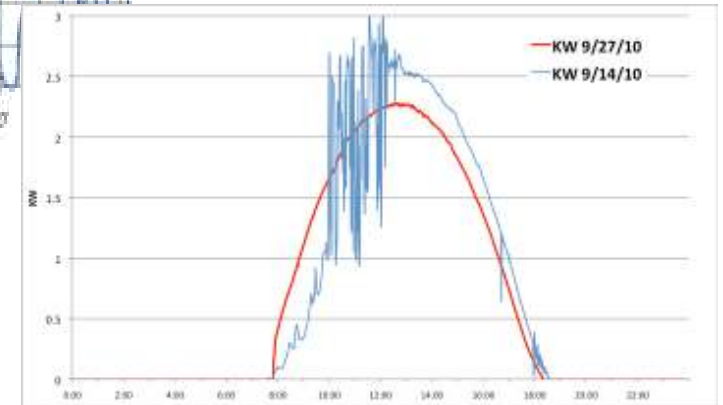
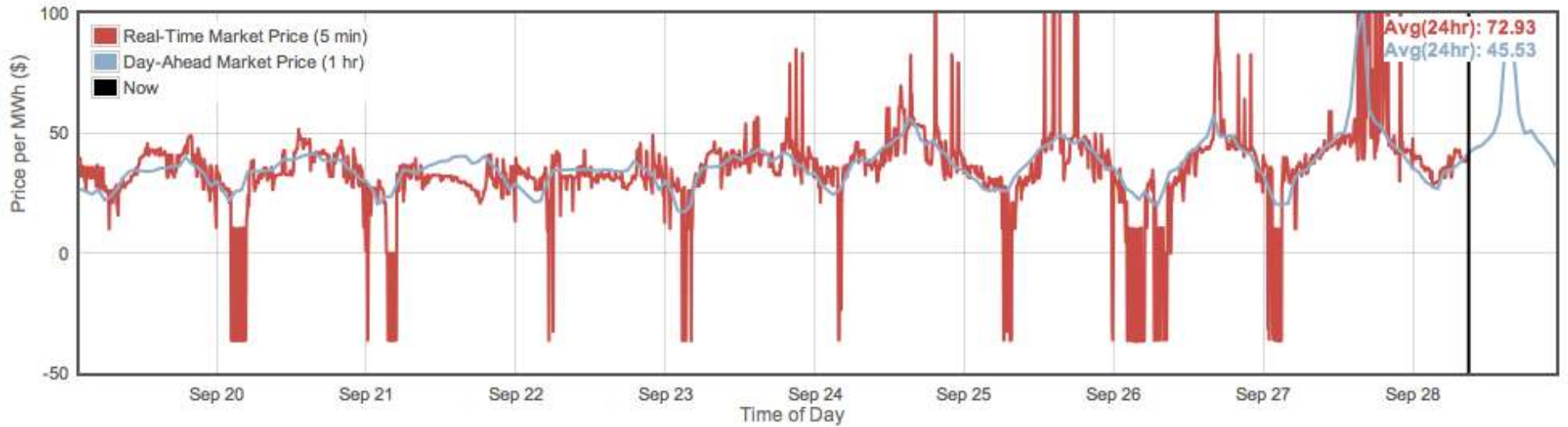


Source: EEX spot prices.



... and @ CA

Energy Price



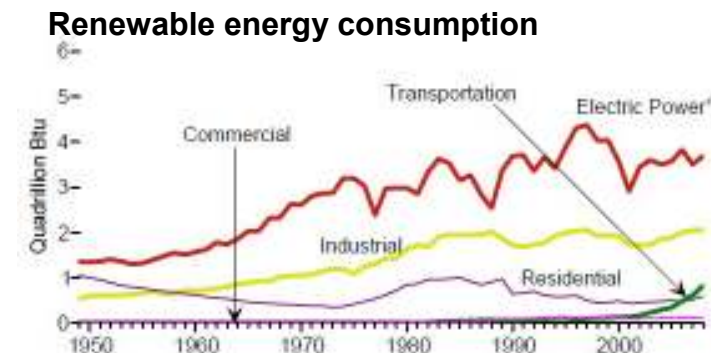
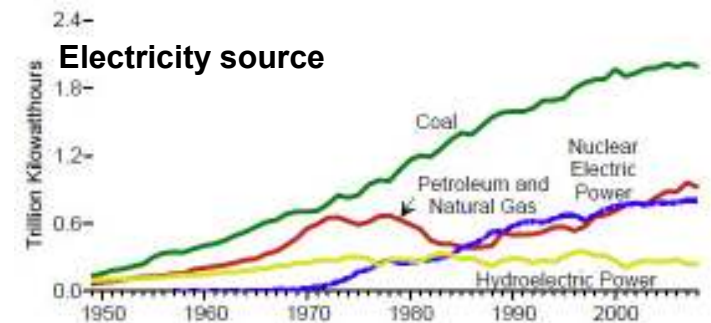
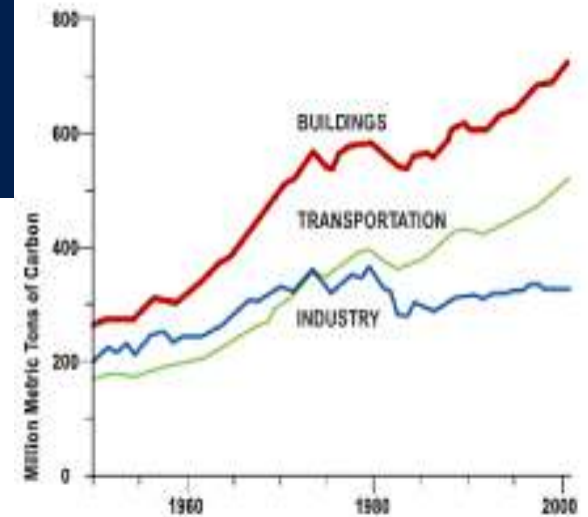


Where to Start?

- **Buildings**

- 72% of electrical consumption (US),
- 40-50% of total consumption,
- 42% of GHG footprint
- US commercial building consumption doubled 1980-2000, 1.5x more by 2025 [NREL]

- Where Coal is used
- Prime target of opportunity for renewable supplies



Local

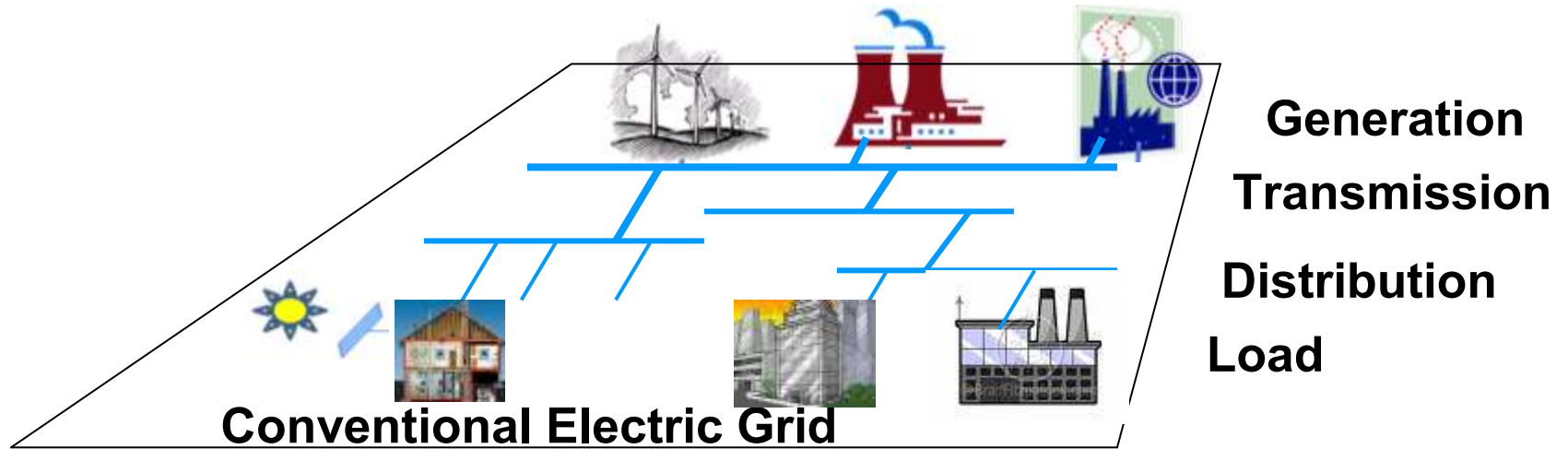


Start from Scratch?

- No!

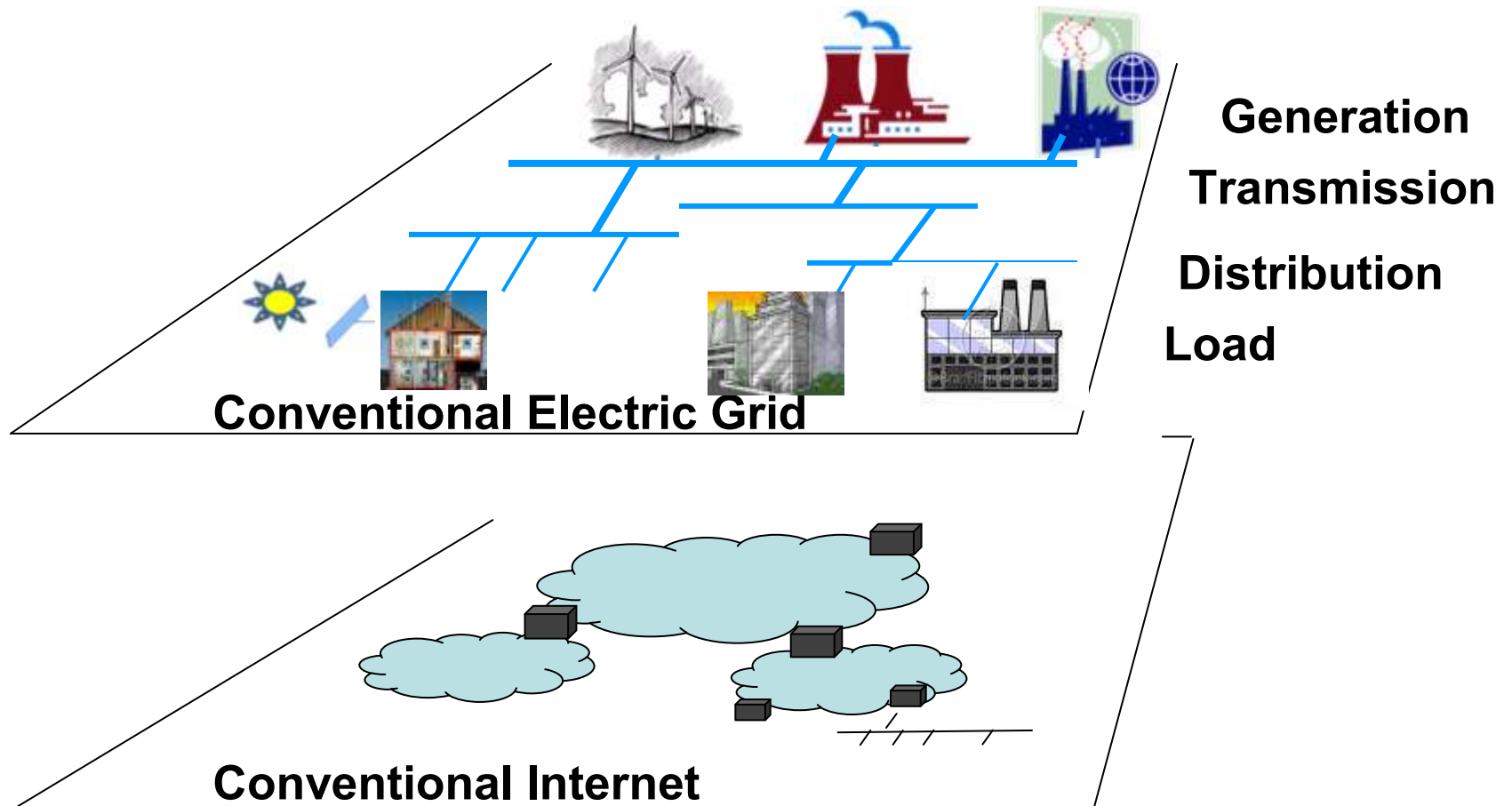


Grid Exists



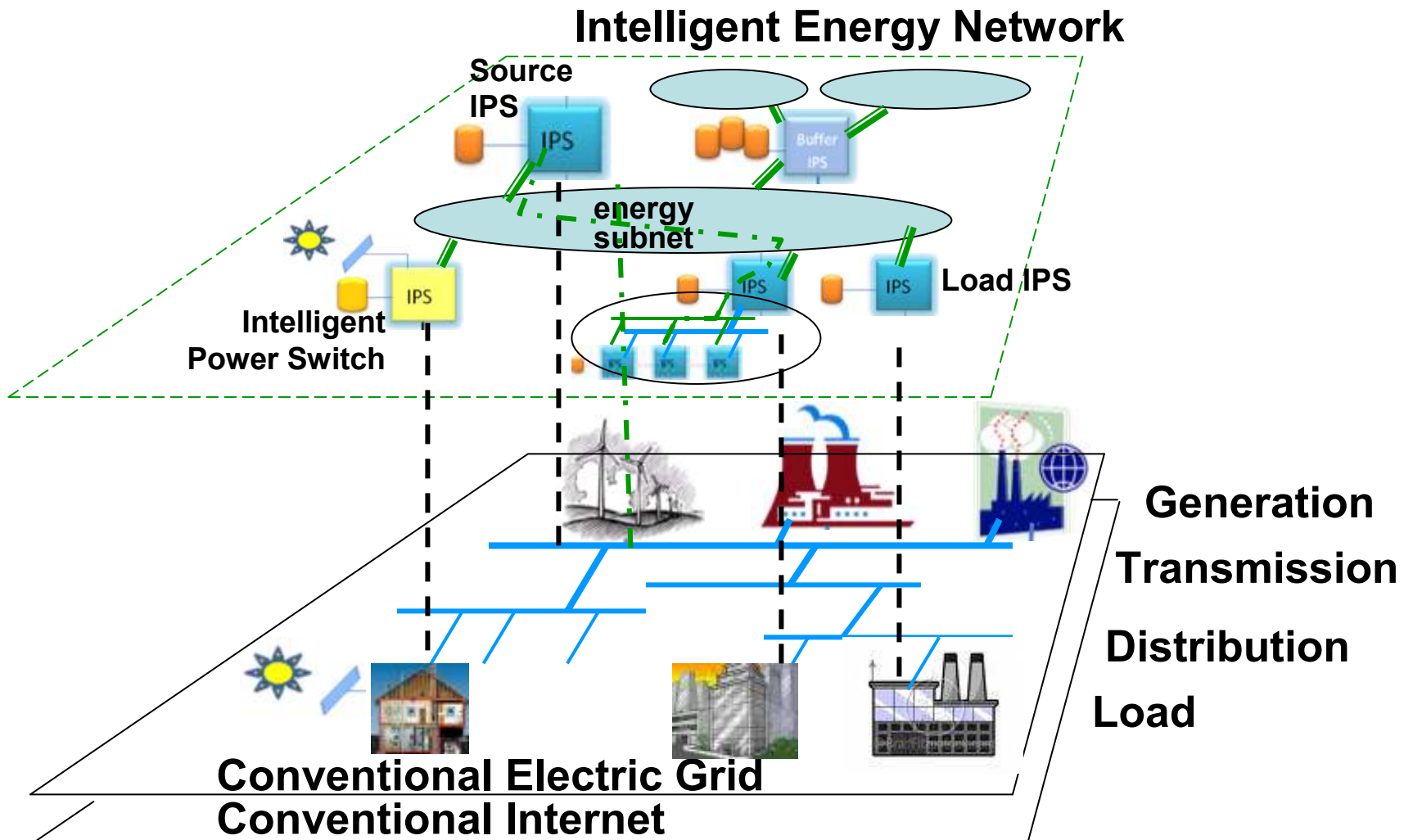


Internet Exists





Intelligent Energy Network as Overlay on Both



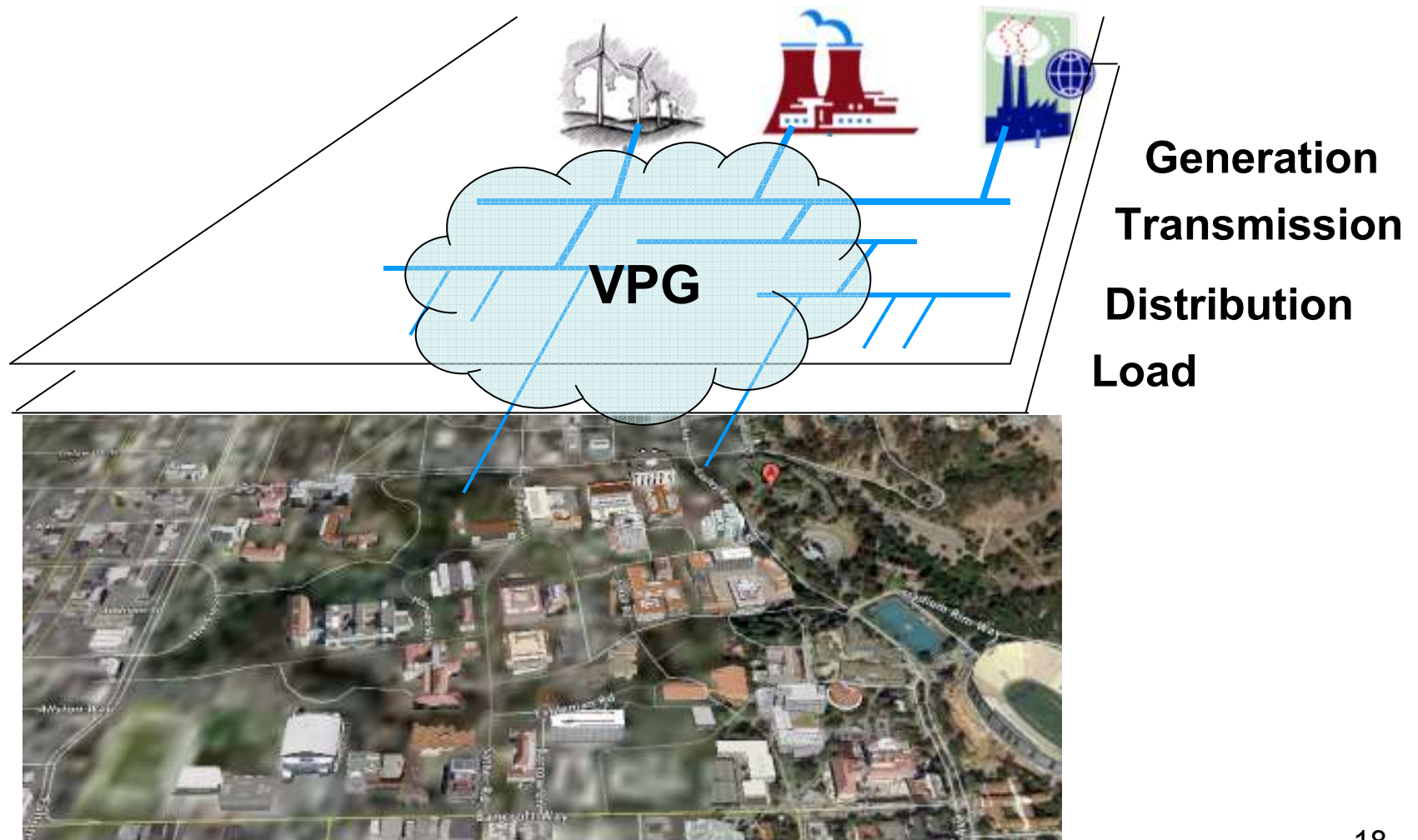


Lessons from the Internet

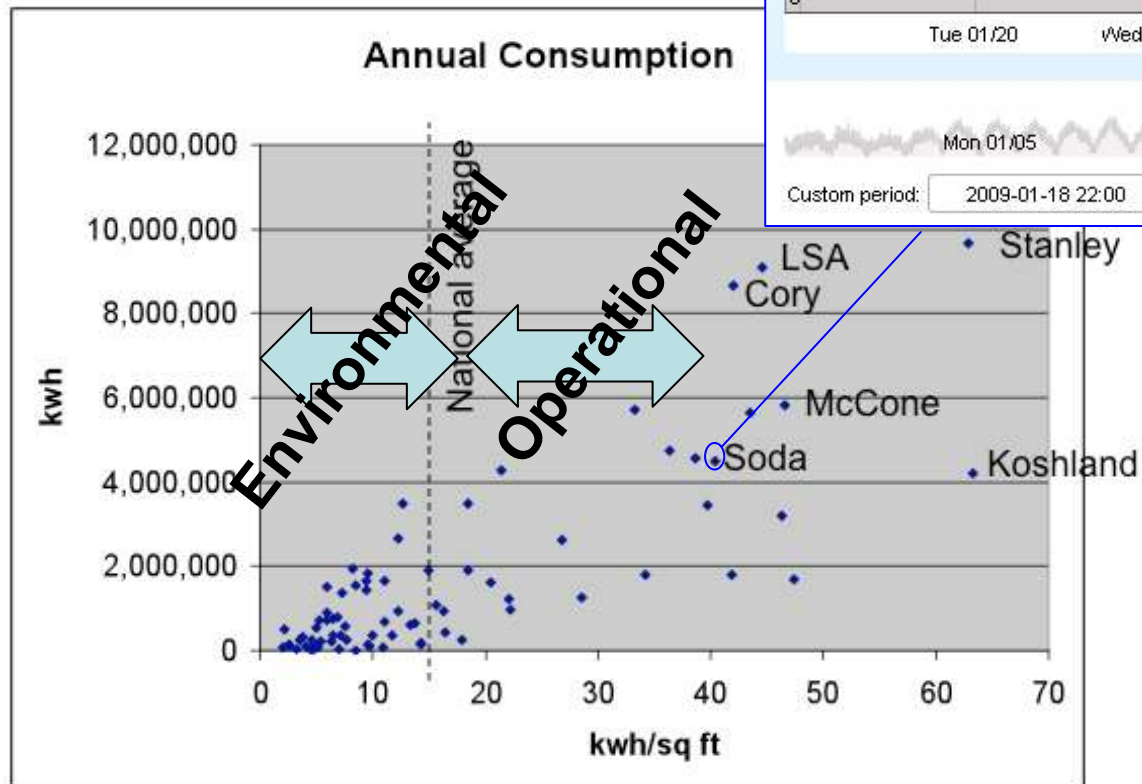
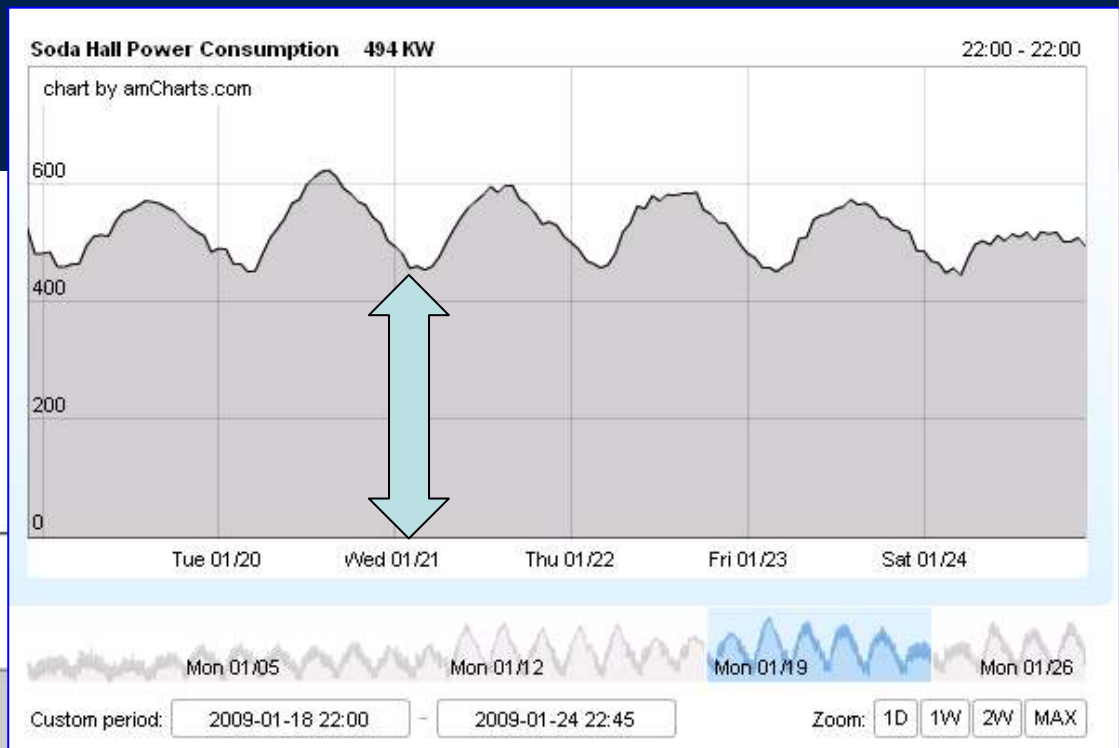
- Measure everywhere, continuously adapt
- Intelligence at the end-points, simple core
- Horizontal Layering, not Vertical Integration
- Universal “narrow waist” – IP
 - ⇒ Absorb new technology
 - ⇒ Enable new applications
 - ⇒ Innovate in the Overlay
 - ⇒ Web: simple, open, machine readable formats



Innovate in a Virtual Private Grid

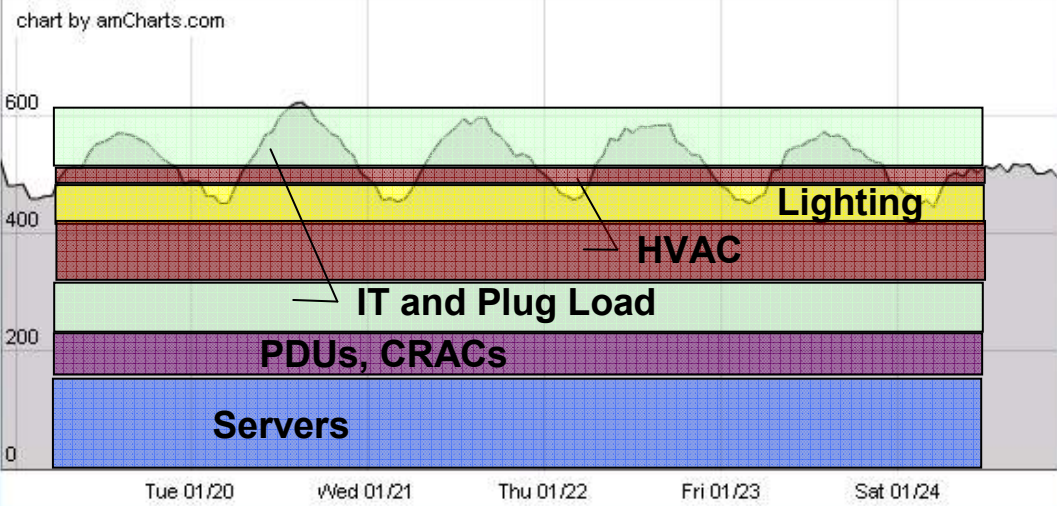


Our Buildings

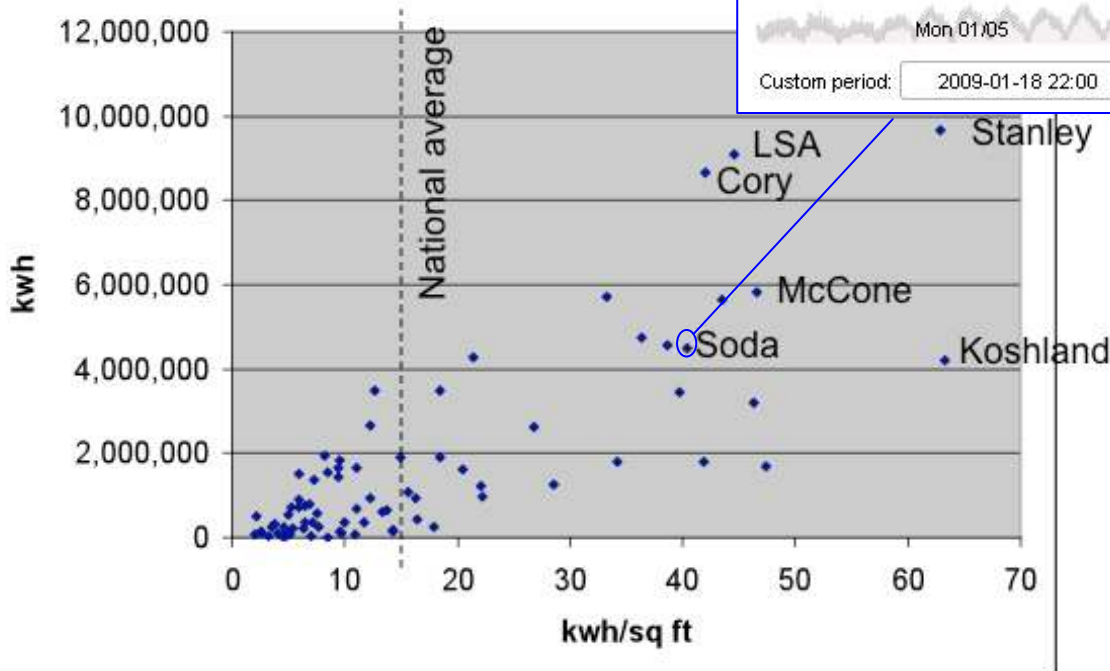


Soda Hall

Soda Hall Power Consumption 494 KW 22:00 - 22:00



Annual Consumption





2020 IT Carbon Footprint

IT footprints

Emissions by sub-sector, 2020

820m tons CO₂

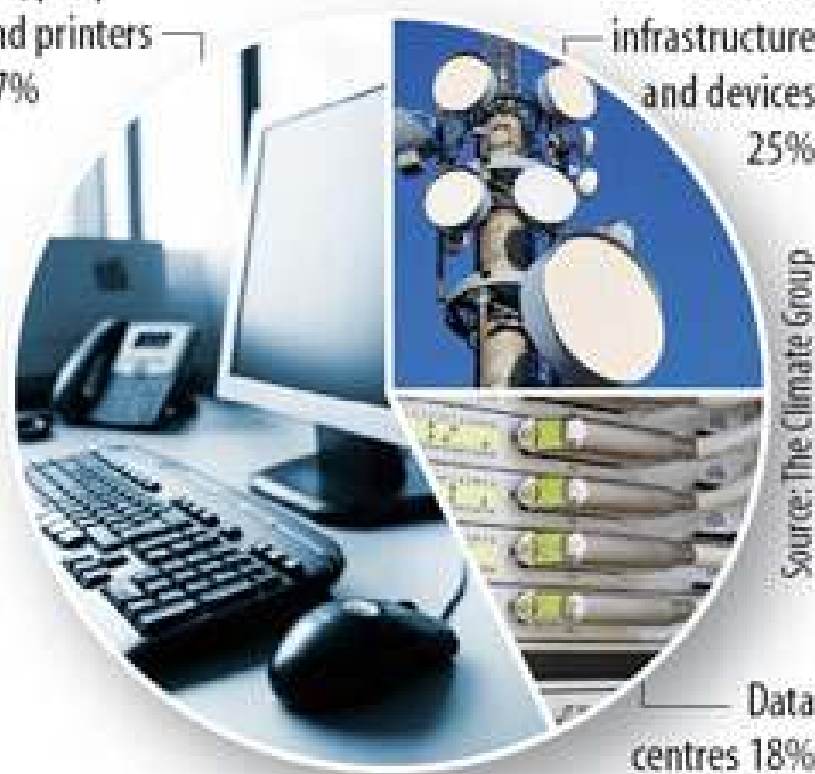
PCs, peripherals
and printers
57%

Telecoms
infrastructure
and devices
25%

360m tons CO₂

2007 Worldwide IT
carbon footprint:
2% = 830 m tons CO₂
Comparable to the
global aviation
industry

Expected to grow
to 4% by 2020



260m tons CO₂

Total emissions: 1.43bn tonnes CO₂ equivalent

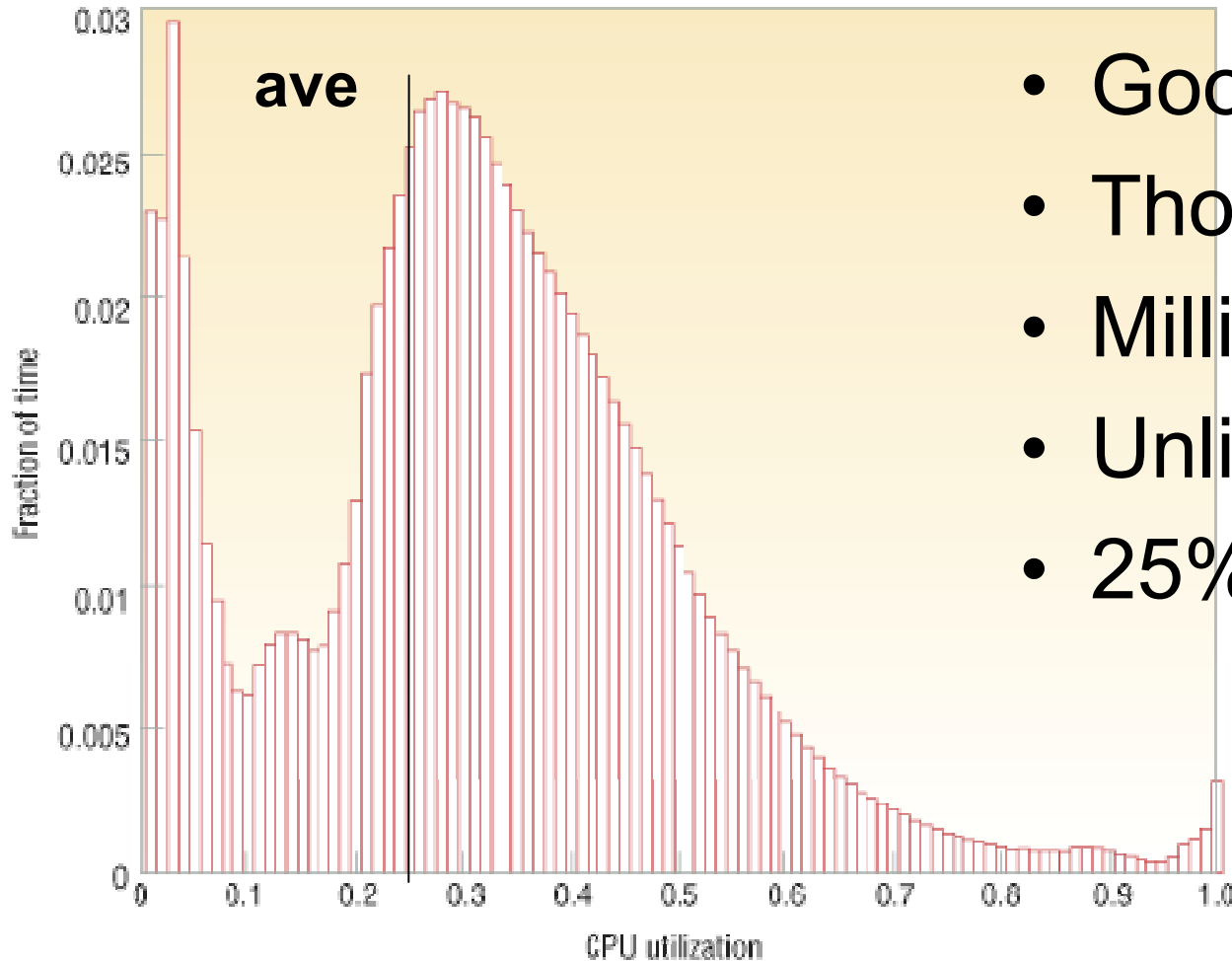


Engineering 101

- Design, Plan, Size, and Test at **Full Load**
 - Performance measured at full Load
- Add headroom and safety margin
- Operate at **Partial Load**



A Prime IT Example



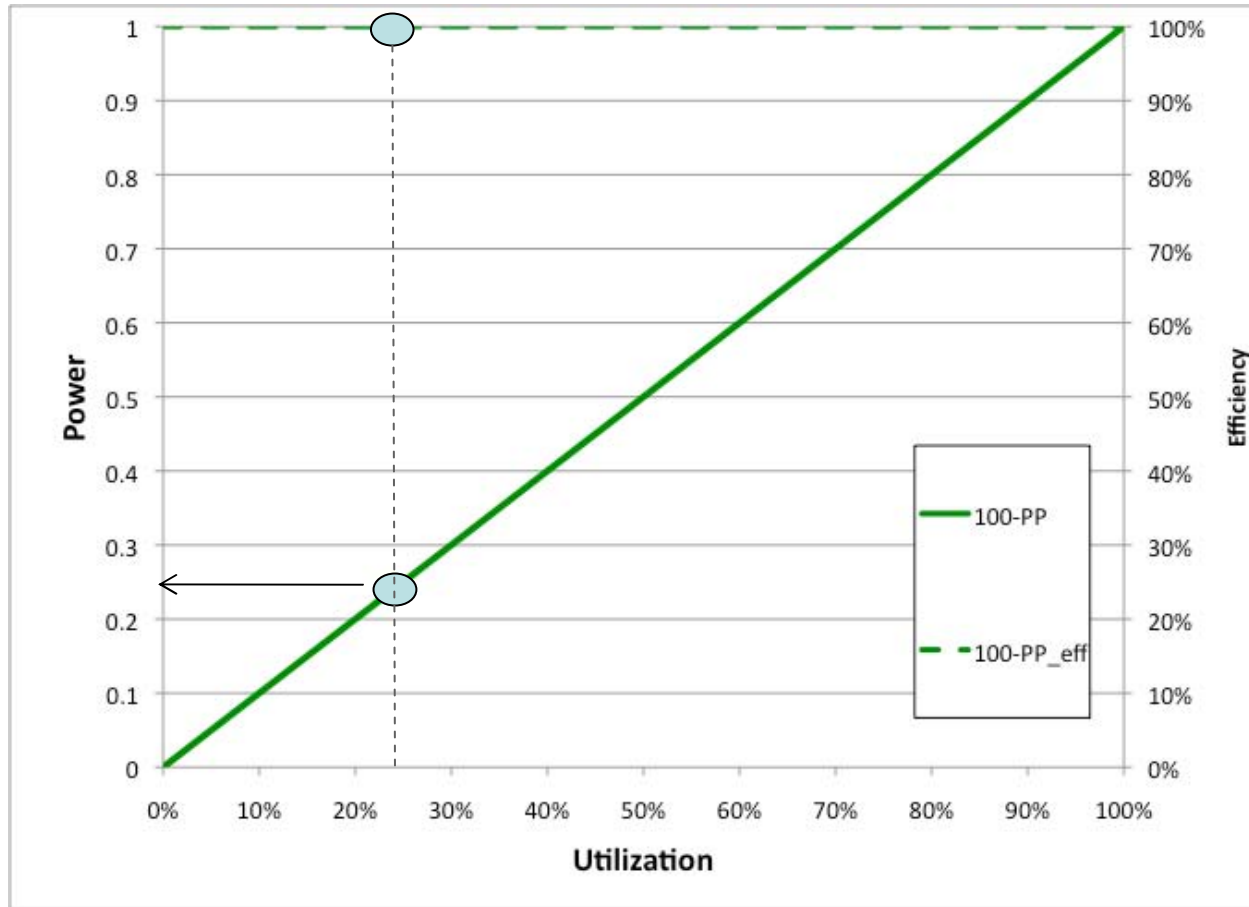
- Google
- Thousand of servers
- Millions of users
- Unlimited demand
- 25% utilized

“The Case for Energy-Proportional Computing,” Luiz André Barroso, Urs Hölzle, *IEEE Computer* December 2007 – study of 5,000 servers



Power Proportionality

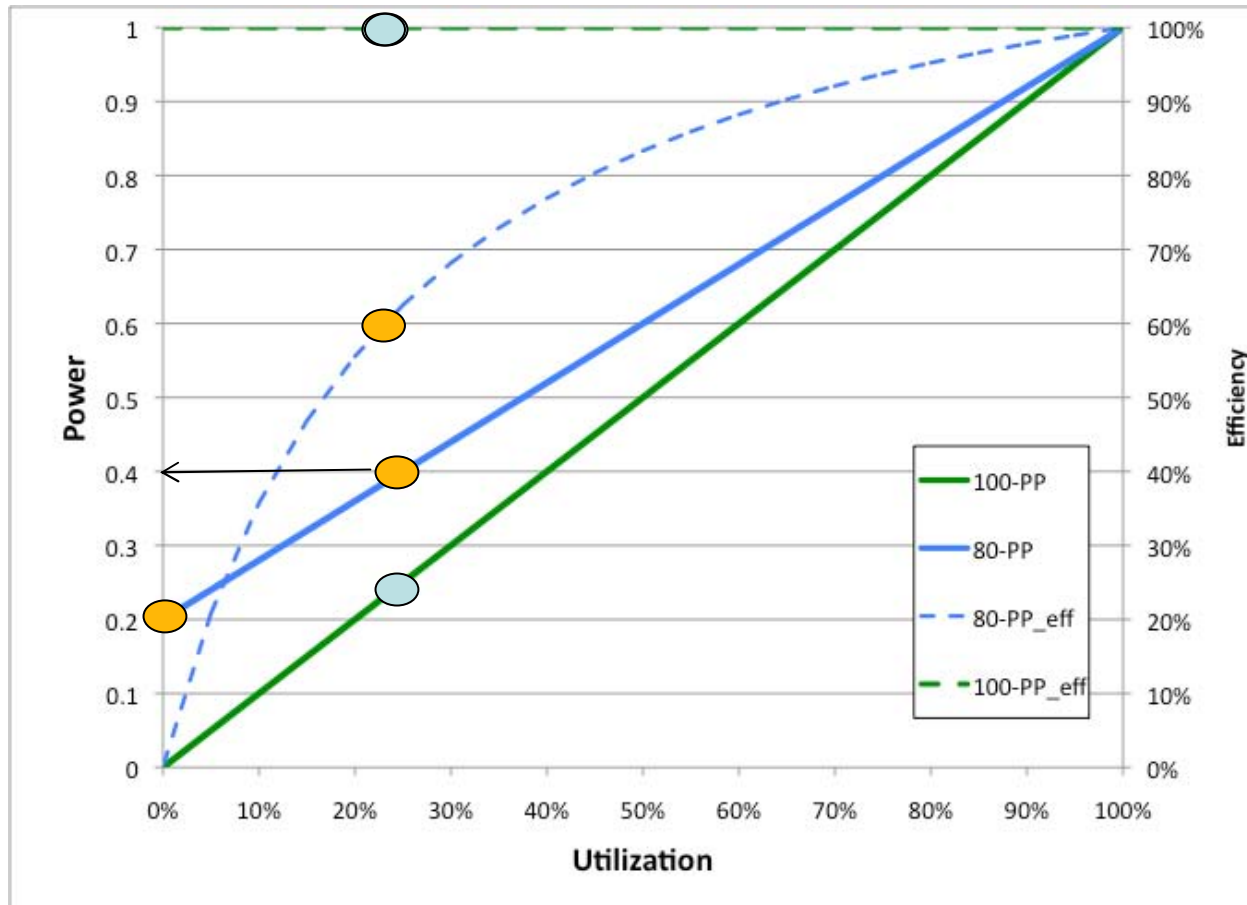
Consumption



Productivity

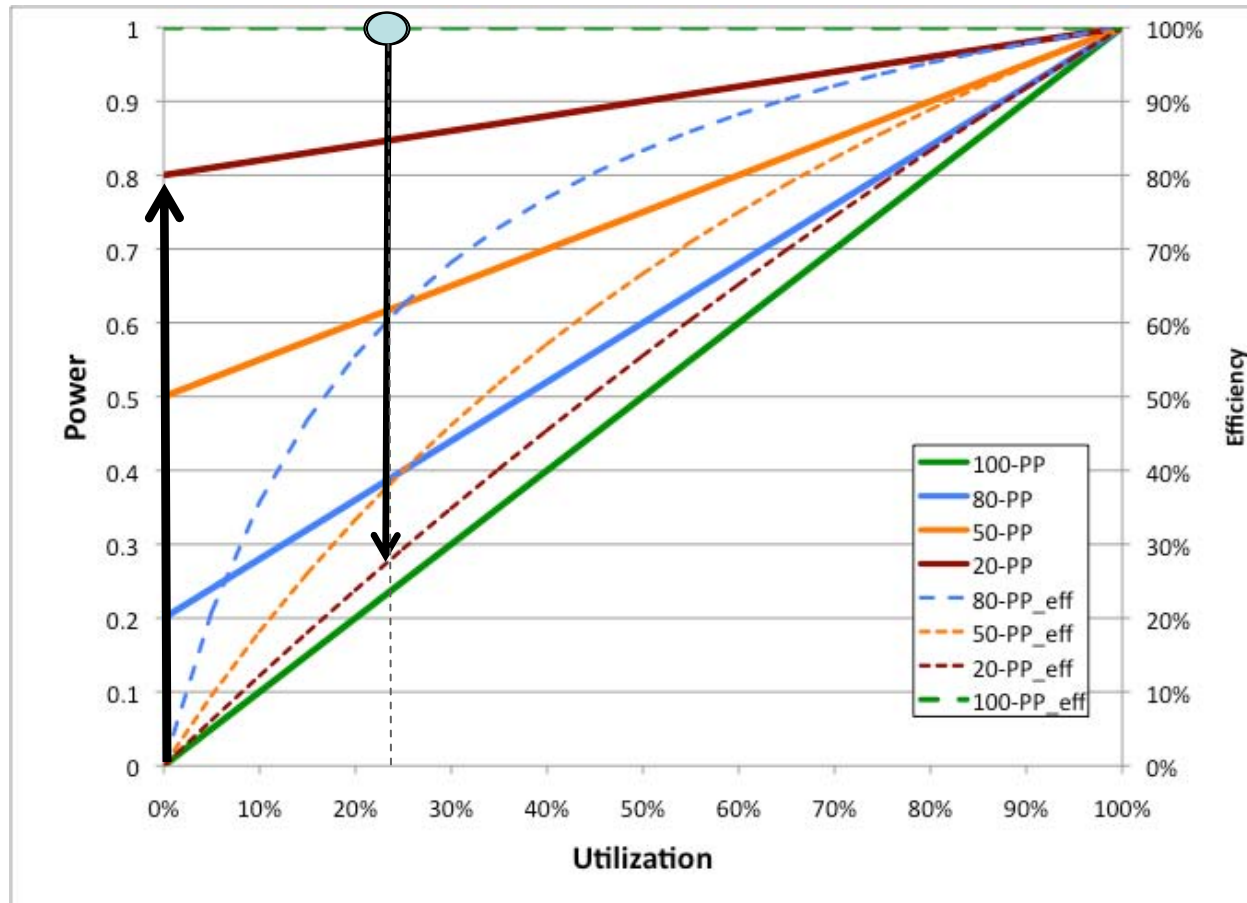


Power Proportionality



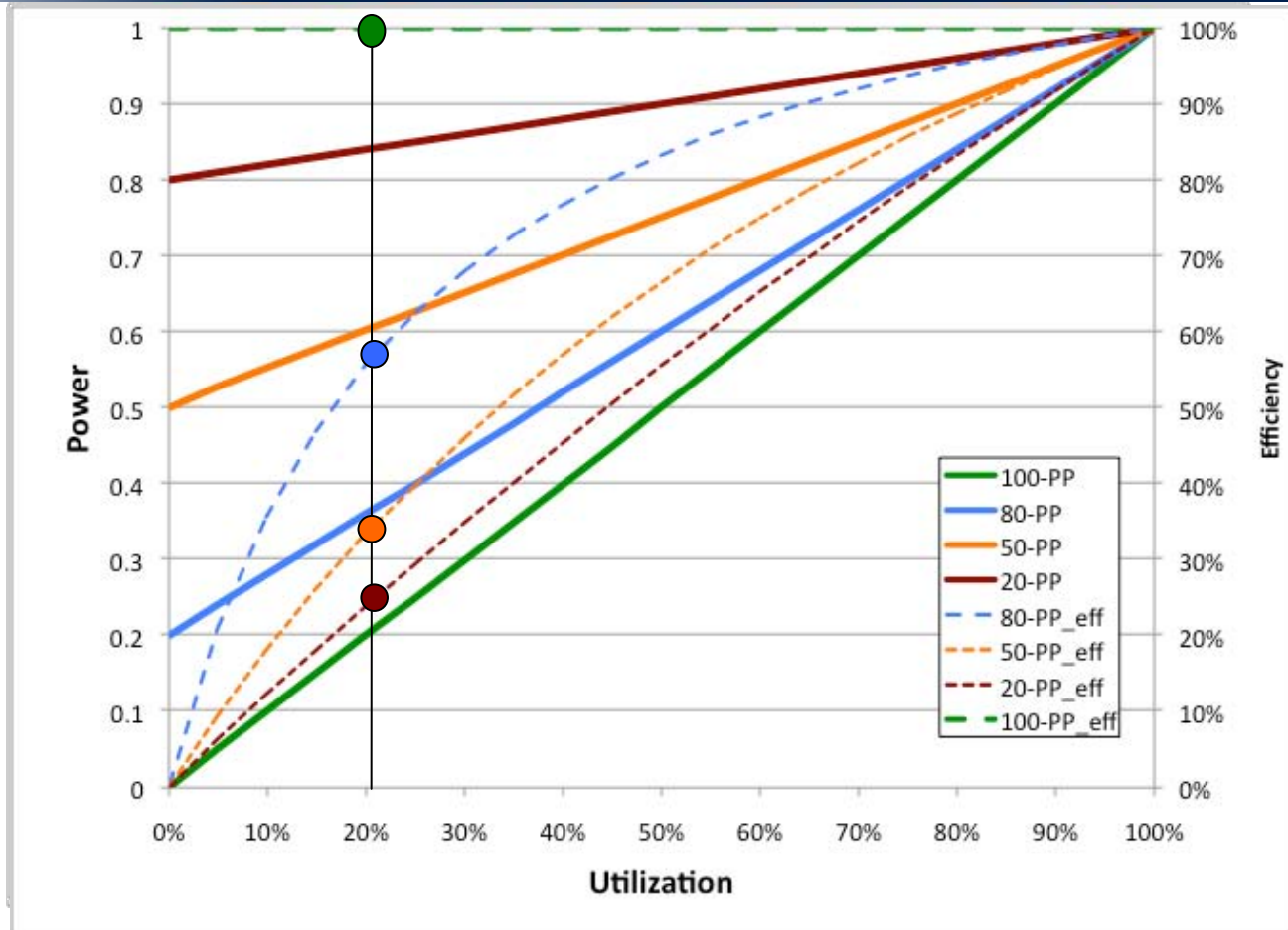


Power Proportionality





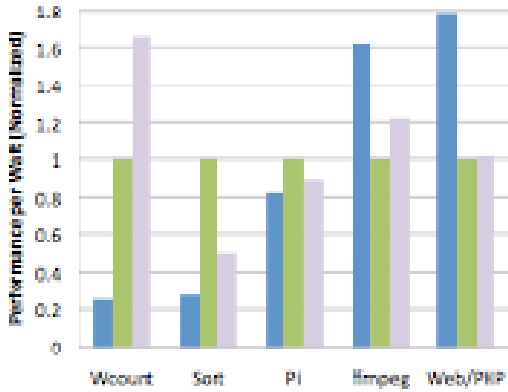
Power Proportionality



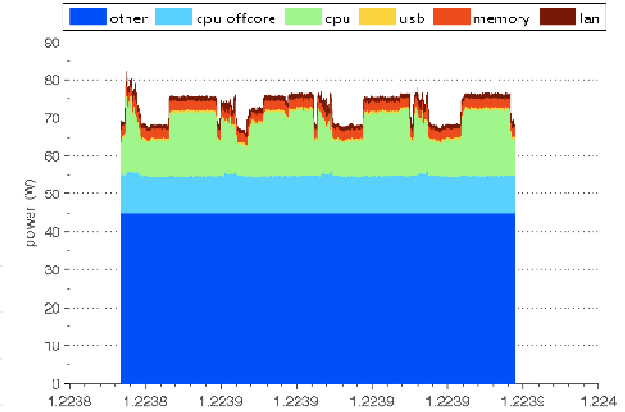
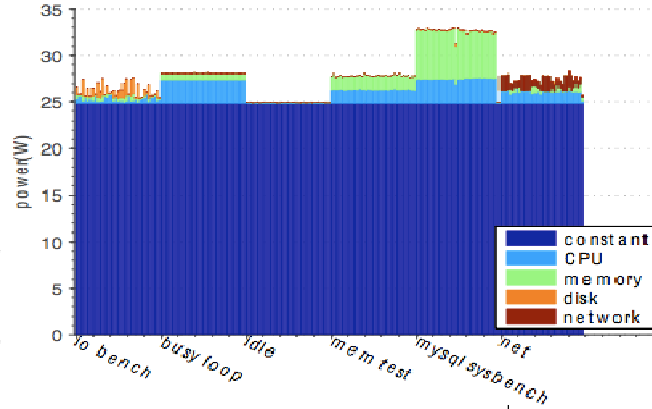
- Measure of scaling down to Partial Load
- Do Nothing Well !



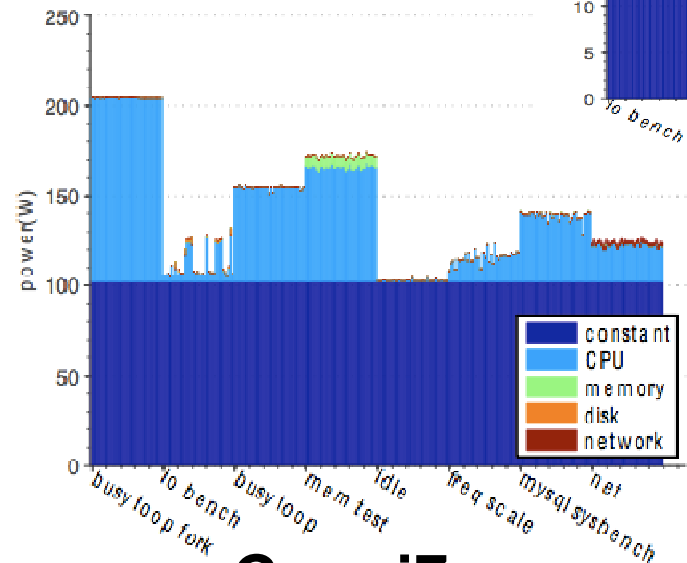
Where does the Power go?



The Glue, not the processor



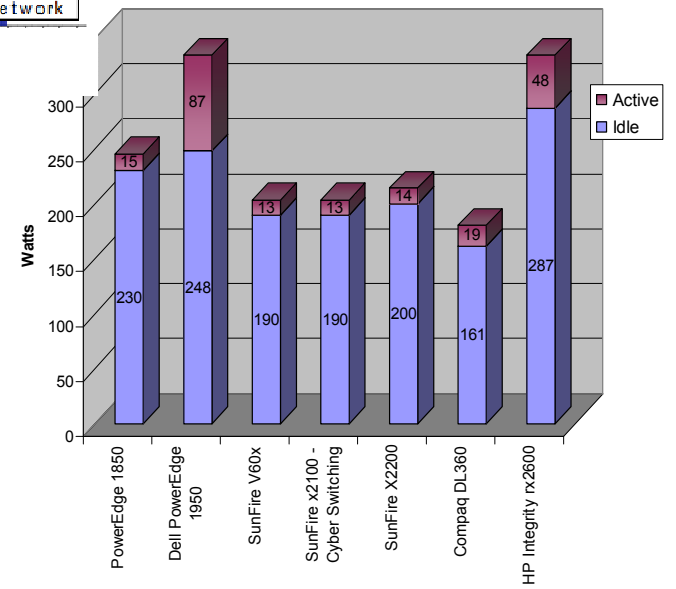
Westmere



Core i7

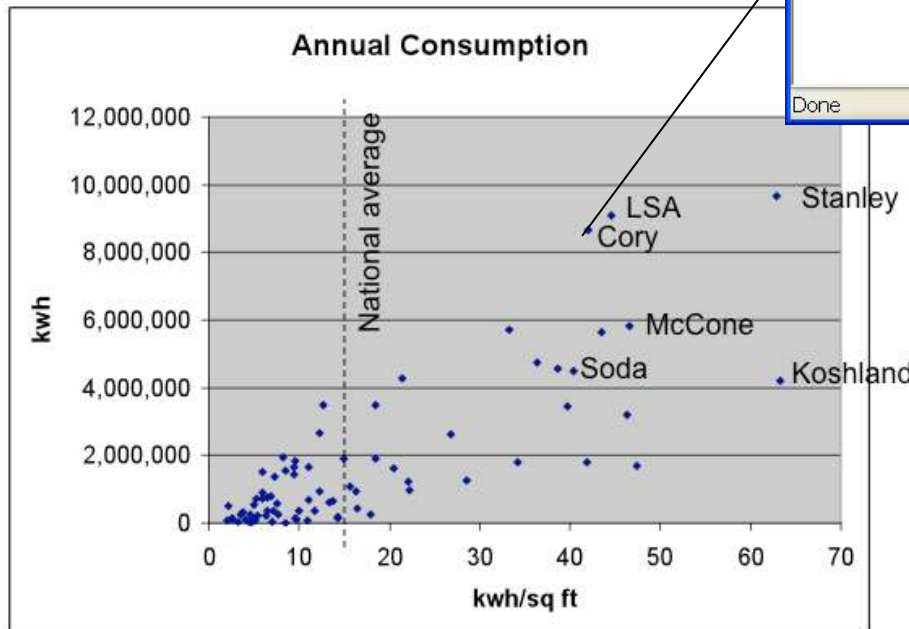
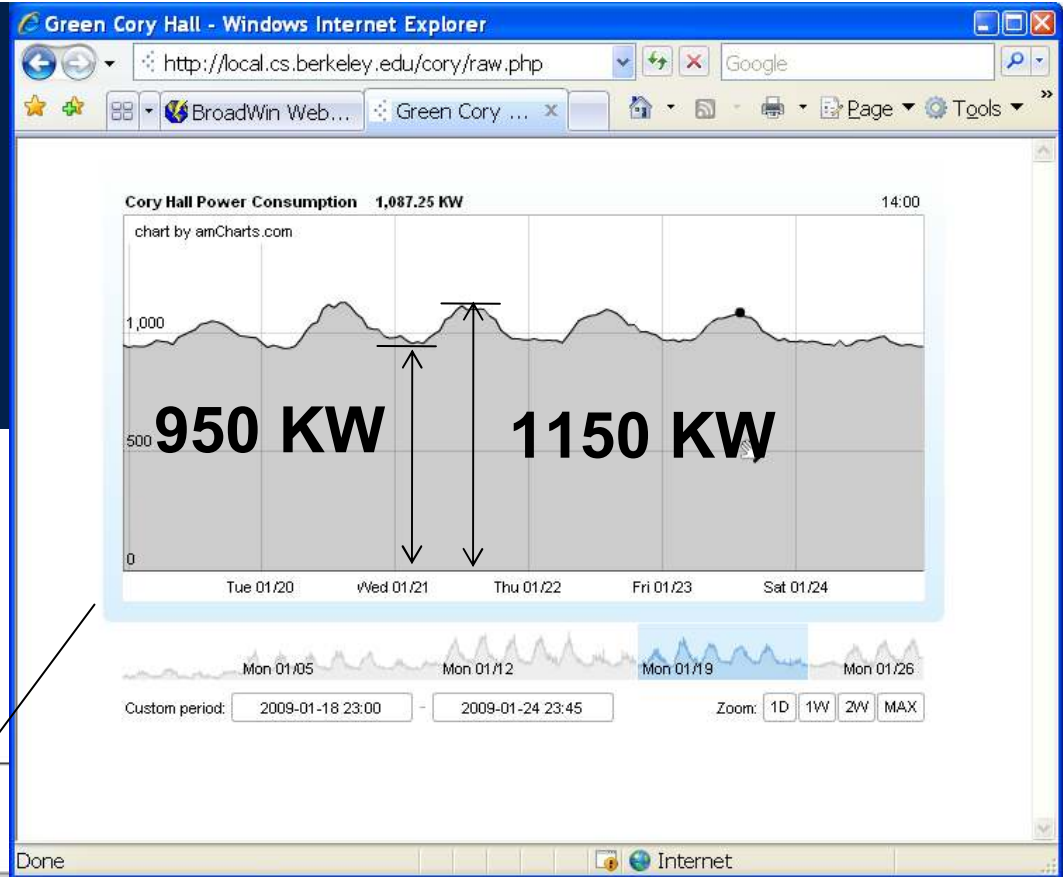
Atom 333

Server Power Consumption



Power-Proportional Buildings ?

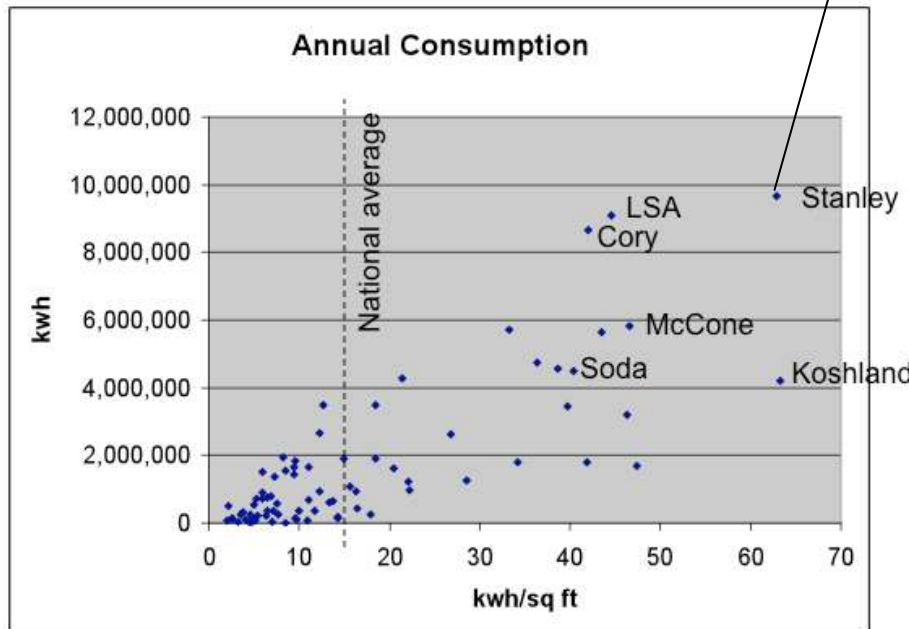
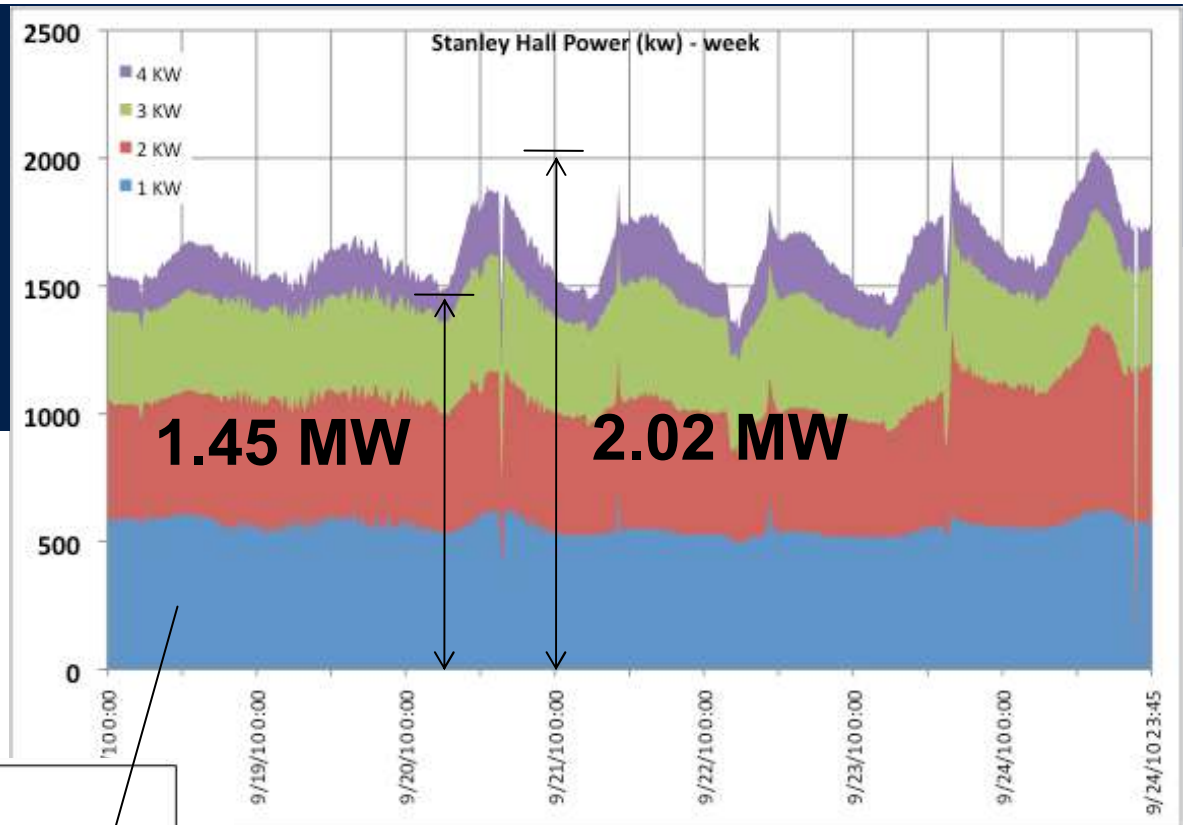
Cory Hall: Office + Semiconductor + IT



Min = 82% of Max

Power-Proportional Buildings ?

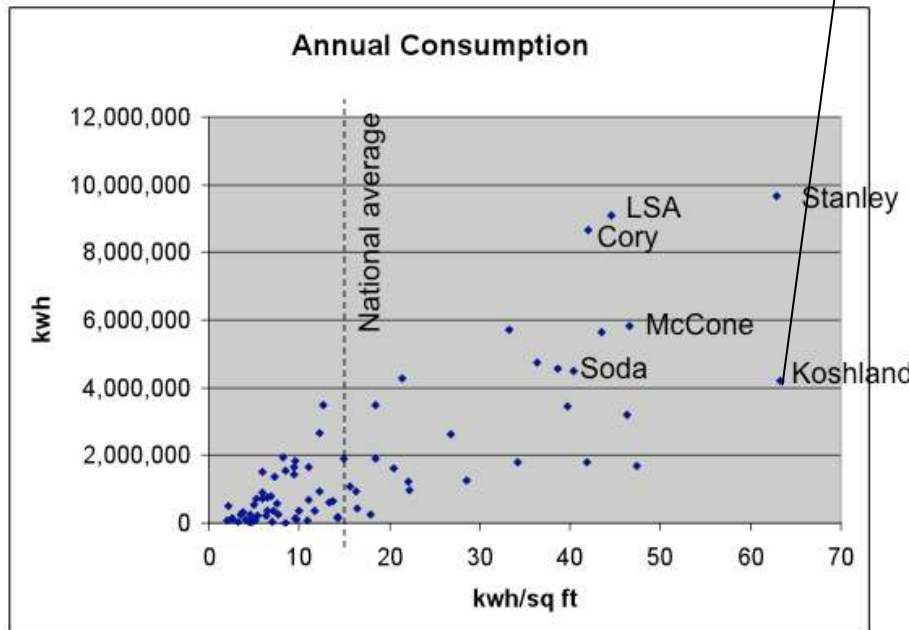
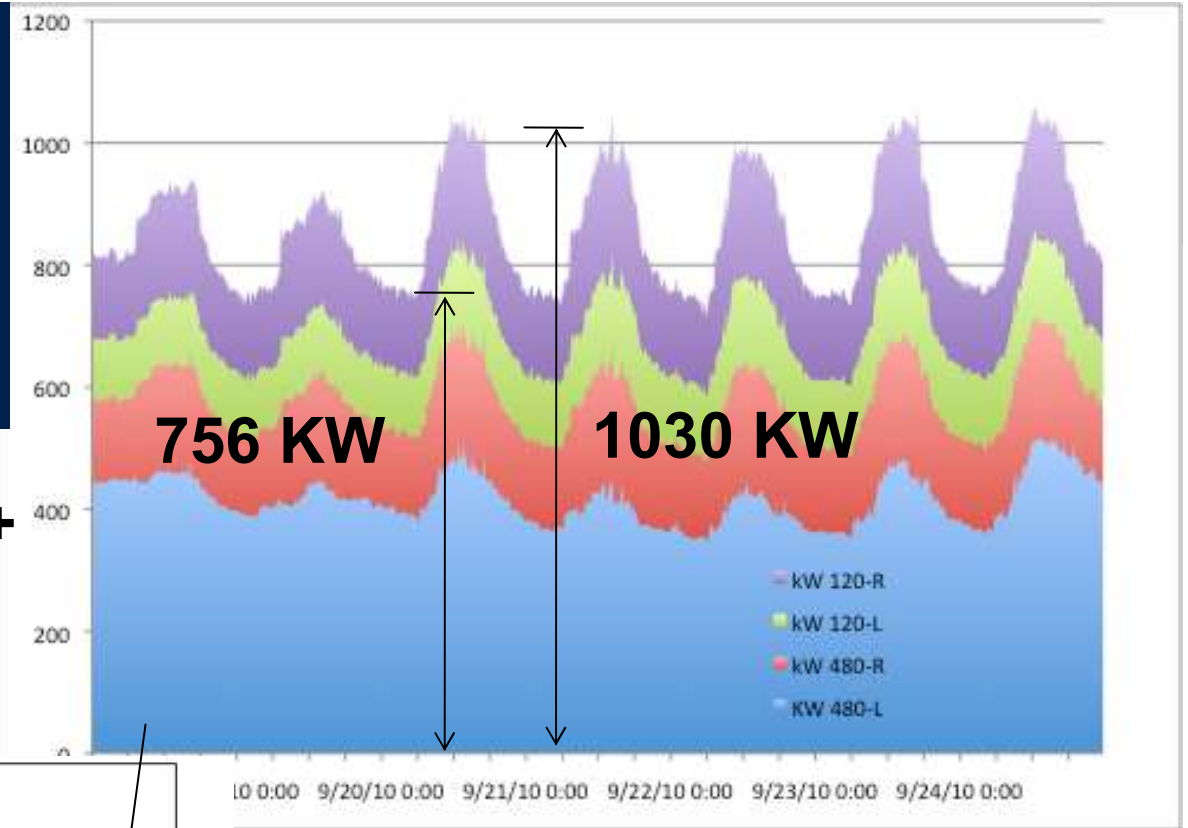
**Stanley Hall:
Office + BioScience
- 13 NMRs**



Min = 72% of Max

Power-Proportional Buildings ?

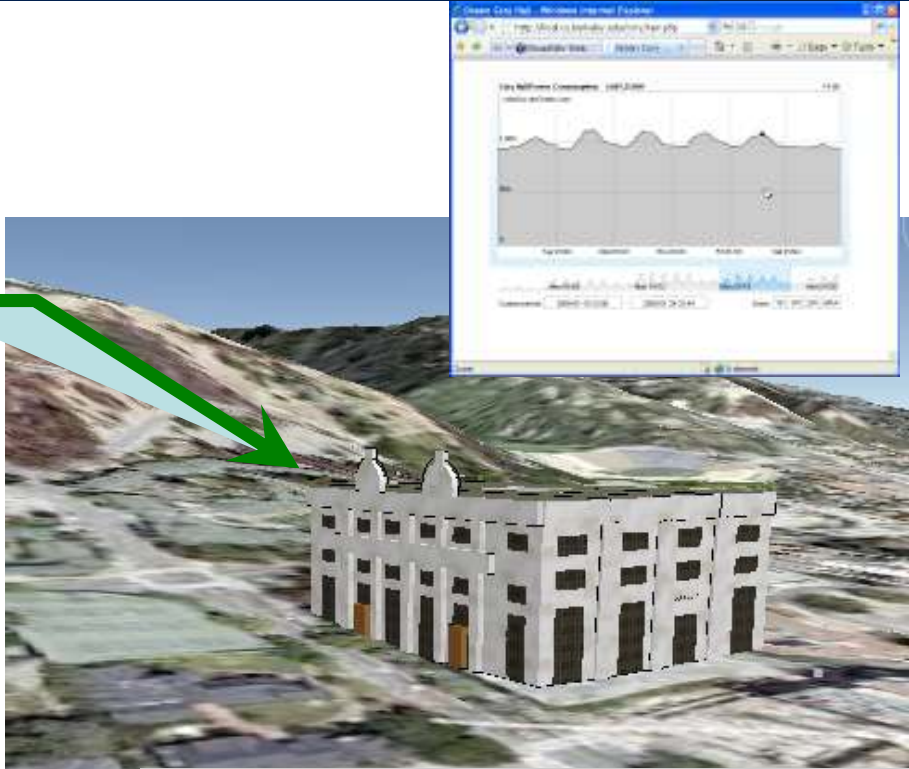
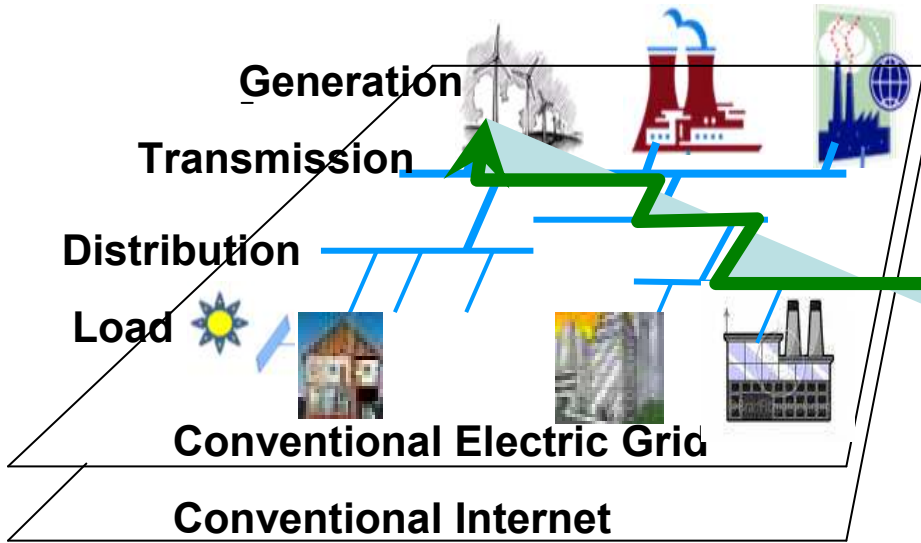
Koshland Hall: Office +



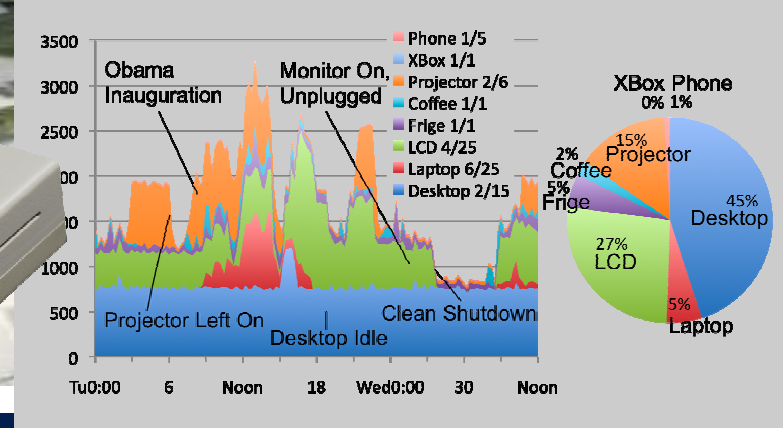
Min = 69% of Max



Building ↔ Grid Testbed

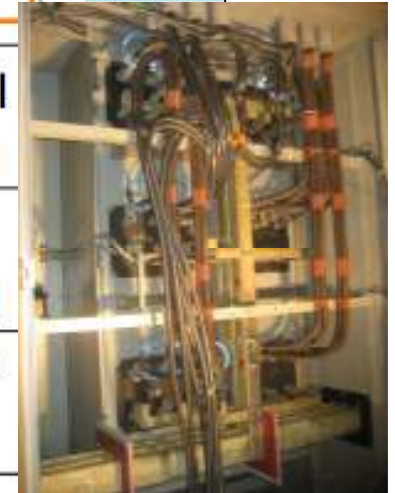
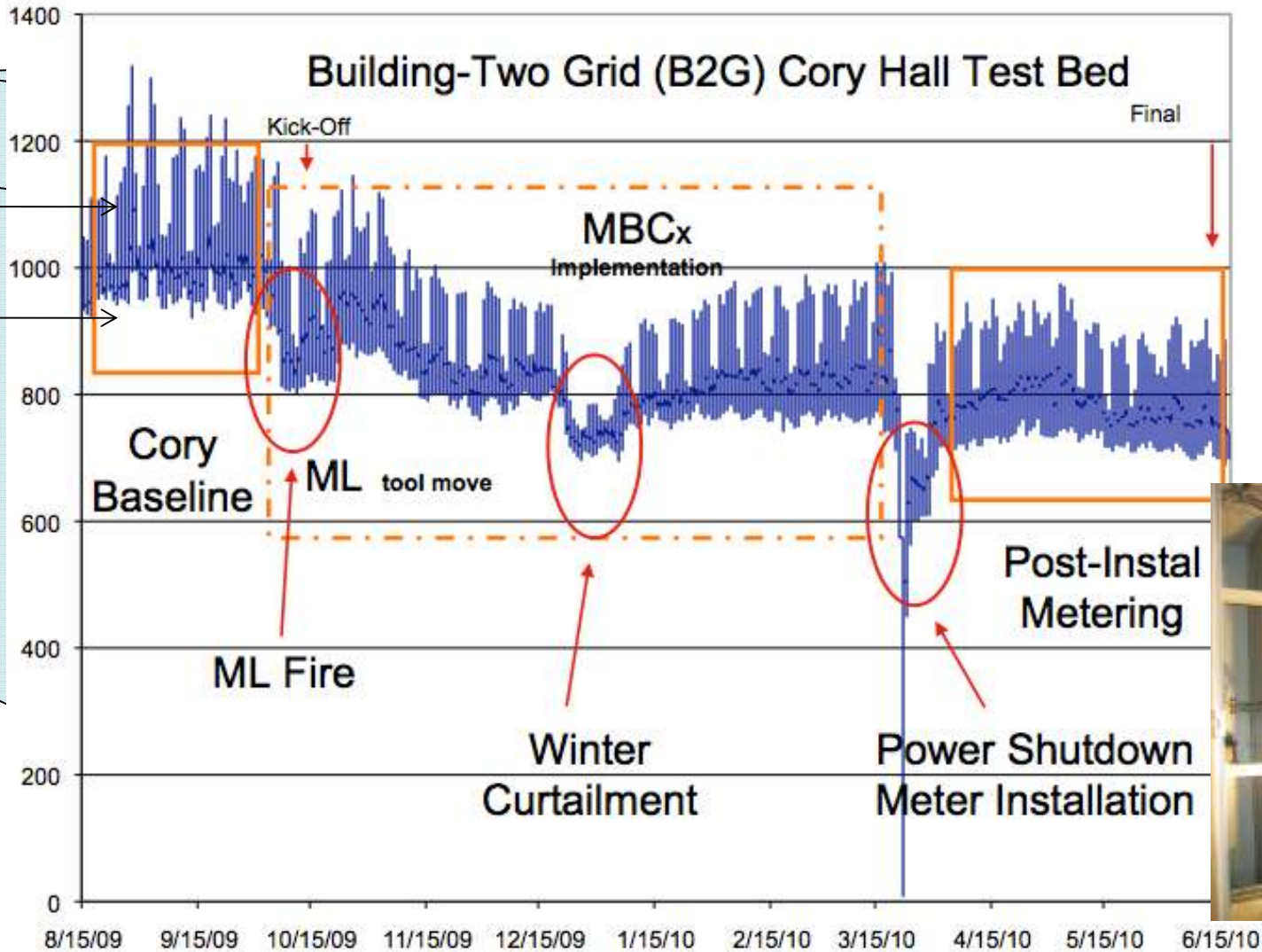


- large complex load
- >1,000 sense points
- Monitor, Model, Mitigate
- In concert with an intelligent grid



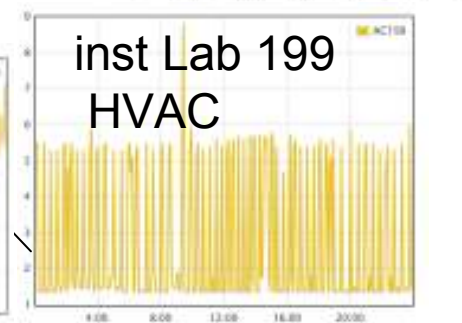
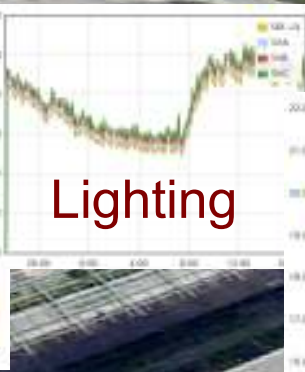
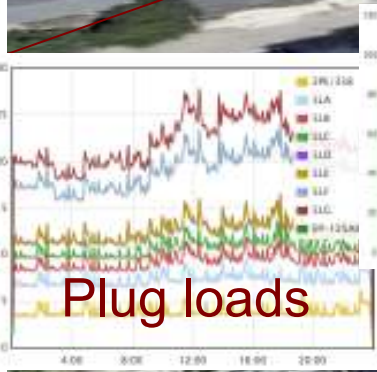
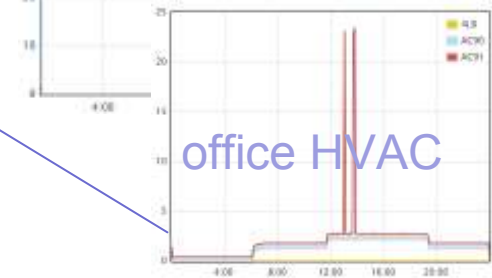
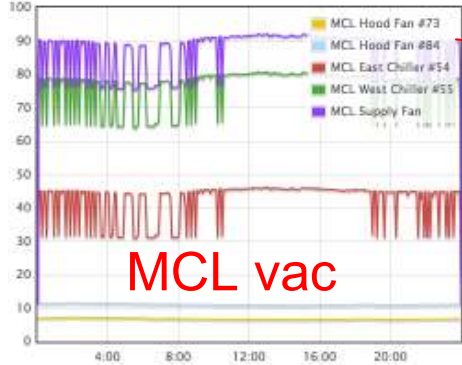
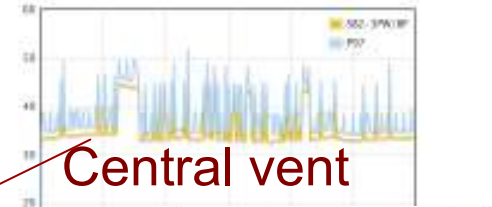
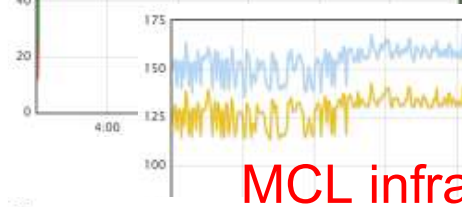
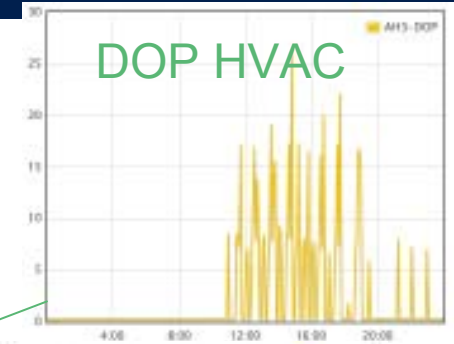
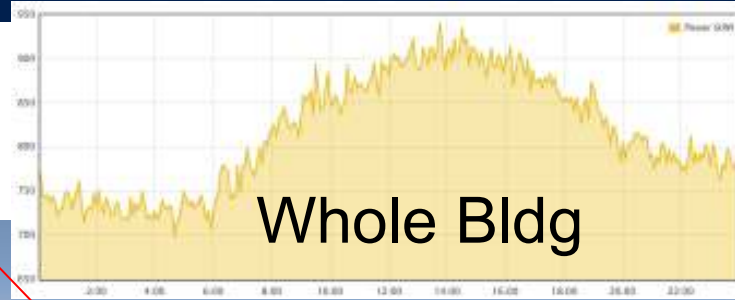
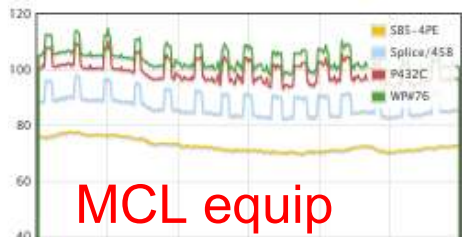


Along the way ...





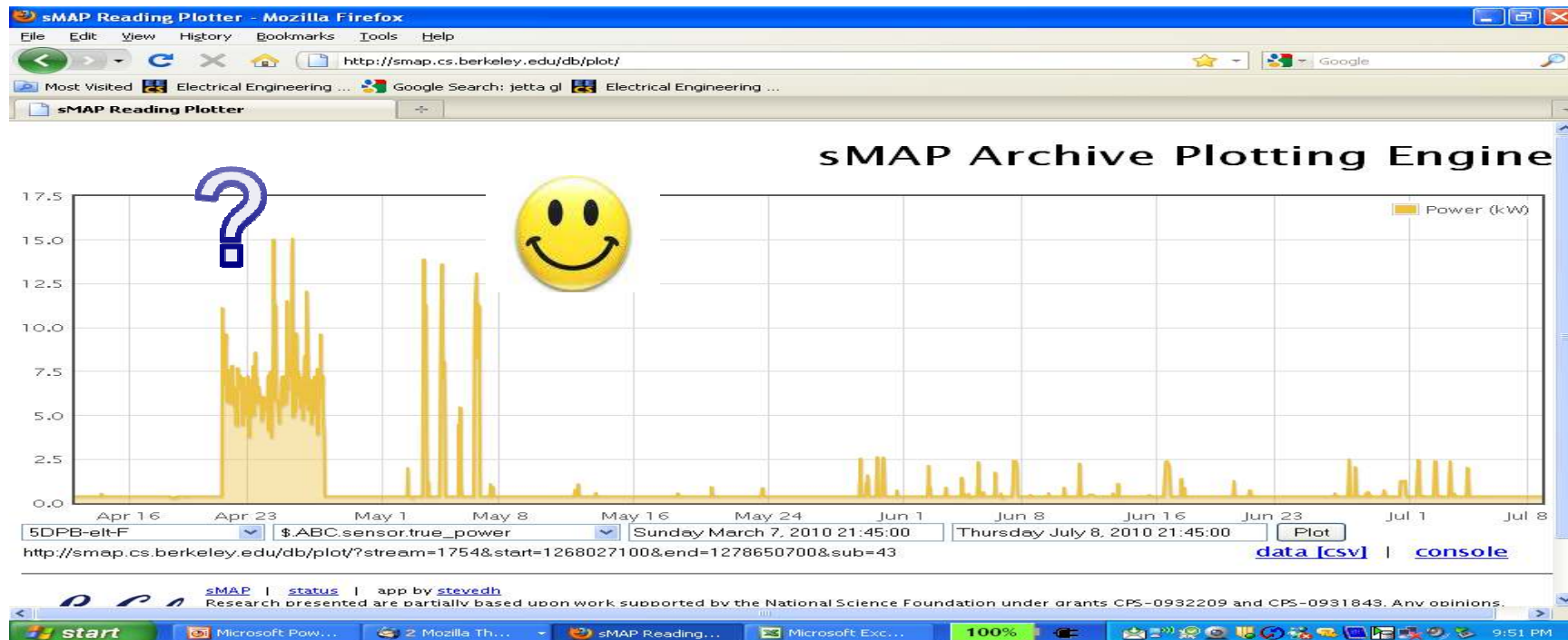
Energy Transparent Building





Keeping an Eye on the Prize

- Monitor Based Commissioning
 - Eliminate simultaneous heat/cool
 - AC91 on schedule

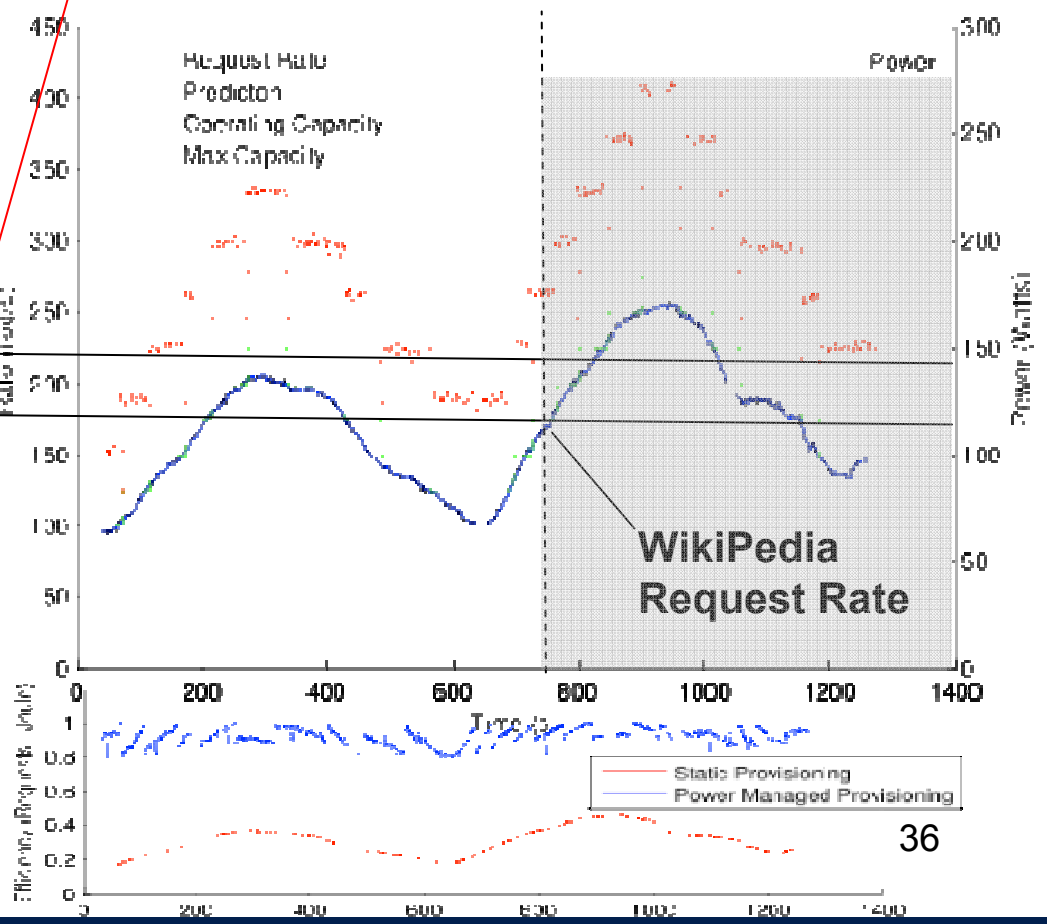
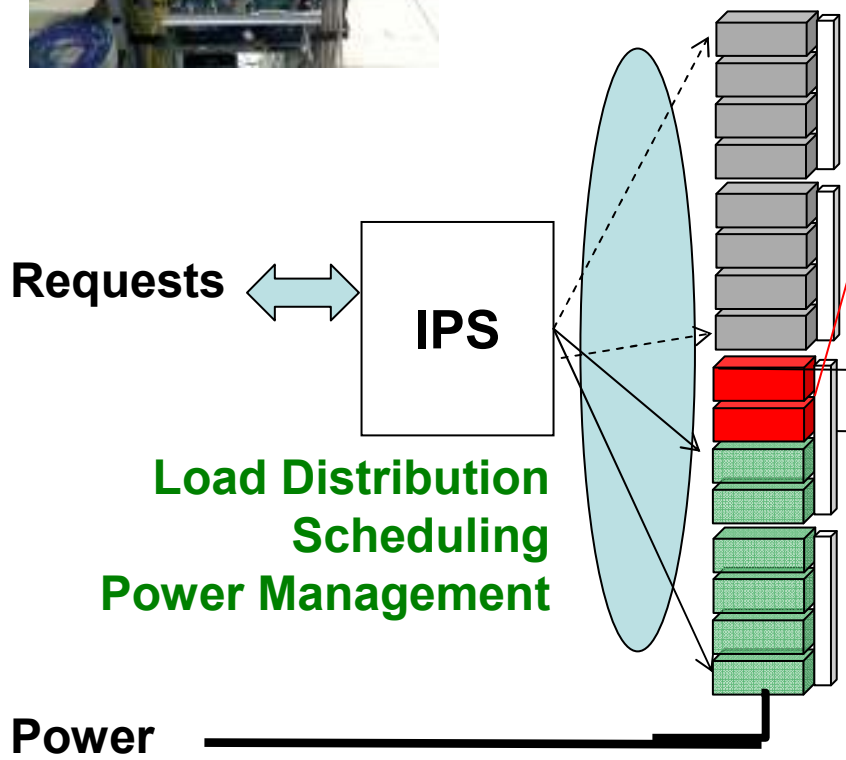




PP Systems of nonPP pieces



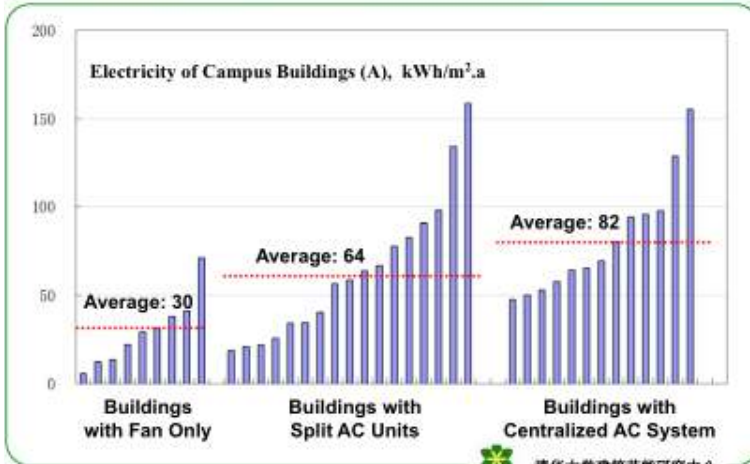
Computational "Spinning Reserve"





Power Proportional Buildings?

Observations on a Campus in Beijing



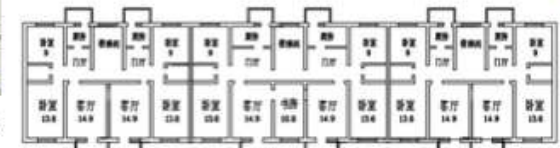
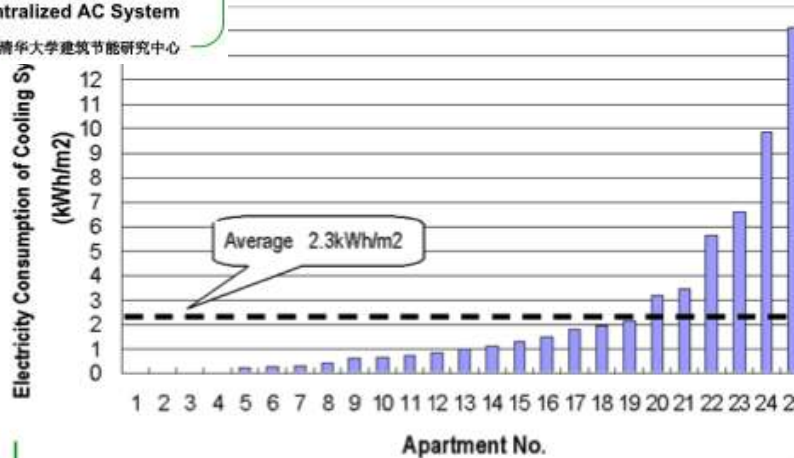
清华大学建筑节能研究中心

Case study: AC in Residential buildings



measured energy consumption
in every units of a residential
building in Beijing, 2006, split unit

Key reason:
Part time
Part space
Open windows



Yi Jiang

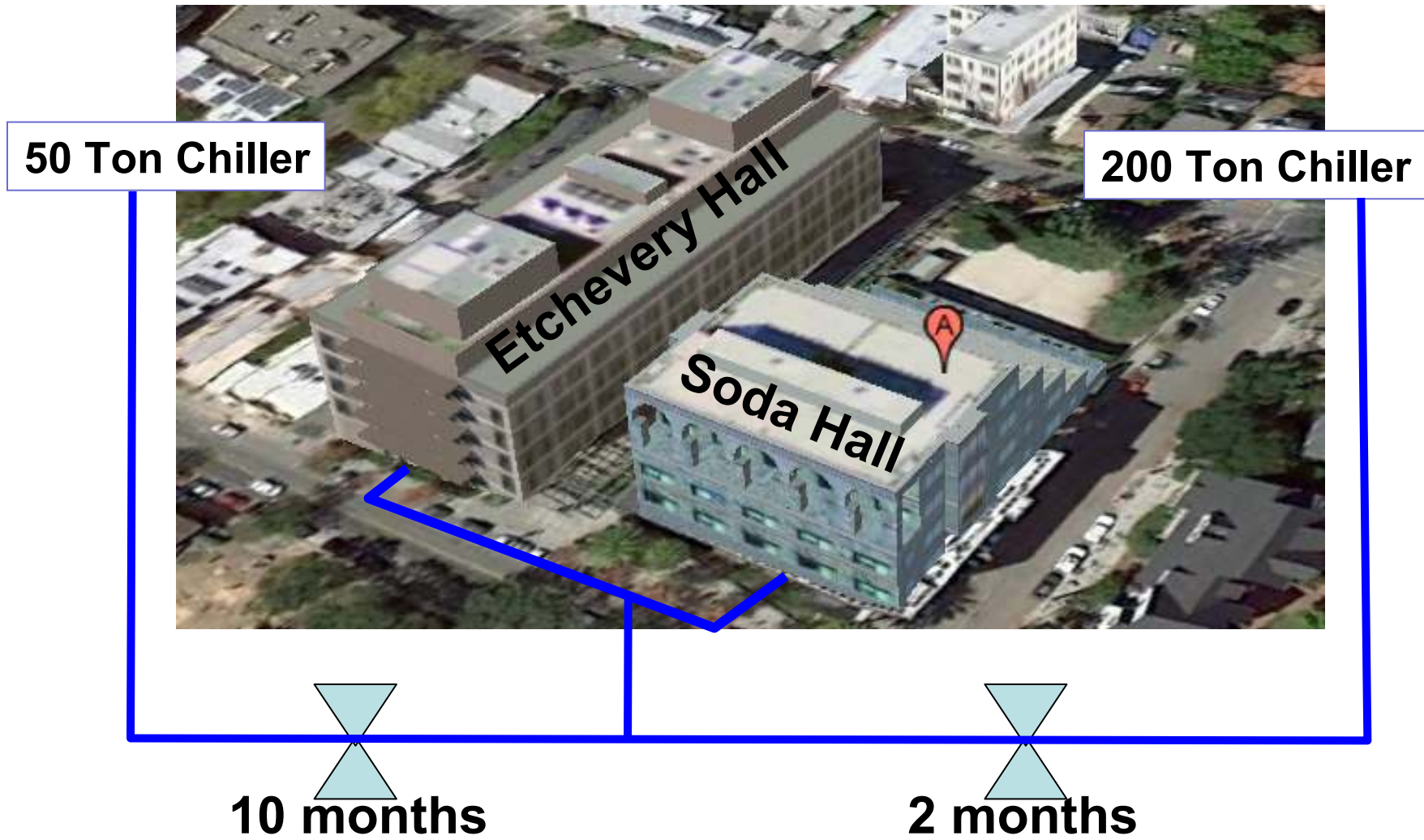
Building Energy Research Centre
Tsinghua University P R China

Centre AC for residential buildings in Beijing: 19.8 kWh/m²,a

- Part-time, Part-space, Natural venting and light



Power Proportional Buildings?



Scott McNally Bldg Manager



Stages of Energy Effectiveness

- Waste Not
 - Do Nothing Well !!!
- Power Proportionality
 - Peak Performance : Power => Safety
 - Optimize Partial Load - from nothing to peak
- Sculpting
 - Identify the energy *slack* and utilize it
- Negotiated Grid / Load / Human Interaction
 - Plan, Forecast, Negotiate, Manage



Energy "Slack"

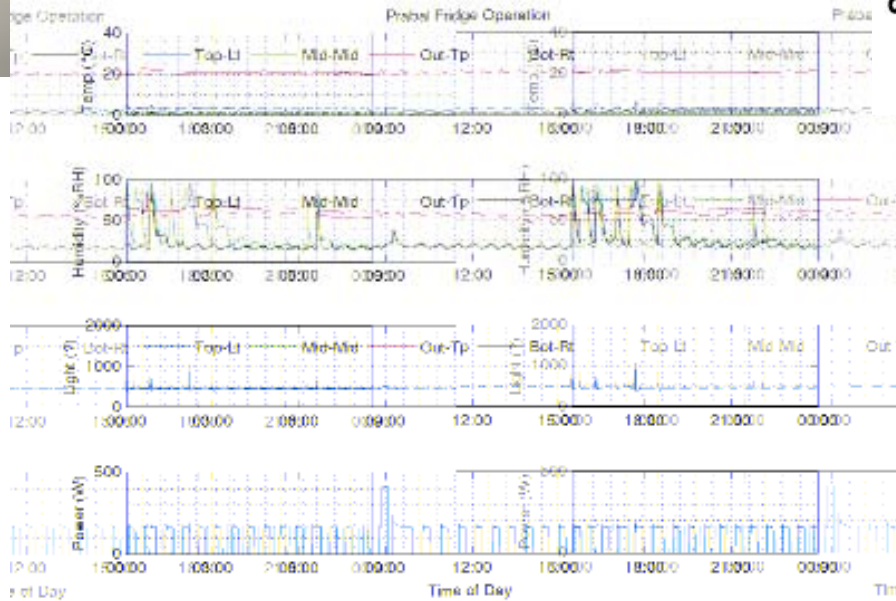
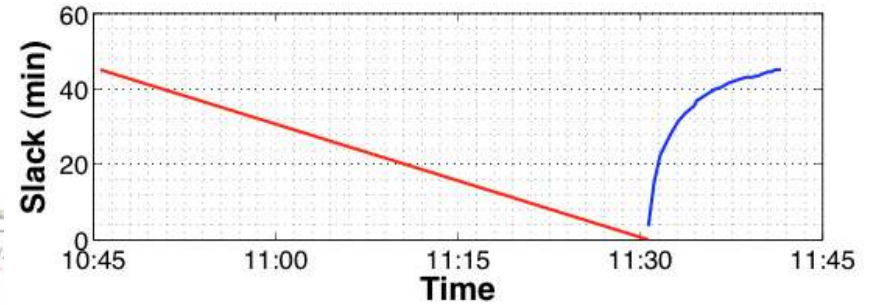
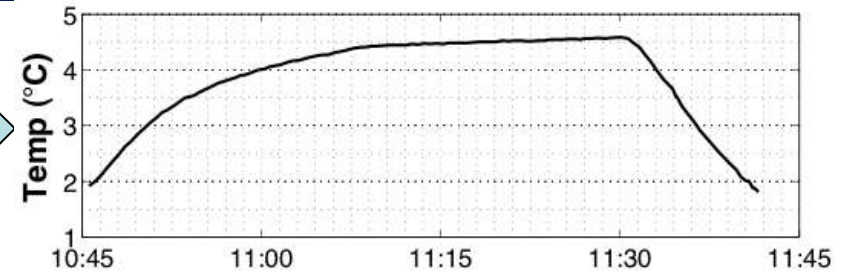
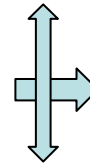
Thermostatically Controlled Load



IPS

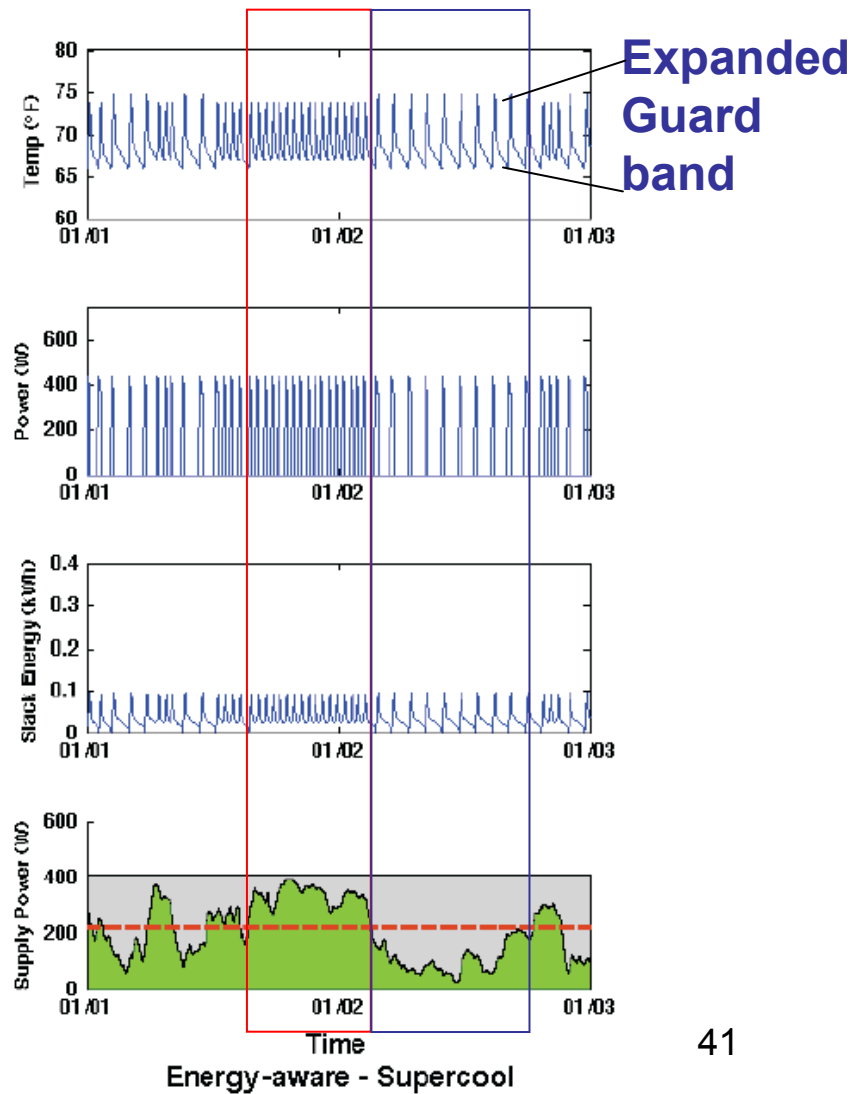
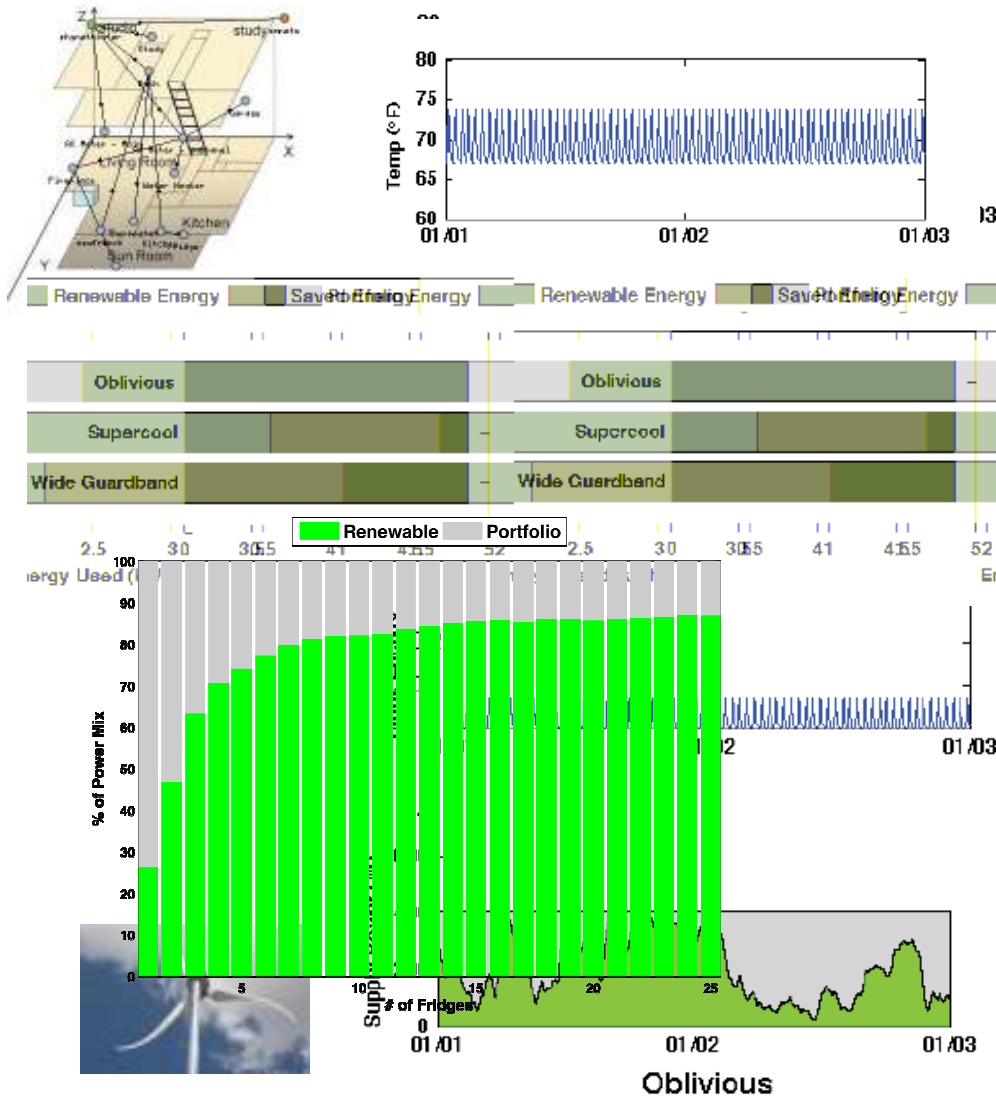
Set Point

Guard band





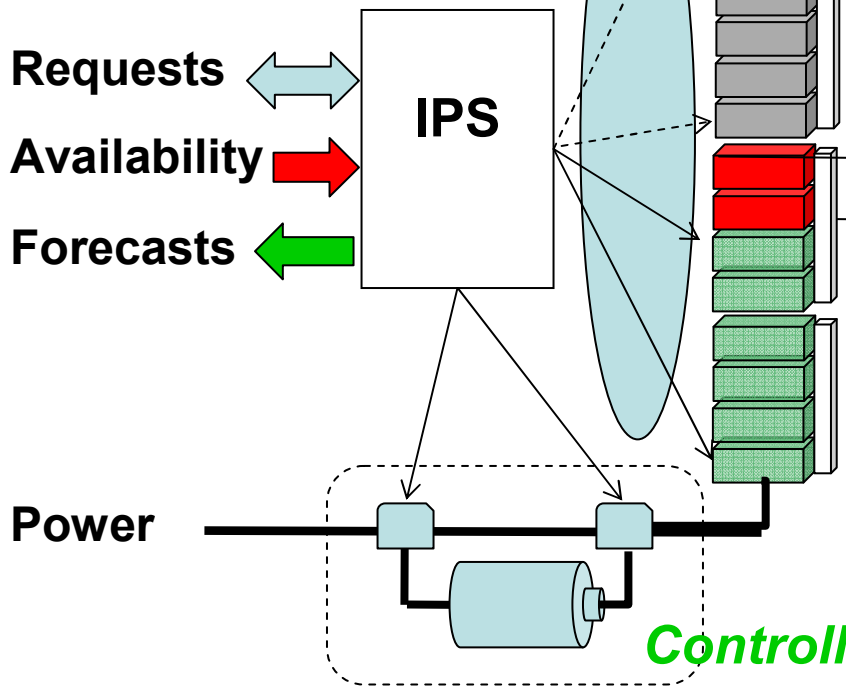
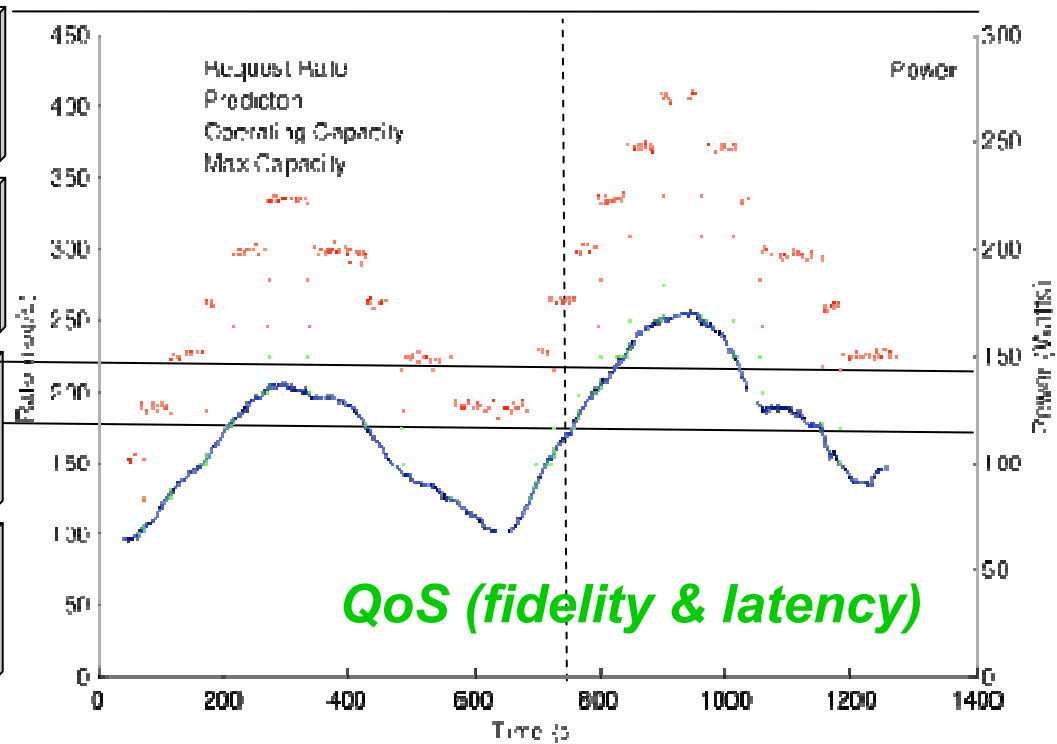
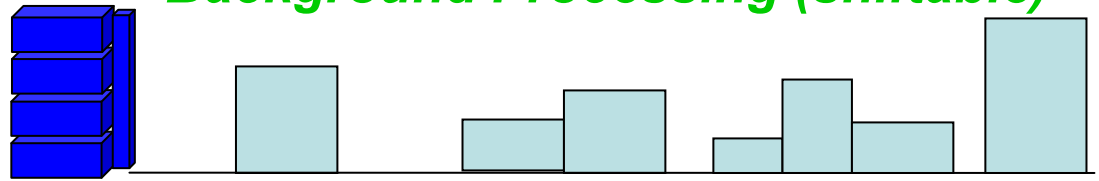
Supply-Following Loads



Supply-Following Computational Loads



Background Processing (shiftable)





... and in buildings



CENTER FOR THE BUILT ENVIRONMENT
Industry/University Research Collaboration

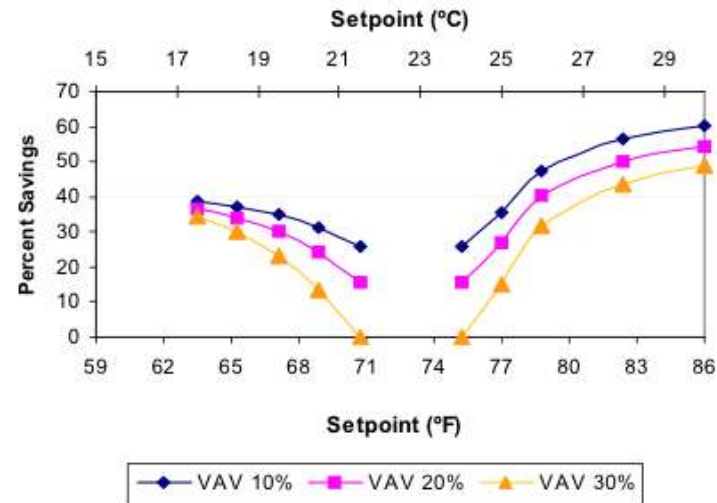
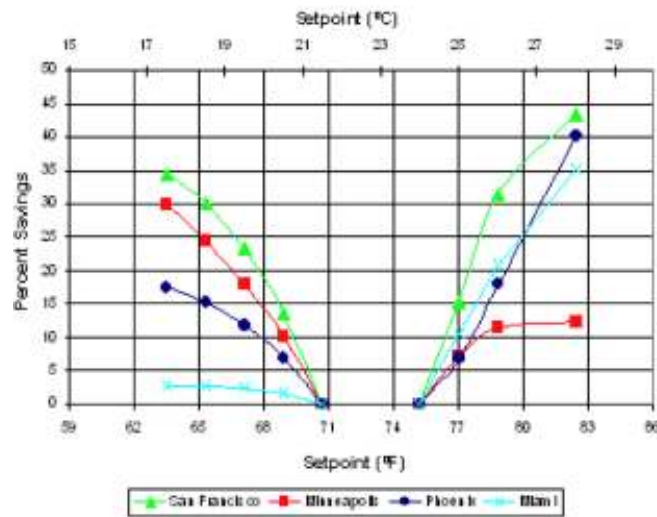


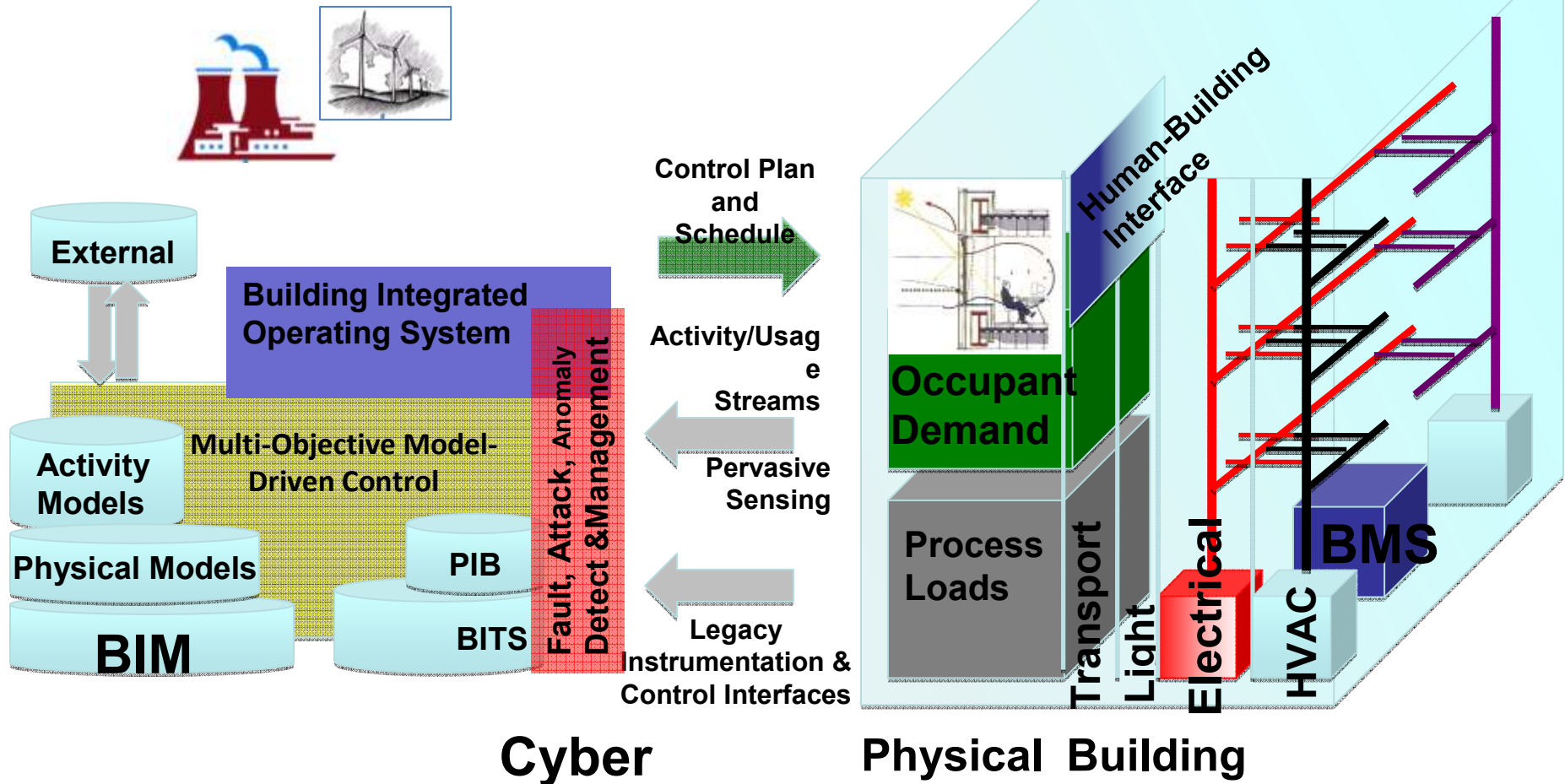
Figure 3. Annual energy use for the prototype in San Francisco with VAV minimum fractions at 10%, 20%, and 30%.

ENERGY SAVINGS FROM EXTENDED AIR TEMPERATURE SETPOINTS AND REDUCTIONS IN ROOM AIR MIXING

Tyler Hoyt, Kwang Ho Lee, Hui Zhang, Edward Arens, Tom Webster



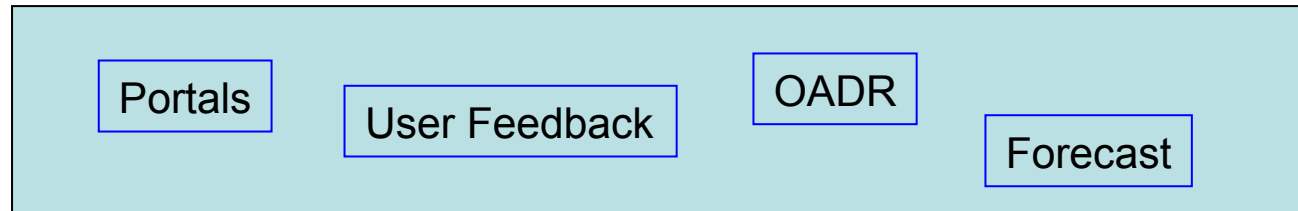
Cyber / Physical Buildings



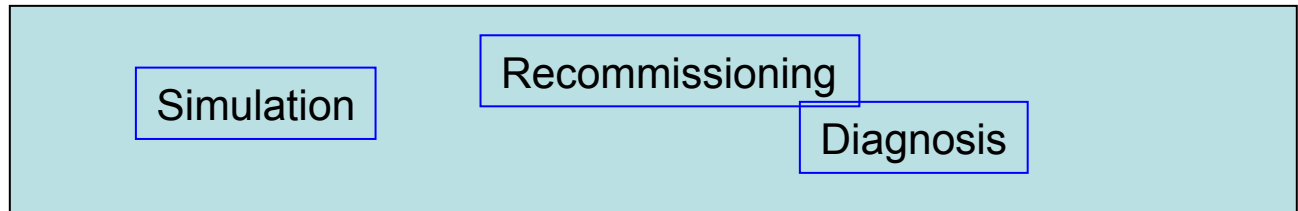


Layered Arch. for Physical Info

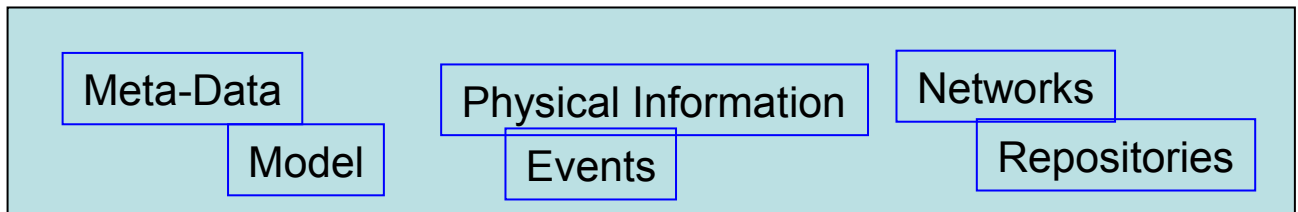
Presentation



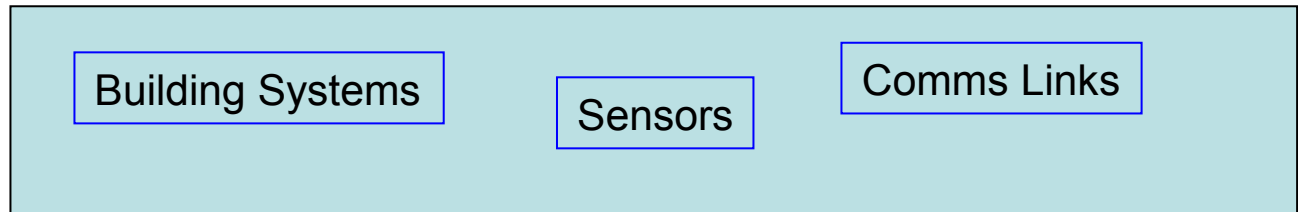
Analysis



Logical

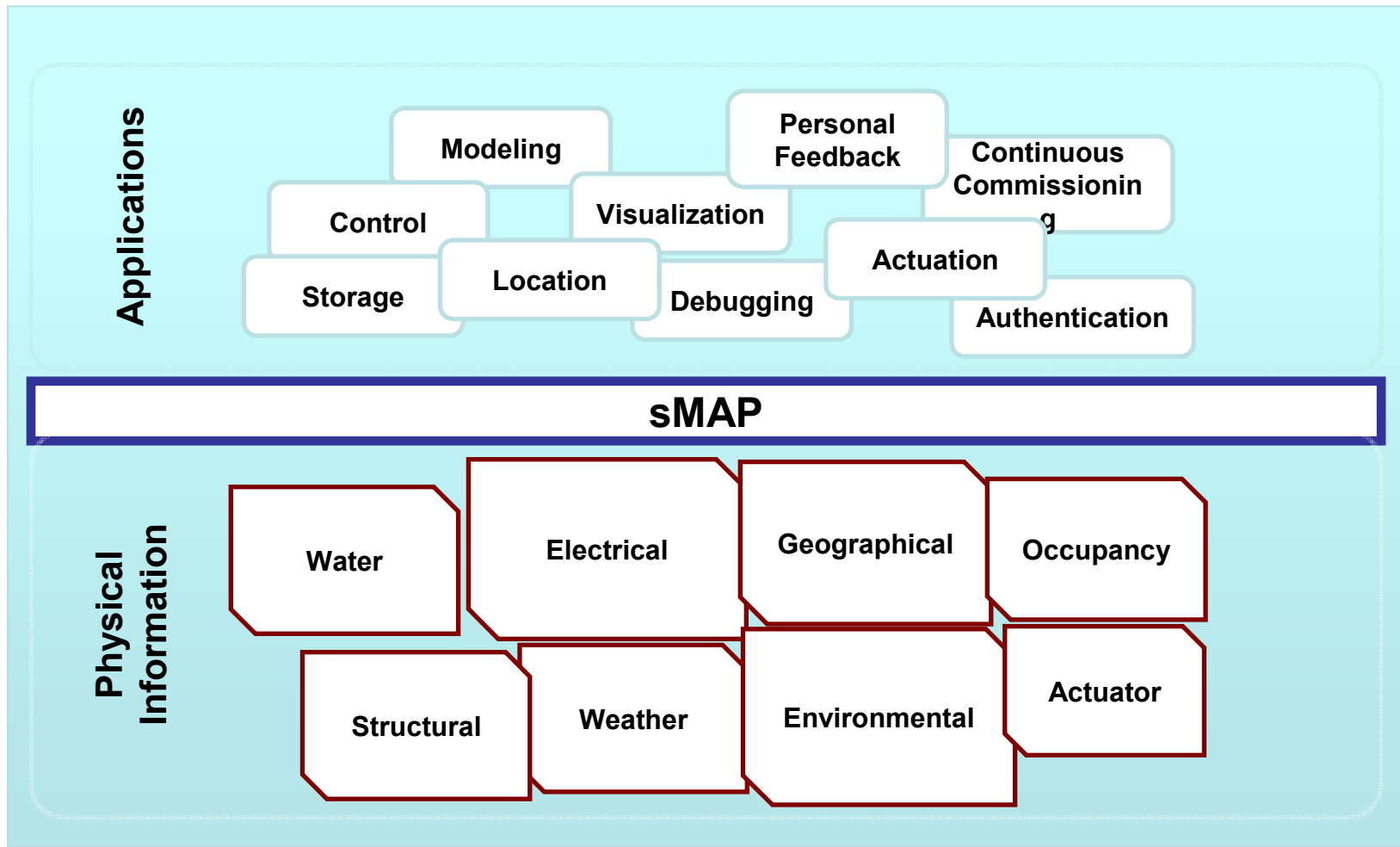


Physical



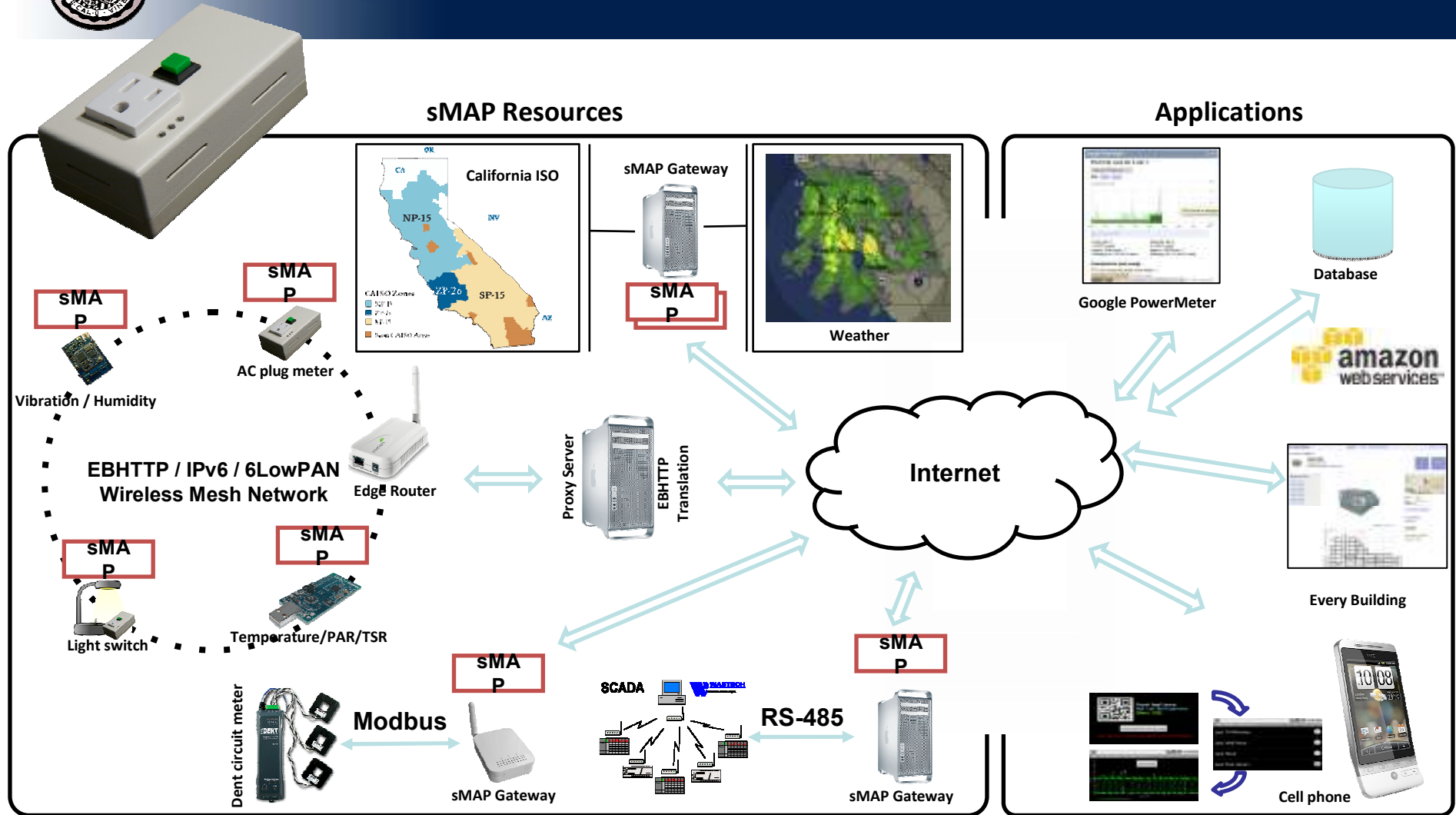


Narrow Waist ?





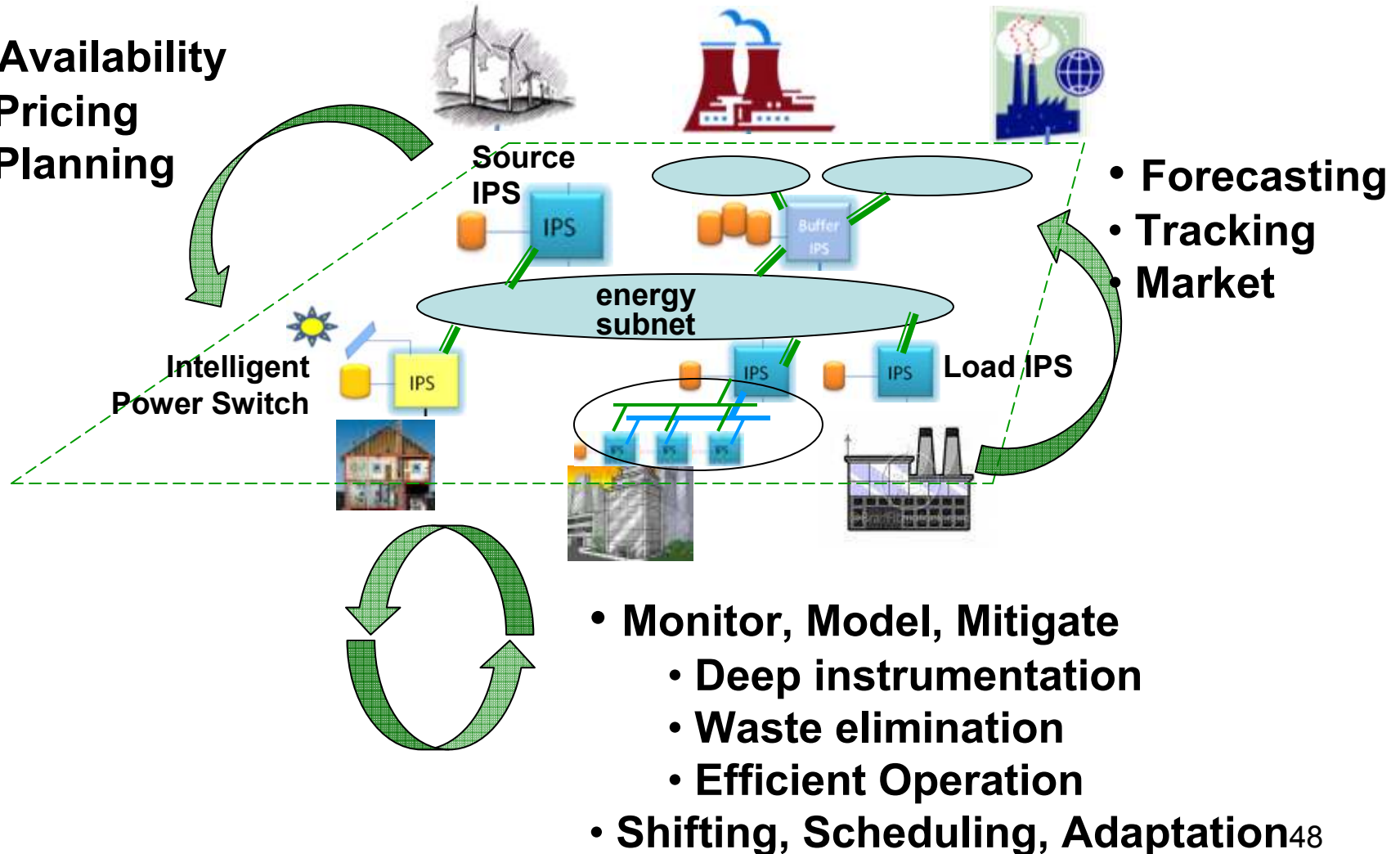
IP everywhere / Real World Web





In a Cooperative Grid

- Availability
- Pricing
- Planning





Thanks

- NSF, CEC, DOE, industry, collaborators
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