Digital Infrastructure in a Carbon-Constrained World

SciPM 2009

Workshop on the Science of Power Management

Arlington, VA

April 9, 2009

Dr. Larry Smarr

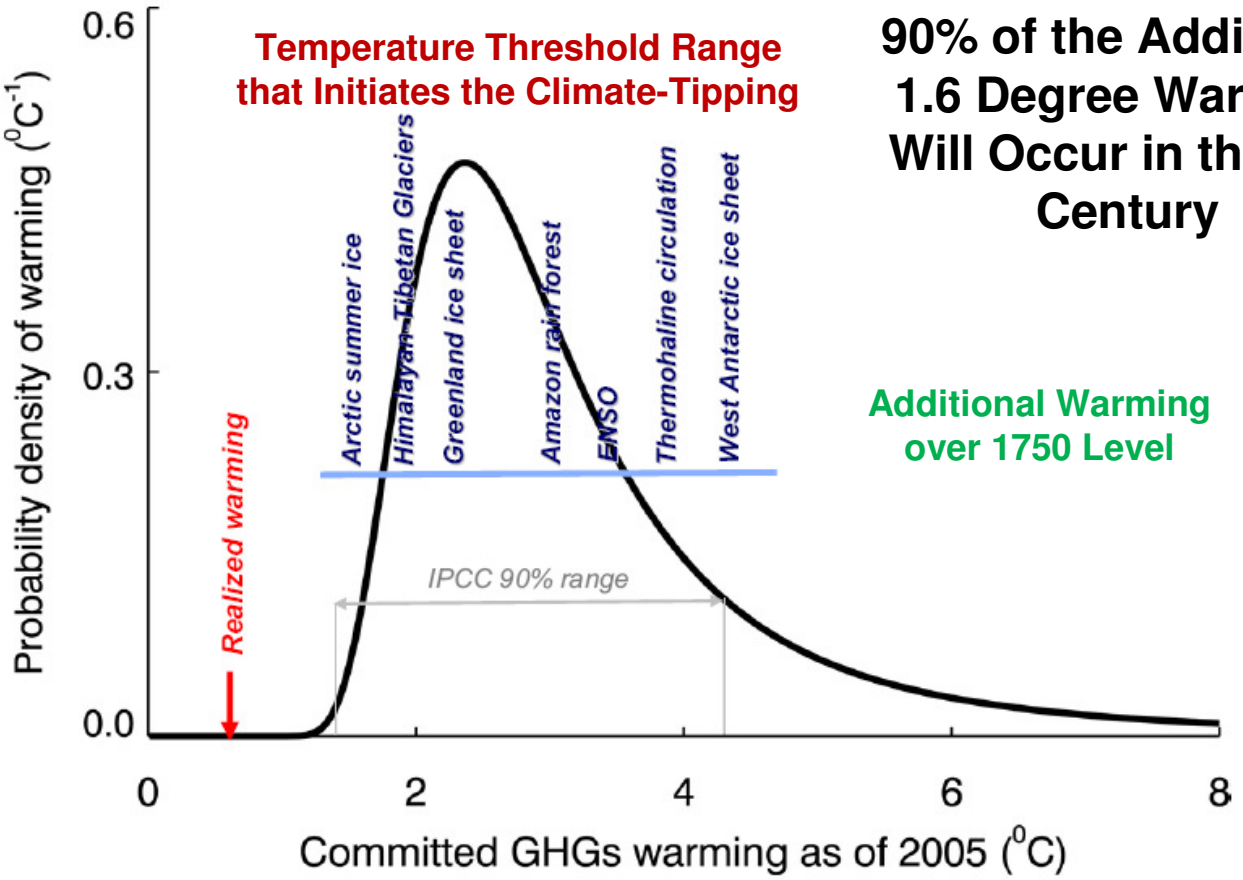
Director, California Institute for Telecommunications and Information Technology

Harry E. Gruber Professor,

Dept. of Computer Science and Engineering

Jacobs School of Engineering, UCSD

The Planet is Already Committed to a Dangerous Level of Warming



90% of the Additional 1.6 Degree Warming Will Occur in the 21st Century

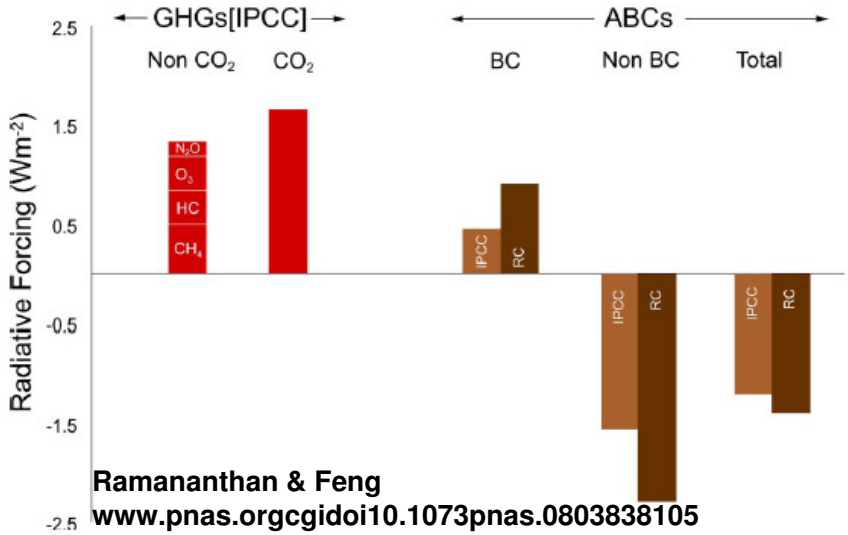
Additional Warming over 1750 Level

V. Ramanathan and Y. Feng, Scripps Institution of Oceanography, UCSD

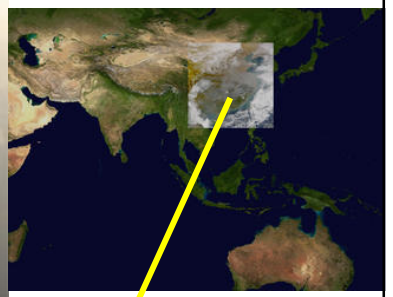
September 23, 2008
www.pnas.orgcgidoi10.1073pnas.0803838105

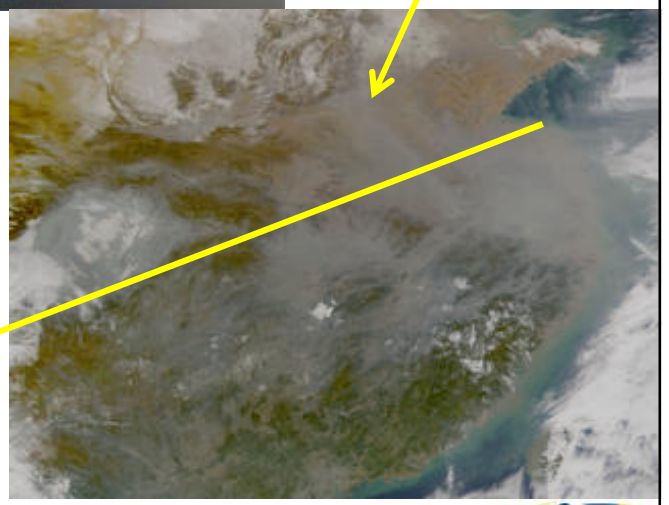
GreenLight Project

Atmospheric Aerosols Cool Climate—
Cleaning Air Pollution will Accelerate Warming!



Ramananthan & Feng
www.pnas.orgcgidoi10.1073pnas.0803838105





NASA satellite image

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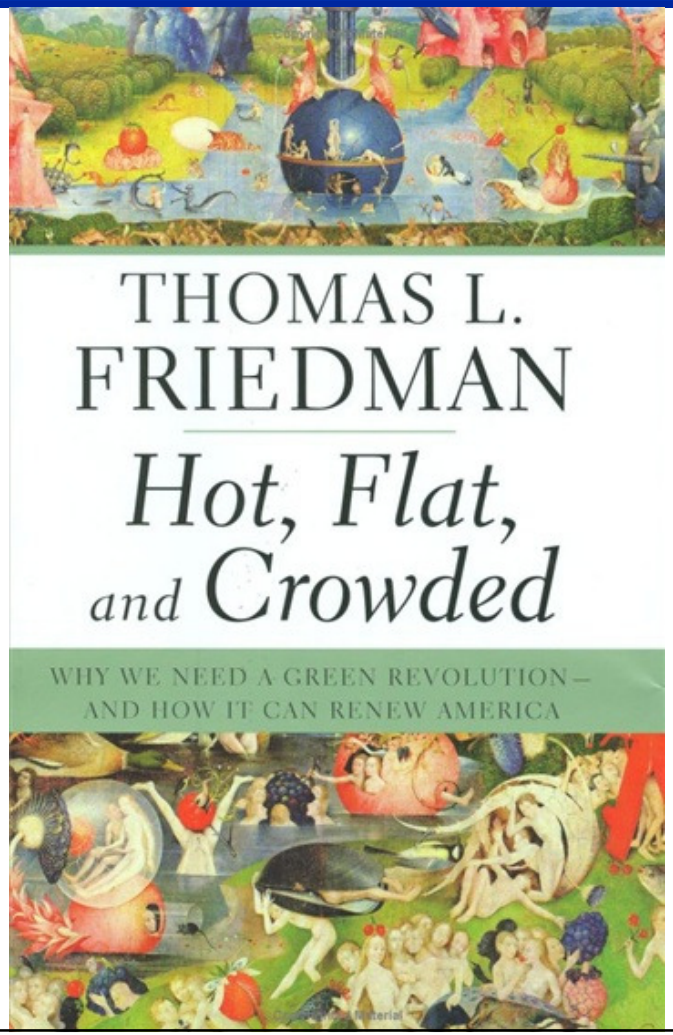
“It Will Be the Biggest Single Peacetime Project Humankind Will Have Ever Undertaken”



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The IPCC Recommends a 25-40% Reduction Below 1990 Levels by 2020

- On September 27, 2006, Governor Schwarzenegger signed California *the Global Warming Solutions Act* of 2006
  - Assembly Bill 32 (AB32)
  - Requires Reduction of GHG by 2020 to 1990 Levels
    - 10% Reduction from 2008 Levels; 30% from BAU 2020 Levels
    - 4 Tons of CO_2-equiv. Reduction for Every Person in California!
- The European Union Requires Reduction of GHG by 2020 to 20% Below 1990 Levels (12/12/2008)
- Australia has Pledged to Cut by 2020 its GHG Emissions 5% from 2000 Levels via the World's Broadest Cap &Trade Scheme (12/15/08) [~5% Below 1990 Levels]
- Neither the U.S. or Canada has an Official Target Yet
  - President Obama Has Endorsed the AB32 2020 Goal

ICT is a Critical Element in Achieving Countries Greenhouse Gas Emission Reduction Targets

GeSI member companies:

- **Bell Canada,**
- **British Telecomm.,**
- **Plc,**
- **Cisco Systems,**
- **Deutsche Telekom AG,**
- **Ericsson,**
- **France Telecom,**
- **Hewlett-Packard,**
- **Intel,**
- **Microsoft,**
- **Nokia,**
- **Nokia Siemens Networks,**
- **Sun Microsystems,**
- **T-Mobile,**
- **Telefónica S.A.,**
- **Telenor,**
- **Verizon,**
- **Vodafone Plc.**

Additional support:

- **Dell, LG.**

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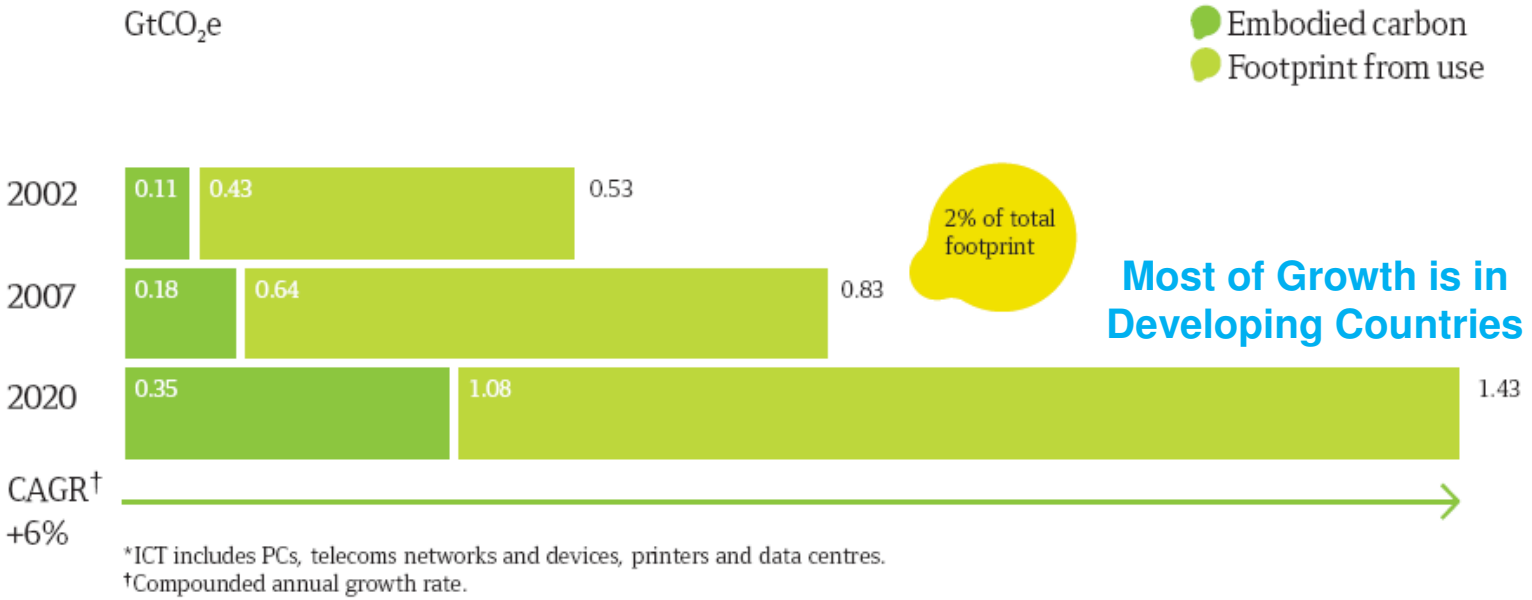
The Global ICT Carbon Footprint is Roughly the Same as the Aviation Industry Today

But ICT Emissions are Growing at 6% Annually!



the assumptions behind the growth in emissions expected in 2020:

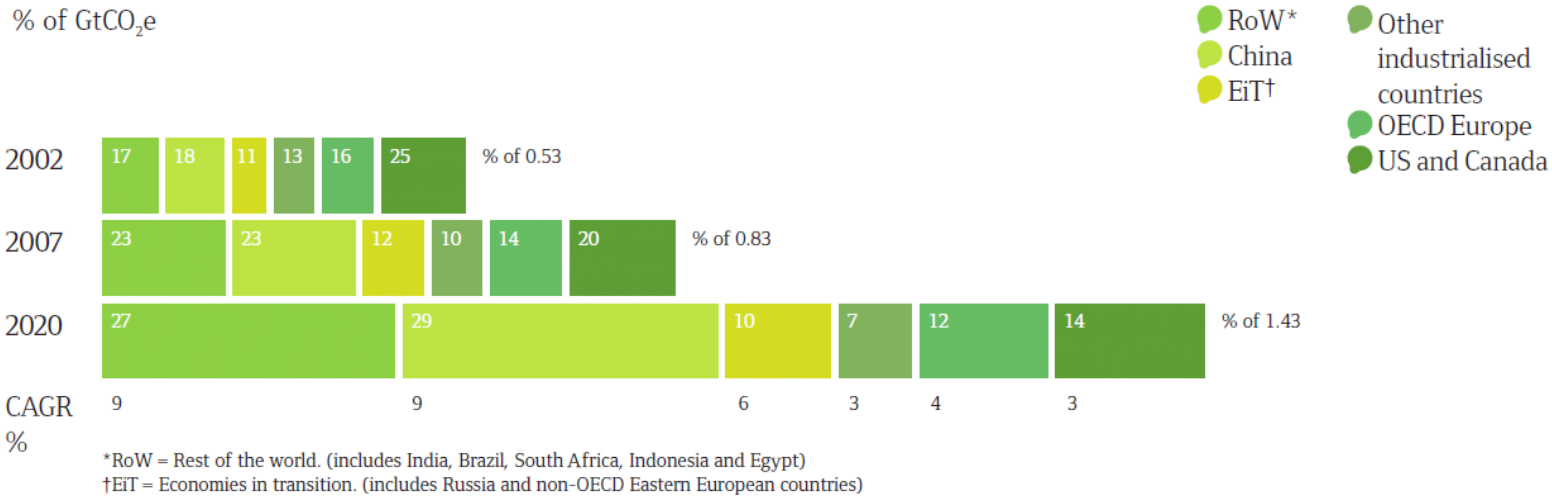
- **takes into account likely efficient technology developments that affect the power consumption of products and services**
- **and their expected penetration in the market in 2020**

GreenLight Project

www.smart2020.org

Reduction of ICT Emissions is a Global Challenge – U.S. and Canada are Small Sources

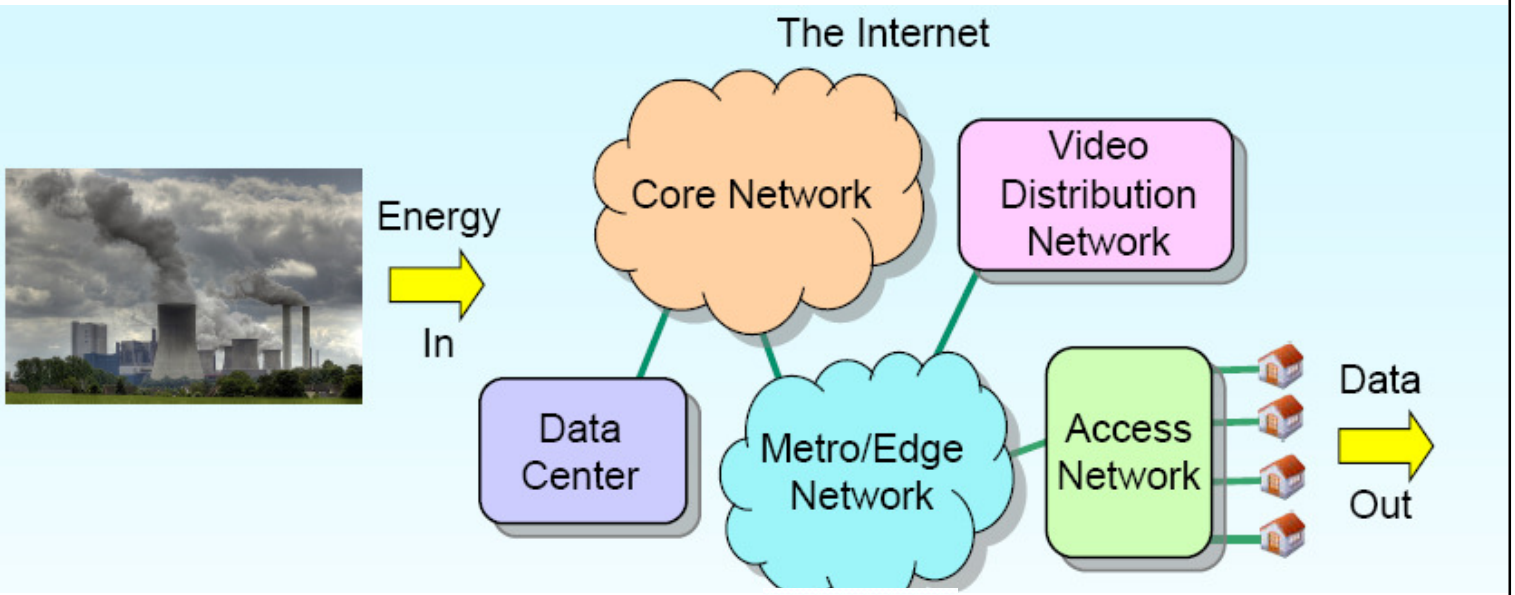
U.S. and Canada Fall From 25% to 14% of Global ICT Emissions by 2020



*RoW = Rest of the world. (includes India, Brazil, South Africa, Indonesia and Egypt)
†EiT = Economies in transition. (includes Russia and non-OECD Eastern European countries)

A System Approach is Required to Reduce Internet's Greenhouse Gas Emissions

- **Estimates Needed for CO2 Emissions from Each Subcomponent**
- **Beware of Tradeoffs:**
  - **"I will clean up my campus by getting rid of clusters and computing in the cloud"**
  - **Is This a Net Reduction?**



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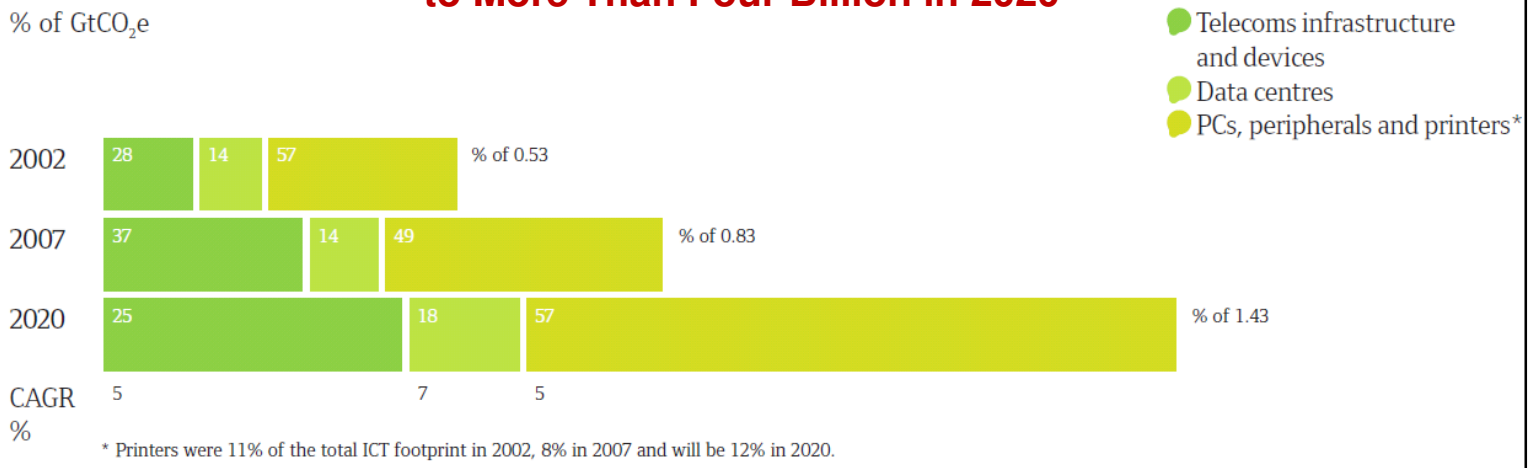
UBIN

Source: Rod Tucker, U Melbourne

The Global ICT Carbon Footprint by Subsector

The Number of PCs (Desktops and Laptops) Globally is Expected to Increase from 592 Million in 2002 to More Than Four Billion in 2020



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

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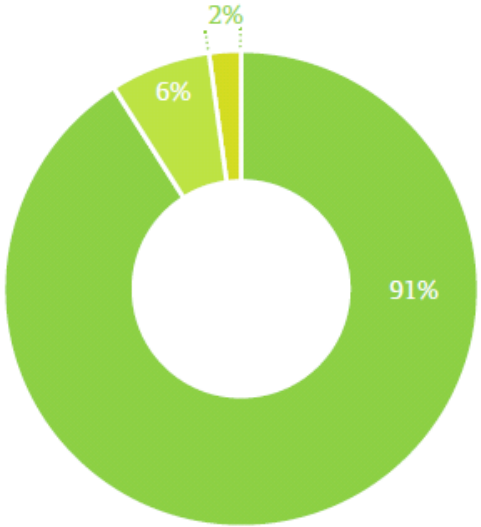
The Composition of the PC Carbon Footprint

Laptop Emissions Grow 50-Fold!

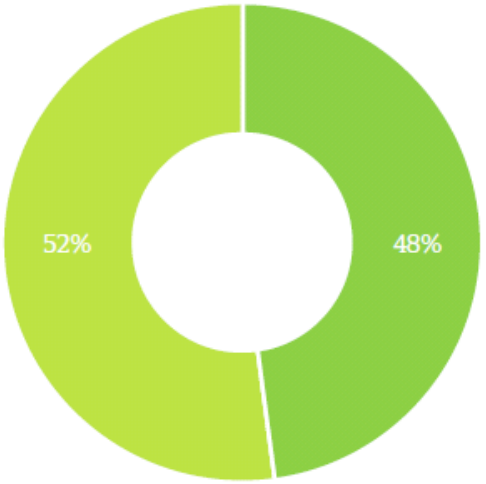
2002
100% = 247 $MtCO_2e$

- Laptops (6 $MtCO_2e$)
- Desktops with LCD monitors (16 $MtCO_2e$)
- Desktops with CRT monitors (226 $MtCO_2e$)



2020
100% = 643 $MtCO_2e$

- Desktops with CRT monitors (0 $MtCO_2e$)
- Laptops (333 $MtCO_2e$)
- Desktops with LCD monitors (309 $MtCO_2e$)



Desktops with CRT monitors represented 44% of the total ICT footprint (91% of 49%).

Desktops with LCD monitors and laptops represented 4% of the total ICT footprint (8% of 49%).

Laptops will represent 22% of the total ICT footprint (52% of 42%).

Desktops with LCD monitors will represent 20% of the total ICT footprint (48% of 42%).

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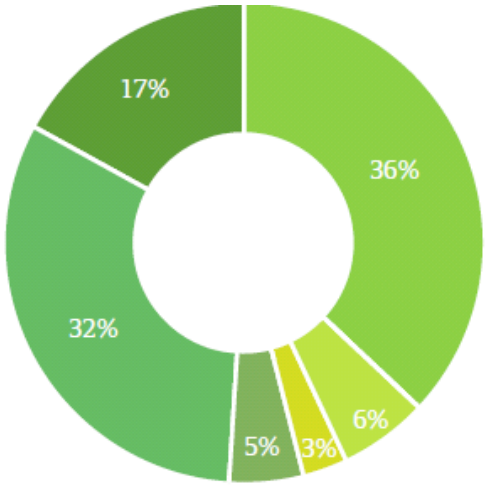
Composition of the Data Center Carbon Footprint

2020 Estimate Includes Savings from Virtualization, Smart Cooling, and Broad Operating Temperature Envelope)

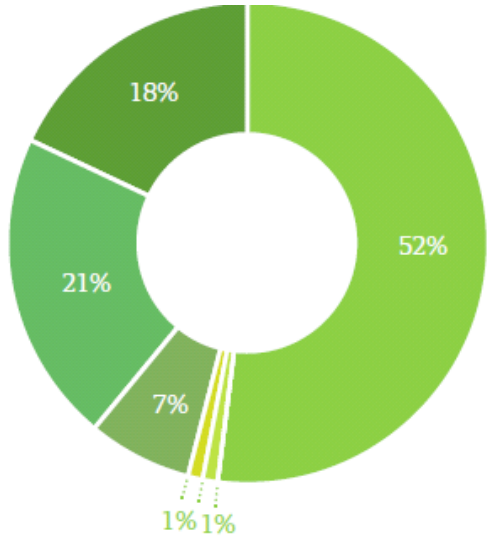
2002
100% = 76
$MtCO_2e$

- Volume servers (27 $MtCO_2e$)
- Cooling systems (24 $MtCO_2e$)
- Power systems (13 $MtCO_2e$)
- Mid-range servers (5 $MtCO_2e$)
- Storage systems (4 $MtCO_2e$)
- High-end servers (2 $MtCO_2e$)



2020
100% = 259
$MtCO_2e$

- Volume servers (136 $MtCO_2e$)
- Cooling systems (70 MtCO2e)
- Power systems (62 $MtCO_2e$)
- Storage systems (18 $MtCO_2e$)
- High-end servers (5 $MtCO_2e$)
- Mid-range servers (2 $MtCO_2e$)



Volume servers represented 5% of the total ICT footprint (36% of 14%).

Data centre cooling systems represented 4% of the total ICT footprint (32% of 14%).

Volume servers will represent 9% of the total ICT footprint (52% of 18%).

Data centre cooling systems will represent 4% of the total ICT footprint (21% of 18%).

Volume Servers Dominate

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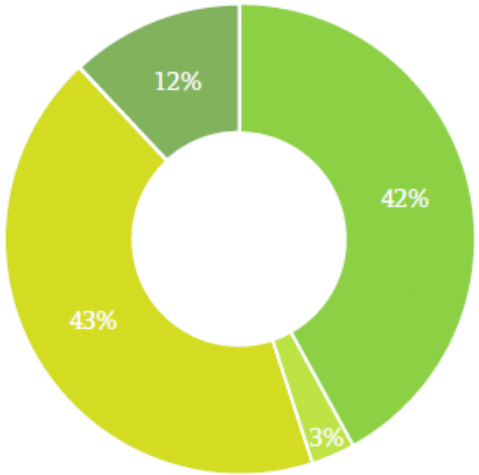
www.smart2020.org

Composition of the Global Telecoms Footprint

Broadband Connection Emissions Up 12-Fold!

2002
100% = 151 $MtCO_2e$

- Mobile (66 $MtCO_2e$)
- Fixed narrowband (64 $MtCO_2e$)
- Telecom devices (18 $MtCO_2e$)
- Fixed broadband (4 $MtCO_2e$)

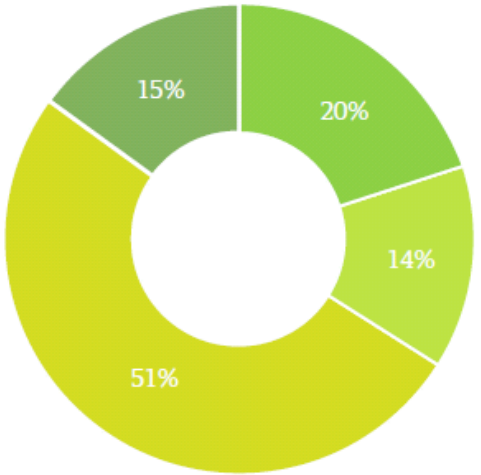


Mobile phones represented 3% of the total ICT footprint (11% of 30%).

Fixed broadband represented 1% of the total ICT footprint (3% of 30%).

2020
100% = 349 $MtCO_2e$

- Mobile (179 $MtCO_2e$)
- Fixed narrowband (70 $MtCO_2e$)
- Telecom devices (51 $MtCO_2e$)
- Fixed broadband (49 $MtCO_2e$)



Mobile phones will represent 1% of the total ICT footprint (6% of 25%).

Mobile phones will represent 13% of the total ICT footprint (51% of 25%)

Fixed broadband will represent 4% of the total ICT footprint (14% of 25%)

Mobile Infrastructure Dominates

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ICT Industry is Already Acting to Reduce Carbon Footprint

Sun's 'portable' Blackbox data center

Company unveils new one-box data center

Sun Microsystems' CEO Jonathan Schwartz showed off the company's new "Project Blackbox" in a Menlo Park, Calif., parking lot Tuesday. Sun says the gear is not only preassembled, but it's tough and arrives ready to run.

HP's Green Business Technology Initiative

Innovative Dynamic Smart Cooling

Cut cooling costs in the data center as much as 40%.

» Learn more

Buying Green

updated 10:47 a.m. EST, Wed November 28, 2007

Google pushes 'green' power initiative

Intel Becomes Largest Purchaser of Green Power in the U.S.

Company Tops EPA Green Power Partner List, Vows to Drive for Greater Efficiency While Spurring Growth in Renewable Market

How Microsoft is going green

Biodiesel trucks, solar-powered data centers are just a couple environmentally friendly track

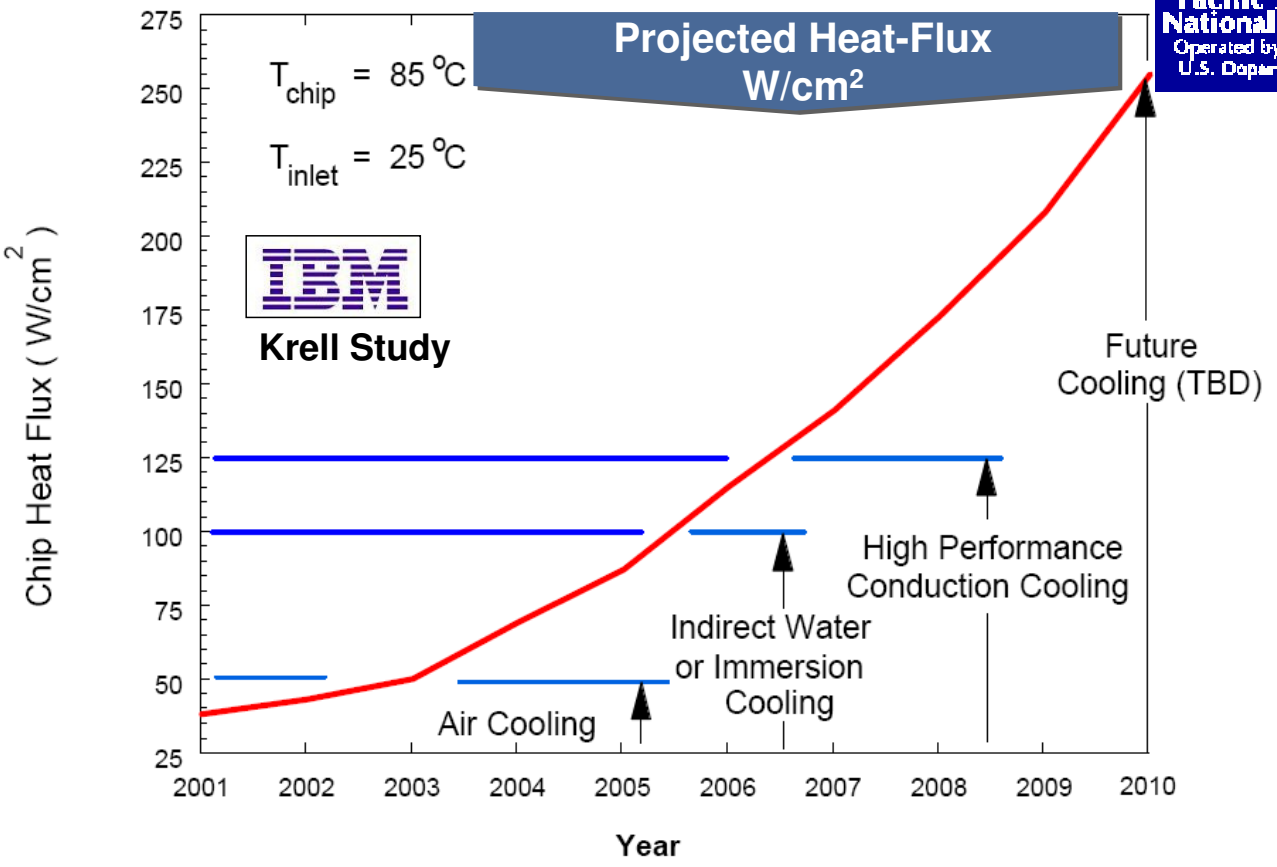
By John Fontana , Network World , 01/09/2008

IBM Project Big Green

Big Green Banner

Project Big Green is a $1 billion investment to dramatically increase the efficiency of IBM products. New IBM products and services,

Data Centers Will Require Advanced Cooling Environments

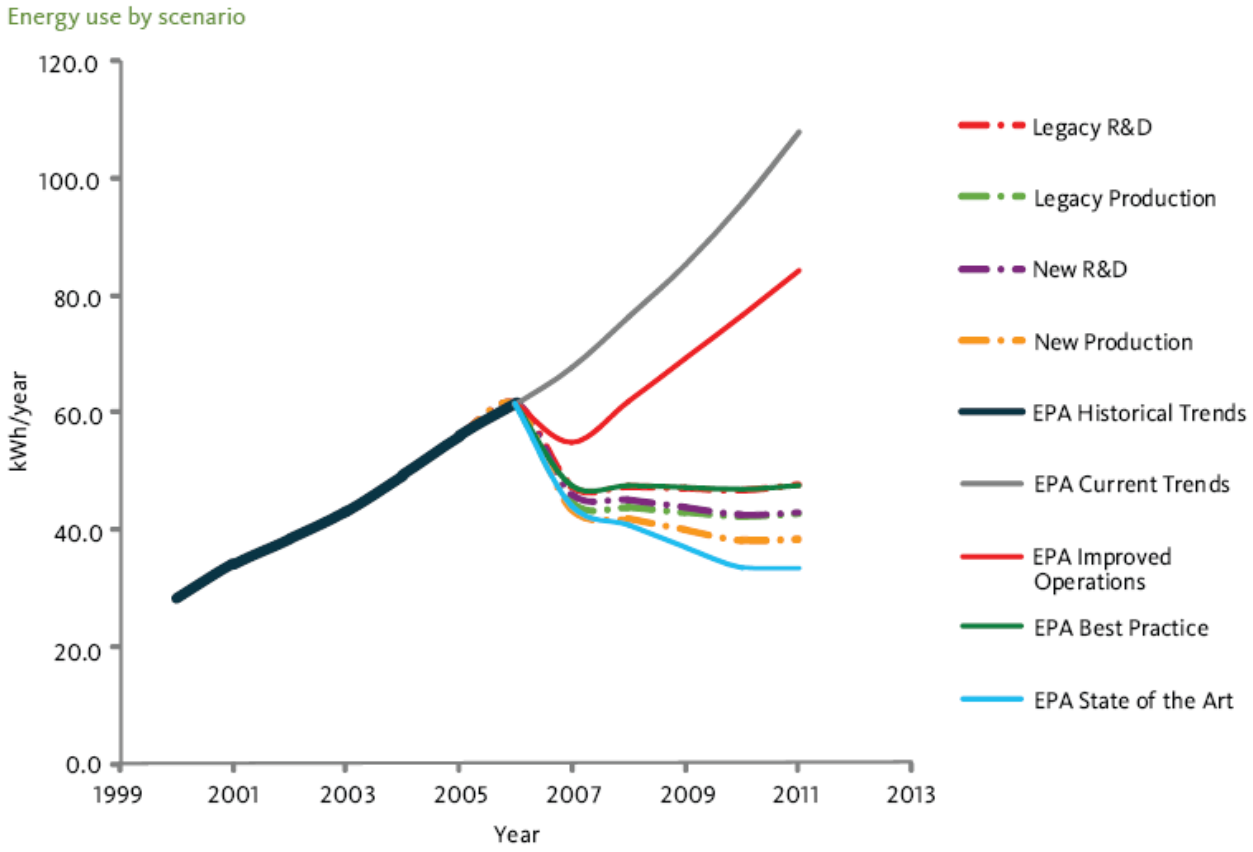


Source: PNNL Smart Data Center-Andrés Márquez, Steve Elbert, Tom Seim, Dan Sisk, Darrel Hatley, Landon Sego, Kevin Fox, Moe Khaleel (http://esdc.pnl.gov/)

GreenLight Project

it²

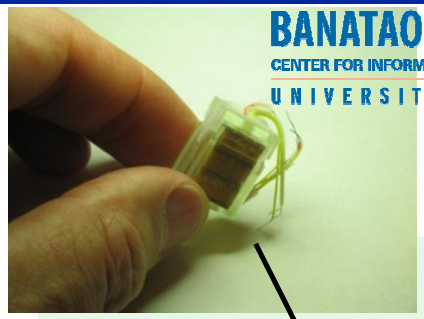
Electricity Usage by U.S. Data Centers: Emission Reductions are Underway



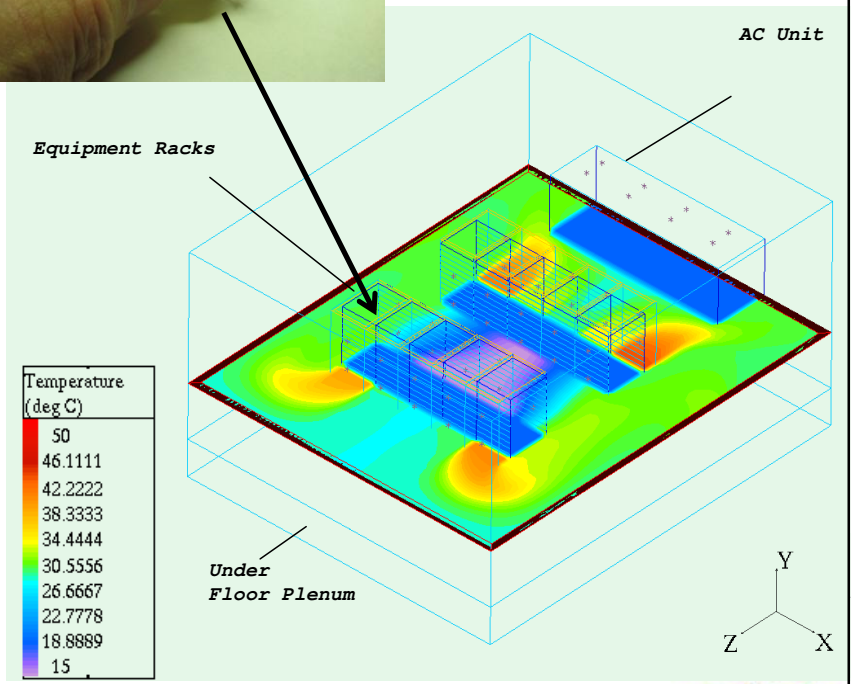
Source: Silicon Valley Leadership Group Report July 29, 2008
https://microsite.accenture.com/svlgreport/Documents/pdf/SVLG_Report.pdf

CITRIS and HP:
Energy Aware Design and Control

- **Wireless Sensor Networks @ CITRIS**
  - **"Micro-Climate" and Use at Each Blade in the Server Farm**
- **CITRIS/HP Redesign and Sensing Saves Up to 45% of Cooling Power Use**
- **Saving ~$400K/yr in Typical Center**



BANATAO INSTITUTE @ CITRIS
CENTER FOR INFORMATION TECHNOLOGY RESEARCH IN THE INTEREST OF SOCIETY
UNIVERSITY OF CALIFORNIA • BERKELEY



GreenLight Project

Source: Paul Wright CITRIS, Profs Van Carey and David Auslander

The Department of Energy's PNNL Energy Smart Data Center Testbed

Strategy

Develop a Testbed Datacenter Facility to Promote Energy Efficiency in Collaboration with other National Labs, industry leaders, and Energy-Focused Organizations

Objectives

- **Demonstrate and Compare Innovative Cooling Technologies**
- **Research Potential Savings in Power Conversion**
- **Partner with Vendors and Chip Manufacturers to Mature New Technologies in a Operational Datacenter Environment**
- **Promote Power Aware Computing**

Pacific Northwest National Laboratory
Operated by Battelle for the U.S. Department of Energy

GreenLight Project

Source: PNNL Smart Data Center-Andrés Márquez, Steve Elbert, Tom Seim, Dan Sisk, Darrel Hatley, Landon Sego, Kevin Fox, Moe Khaleel (http://esdc.pnl.gov/)

The NSF-Funded GreenLight Project
Giving Users Greener Compute and Storage Options

UCSD Structural Engineering Dept. Conducted Sun MD Tests May 2007

7 Racks plus Network

Takes up 2 Parking Spaces

Data Power Cooling

- **Measure and Control Energy Usage:**
  - **Sun Has Shown up to 40% Reduction in Energy**
  - **Active Management of Disks, CPUs, etc.**
  - **Measures Temperature at 5 Levels in 8 Racks**
  - **Power Utilization in Each of the 8 Racks**
  - **Chilled Water Cooling Systems**

UCSD (Calit2 & SOM) Bought Two Sun MDs May 2008

GreenLight Project

Source: Tom DeFanti, Calit2; GreenLight PI

The GreenLight Project: Instrumenting the Energy Cost of Computational Science

- **Focus on 5 Communities with At-Scale Computing Needs:**
  - **Metagenomics**
  - **Ocean Observing**
  - **Microscopy**
  - **Bioinformatics**
  - **Digital Media**

- **Measure, Monitor, & Web Publish Real-Time Sensor Outputs**
  - **Via Service-oriented Architectures**
  - **Allow Researchers Anywhere To Study Computing Energy Cost**
  - **Enable Scientists To Explore Tactics For Maximizing Work/Watt**
- **Develop Middleware that Automates Optimal Choice of Compute/RAM Power Strategies for Desired Greenness**
- **Partnering With Minority-Serving Institutions Cyberinfrastructure Empowerment Coalition**

GreenLight Project

Source: Tom DeFanti, Calit2; GreenLight PI

Research Needed on How to Deploy a Green CI

- **Computer Architecture**
  - Rajesh Gupta/CSE
- **Software Architecture**
  - Amin Vahdat, Ingolf Kruger/CSE
- **CineGrid Exchange**
  - Tom DeFanti/Calit2
- **Visualization**
  - Falko Kuster/Structural Engineering
- **Power and Thermal Management**
  - Tajana Rosing/CSE
- **Analyzing Power Consumption Data**
  - Jim Hollan/Cog Sci
- **Direct DC Datacenters**
  - Tom Defanti, Greg Hidley

GreenLight Project http://greenlight.calit2.net

New Techniques for Dynamic Power and Thermal Management to Reduce Energy Requirements

NSF Project Greenlight

- Green Cyberinfrastructure in Energy-Efficient Modular Facilities
- Closed-Loop Power &Thermal Management

Dynamic Power Management (DPM)

•Policies Capable of Optimal DPM for a Given Class of Workloads
•Machine Learning to Adapt
- Select Among Specialized Policies
- Use Sensors and Performance Counters to Monitor
- Multitasking/Within Task Adaptation of Voltage and Frequency

Dynamic Thermal Management (DTM)

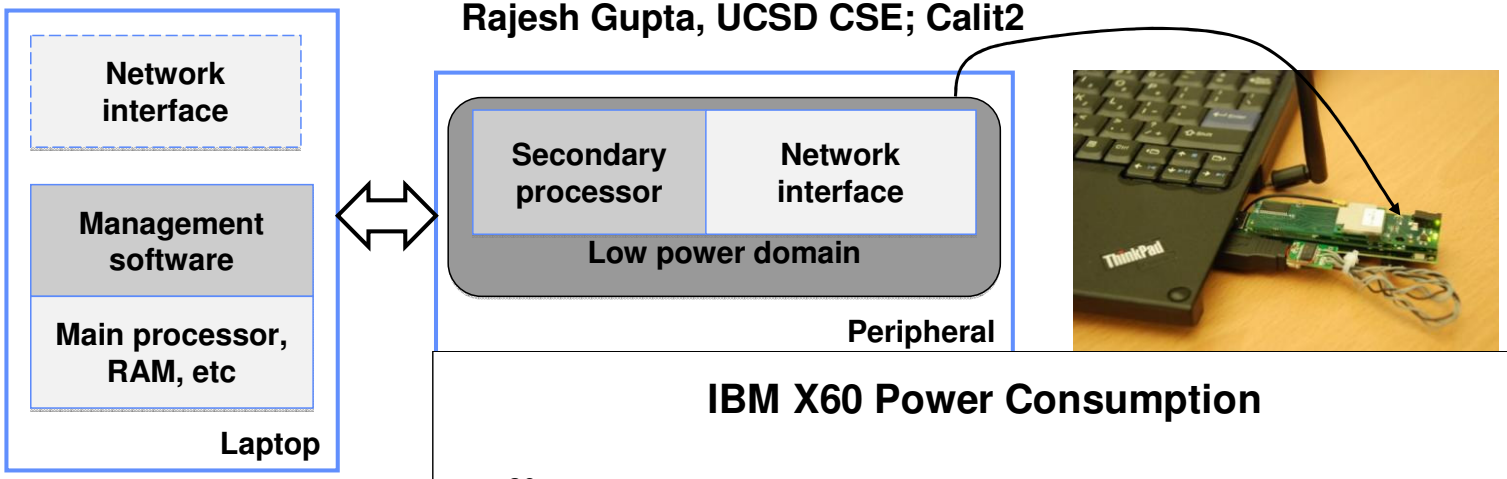
- Workload Scheduling:
  - Power vs. Thermal Management
  - Runtime Adaptation to Obtain Best Temporal and Spatial Profiles Using Closed-Loop Sensing
  - Negligible Performance Overhead
- Machine Learning for Dynamic Adaptation
- Proactive Thermal Management

GreenLight Project

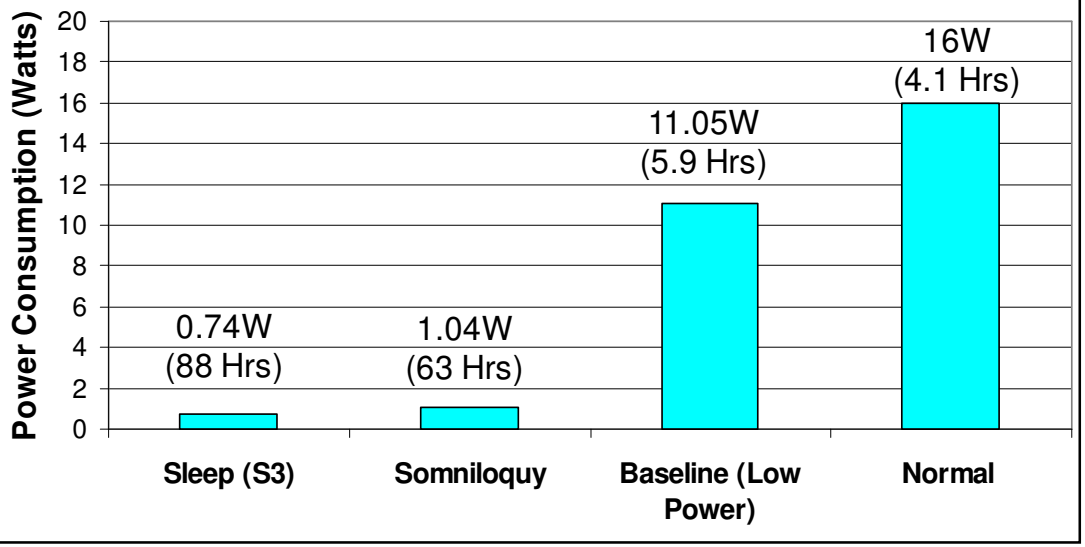
System Energy Efficiency Lab (seelab.ucsd.edu)
Prof. Tajana Šimunić Rosing, CSE, UCSD

GreenLight Project: Putting Machines To Sleep Transparently

Rajesh Gupta, UCSD CSE; Calit2



Somniloquy Enables Servers to Enter and Exit Sleep While Maintaining Their Network and Application Level Presence



GreenLight Project

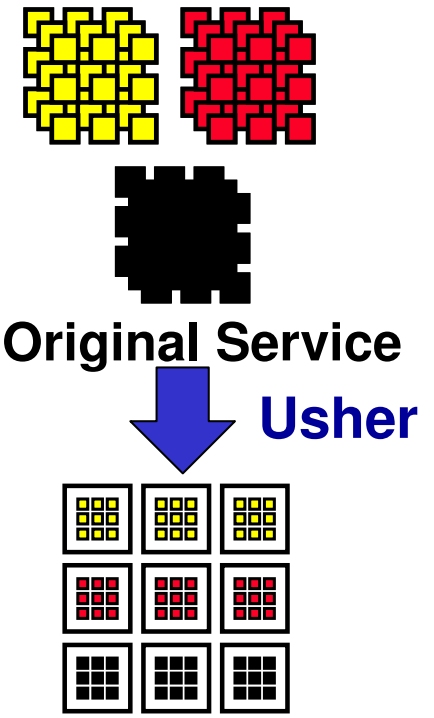
Improve Mass Spectrometry's Green Efficiency By Matching Algorithms to Specialized Processors

- **Inspect Implements the Very Computationally Intense MS-Alignment Algorithm for Discovery of Unanticipated Rare or Uncharacterized Post-Translational Modifications**
- **Solution: Hardware Acceleration with a FPGA-Based Co-Processor**
  - **Identification and Characterization of Key Kernel for MS-Alignment Algorithm**
  - **Hardware Implementation of Kernel on Novel FPGA-based Co-Processor (Convey Architecture)**
- **Results:**
  - **300x Speedup & Increased Computational Efficiency**

Large Savings in Energy Per Application Task

Virtualization at Cluster Level for Consolidation and Energy Efficiency

Source: Amin Vadhat, CSE, UCSD



- Fault Isolation and Software Heterogeneity, Need to Provision for Peak Leads to:
  - Severe Under-Utilization
  - Inflexible Configuration
  - High Energy Utilization
- Usher / DieCast enable:
  - Consolidation onto Smaller Footprint of Physical Machines
  - Factor of 10+ Reduction in Machine Resources and Energy Consumption

GreenLight Project

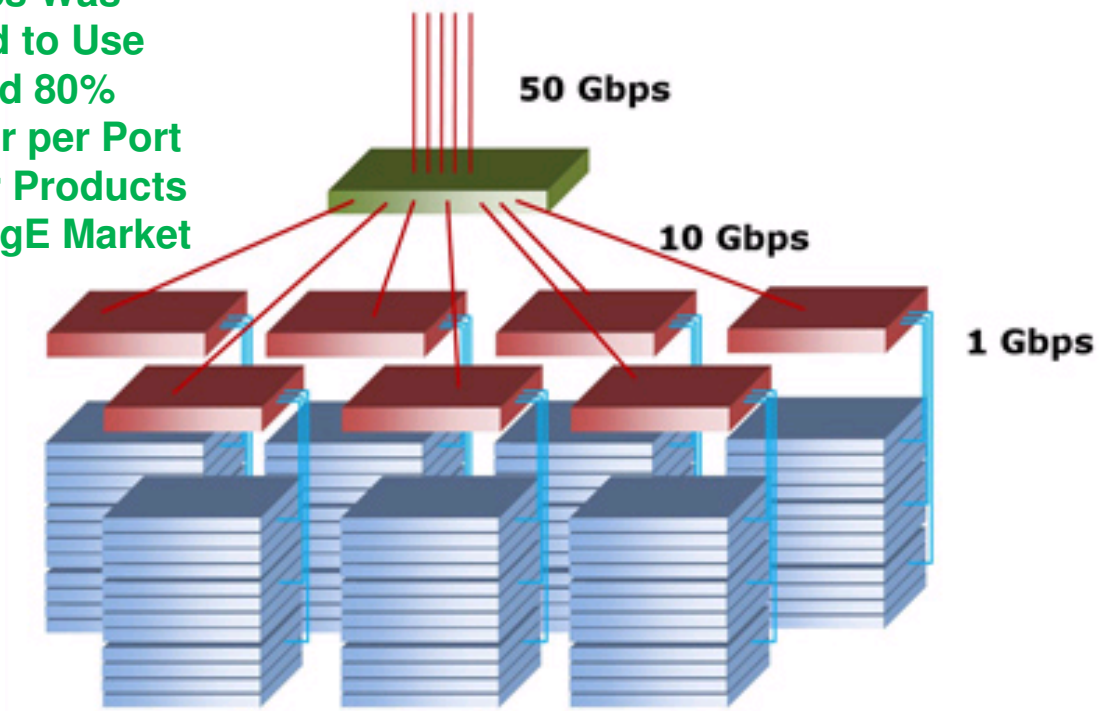
UCSDCSE Computer Science and Engineering

cns center for networked systems

it2

GreenLight Provides a Environment for Innovative "Greener" Products to be Tested

Quadrics Was Designed to Use 20% and 80% Less Power per Port Than Other Products in the 10 GigE Market



GreenLight topology for 10GE link aggregation: When complete, the servers (blue) will connect to edge switches (red) via 1 Gbps links, and the edge switches will connect to each other via the 10 Gbps links of the Quadrics TG201 switch (green).

GreenLight Project

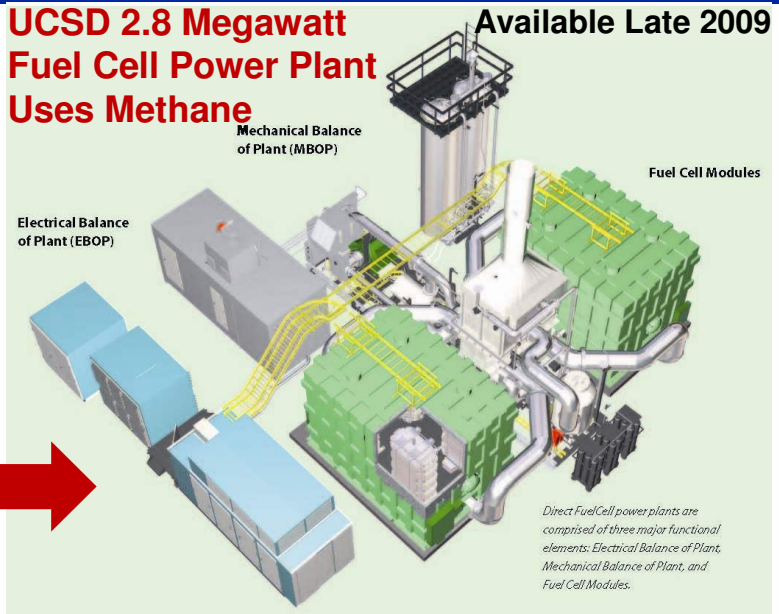
www.calit2.net/newsroom/article.php?id=1482

UCSD is Installing Zero Carbon Emission Solar and Fuel Cell DC Electricity Generators

San Diego's Point Loma Wastewater Treatment Plant Produces Waste Methane

UCSD 2.8 Megawatt Fuel Cell Power Plant Uses Methane

Available Late 2009



2 Megawatts of Solar Power Cells Being Installed

GreenLight Project

it²

Zero Carbon GreenLight Experiment: DC-Powered Modular Data Center

- **Concept—Avoid DC to AC to DC Conversion Losses**
  - Computers Use DC Power Internally
  - Solar and Fuel Cells Produce DC
  - Both Plug into the AC Power Grid
  - Can We Use DC Directly (With or Without the AC Grid)?

Sun Box <200kWatt

- **DC Generation Can Be Intermittent**
  - Depends on Source
    - Solar, Wind, Fuel Cell, Hydro
  - Can Use Sensors to Shut Down or Sleep Computers
  - Can Use Virtualization to Halt/Shift Jobs
- **Experiment Planning Just Starting**
  - Collaboration with Sun and LBNL
  - NSF GreenLight Year 2 and Year 3 Funds

GreenLight Project

Source: Tom DeFanti, Calit2; GreenLight PI

Power Management in the Cellular Infrastructure: Calit2 Achieves 58% Power Amplifier Efficiency

Standard Commercial Base Station Power Amp is 10% Efficient

Calit2 High-Power Amplifier Lab

freescale semiconductor

TriQuint SEMICONDUCTOR

HUAWEI

ERICSSON

GreenLight Project

Power Transistor Tradeoffs:

Si-LDMOS, GaN, & GaAs

Price & Performance

Eudyna

Power Amplifier Tradeoffs:

WiMAX & 3.9GPP LTE

Efficiency & Linearity

STMicroelectronics

Digital Signal Processing Tradeoffs:

NOKIA

Pre-Distortion, Memory Effects & Power Control

QUALCOMM

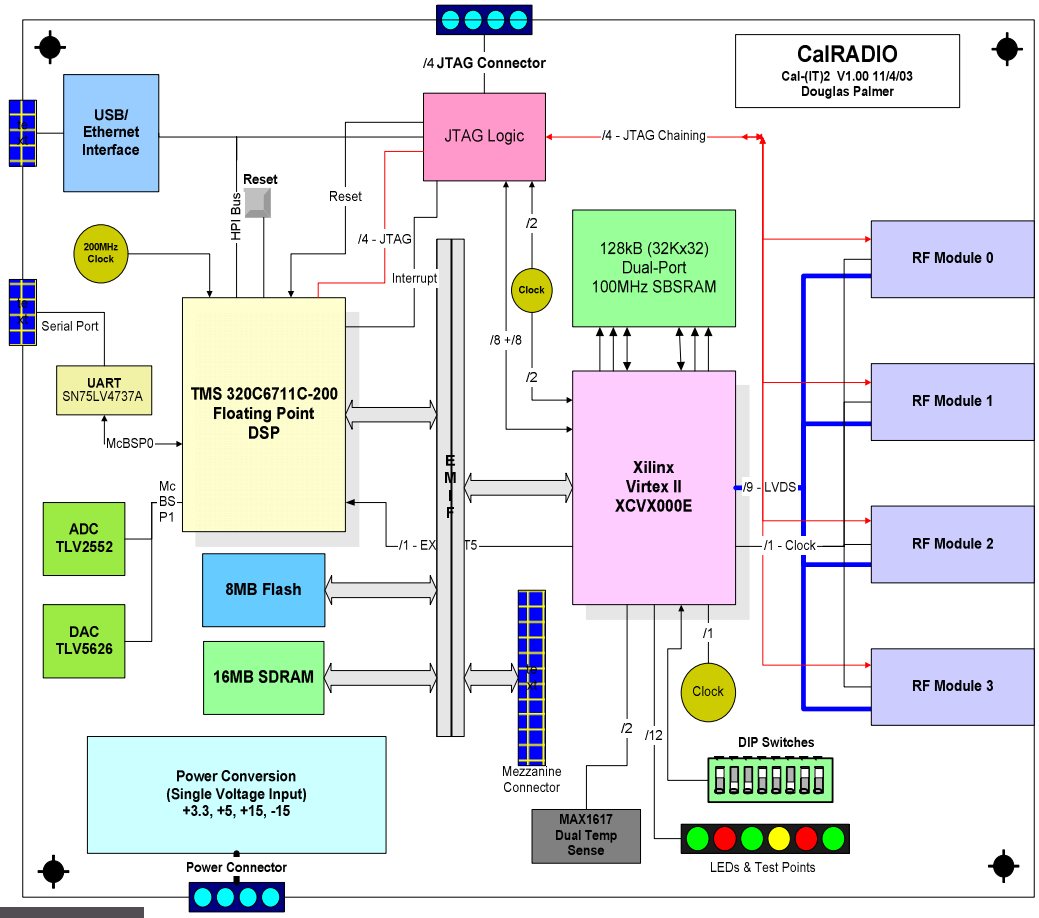
MIPS & Memory

it2

www.universityofcalifornia.edu/news/article/19058

Source: Don Kimball, Calit2

CalRadio:
Enabling Energy Reduction Research in Smart Radios



GreenLight Project

CalRadio Opens Up Each Layer to Your Software

#	ISO- Layer	CalRadio 1b Processing Element
7	Application	ARM Processor – User App
6	Presentation	ARM Processor - ucLinux
5	Session	ARM Processor - ucLinux
4	Transport	ARM Processor - ucLinux
3	Network	ARM Processor - ucLinux
2	Data Link	DSP - MAC
1	Physical – hardware connection	RF Module – Baseband Processor

Interlayer communications are very simple!

CalRadio as a Testbed for Power Management

- A 802.11 MAC
  - Fully 'C' Programmable
  - Implemented in a Low-Power DSP
- Fast and Easily Tested Control of the Power Dynamics
- Not Constrained to Standard 802.11 PHY/MAC Protocols
- Increased QoS Within a Channel Yielding Better Power Management

CalRadio Research Areas:

- Alex Snoeren - RTS/CTS Multi-Hop Management
- Curt Schurgers - Packet by Packet Energy Management
- Per Johanson - Battery Life Management in Mesh Networks
- Danko Antolovic – 16 Antenna Diversity Transceiver

Source: Doug Palmer, Calit2

Application of ICT Can Lead to a 5-Fold Greater Decrease in GHGs Than its Own Carbon Footprint

While the sector plans to significantly step up the energy efficiency of its products and services, ICT's largest influence will be by enabling energy efficiencies in other sectors, an opportunity that could deliver carbon savings five times larger than the total emissions from the entire ICT sector in 2020.

--Smart 2020 Report

Major Opportunities for the United States*

- Smart Electrical Grids
- Smart Transportation Systems
- Smart Buildings
- Virtual Meetings

*** Smart 2020 United States Report Addendum**

www.smart2020.org

GreenLight Project

Use University Campuses as Green IT Testbeds

- **Campuses are Small Cities**
  - Consolidated Clusters over Dedicated Optical Channels
  - Low Energy Mobile Infrastructure
  - Sensors and Actuators in Intelligent Buildings
  - Low Carbon Transportation System
  - Smart Electricity Grid
  - Ubiquitous Teleconferencing
  - Research on How to Change End User Behavior
- **Calit2 is Partnering with UCSD and UCI**
  - "Green Living Laboratories of the Future"