Project GreenLight: Optimizing Cyberinfrastructure for a Carbon Constrained World

Keynote Talk for the Joint

33rd IEEE International Computer Software and Applications Conference

COMPSAC 2009

and the 9th Annual International Symposium on Applications and the Internet

SAINT 2009

Seattle, WA

July 21, 2009

Dr. Larry Smarr

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Harry E. Gruber Professor,

Dept. of Computer Science and Engineering

Jacobs School of Engineering, UCSD

GreenLight Project

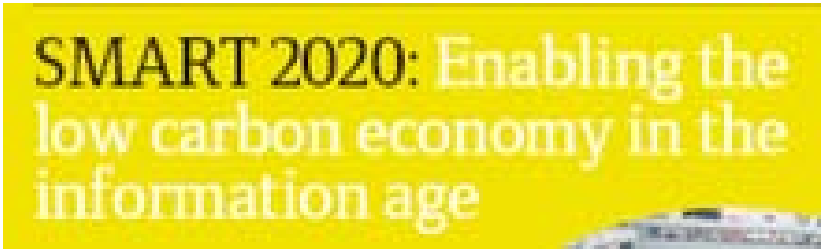
Abstract

This year marks a turning point in the debate on global climate change in which the focus is rapidly moving from a scientific analysis of how human activity effects climate change to a political process on how best to regulate greenhouse gas (GHG) emissions. The global Information and Communication Technology (ICT) industry produces GHGs equivalent to that produced by the aviation industry (~2-3 %). Furthermore, the ICT sector's emissions will nearly triple, in a business as usual scenario, from 2002 to 2020. On the other hand, the Climate Group estimates that transformative application of ICT to electricity grids, logistic chains, intelligent transportation and building infrastructure, and other social systems can reduce global GHG emissions by ~15%, five times ICT's own footprint! I will discuss two campus testbeds for exploring these complex tradeoffs. The NSF-funded GreenLight Project (http://greenlight.calit2.net), deployed at UCSD, creates an instrumented data center which allows for detailed real time data measurements of the critical subcomponents and then making that data publically available on the web so that the results can guide users who wish to lower the energy cost of computation and storage. The second testbeds are the UCSD and UCI campuses themselves, which are functionally small towns with their own power grids, commuter transportation systems, hospitals, and populations in the tens of thousands and so are at-scale Green IT testbeds. Calit2 is working with campus administration, faculty and staff to instrument these campuses as Living Laboratories of the Green Future.



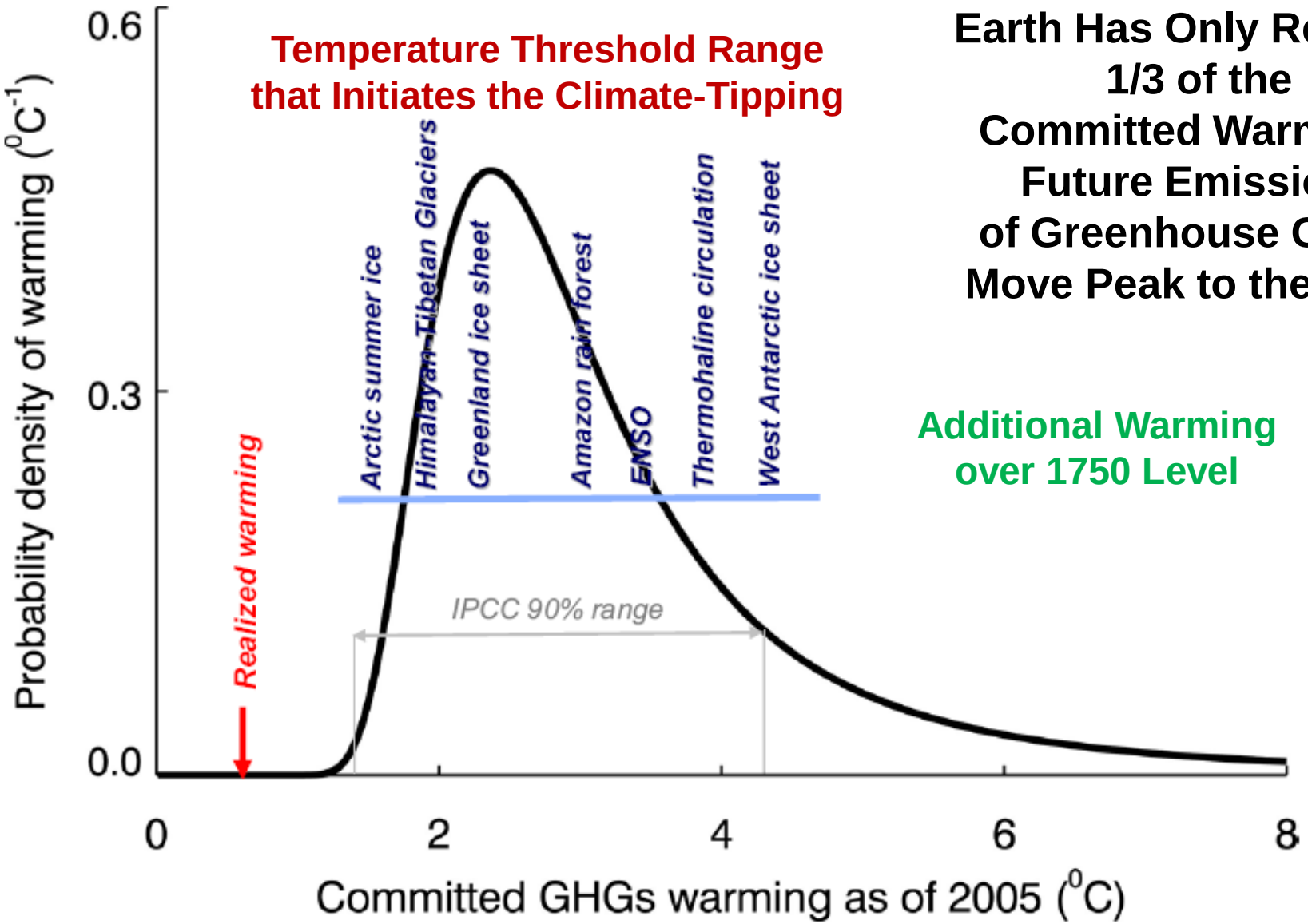
ICT is a Key Sector in the Fight Against Climate Change

Applications of ICT
could enable emissions reductions
of 7.8 Gt CO_2e in 2020,
or 15% of business as usual emissions.
But it must keep its own growing footprint in check
and overcome a number of hurdles
if it expects to deliver on this potential.





The Planet is Already Committed to a Dangerous Level of Warming



Earth Has Only Realized 1/3 of the Committed Warming - Future Emissions of Greenhouse Gases Move Peak to the Right

Additional Warming over 1750 Level

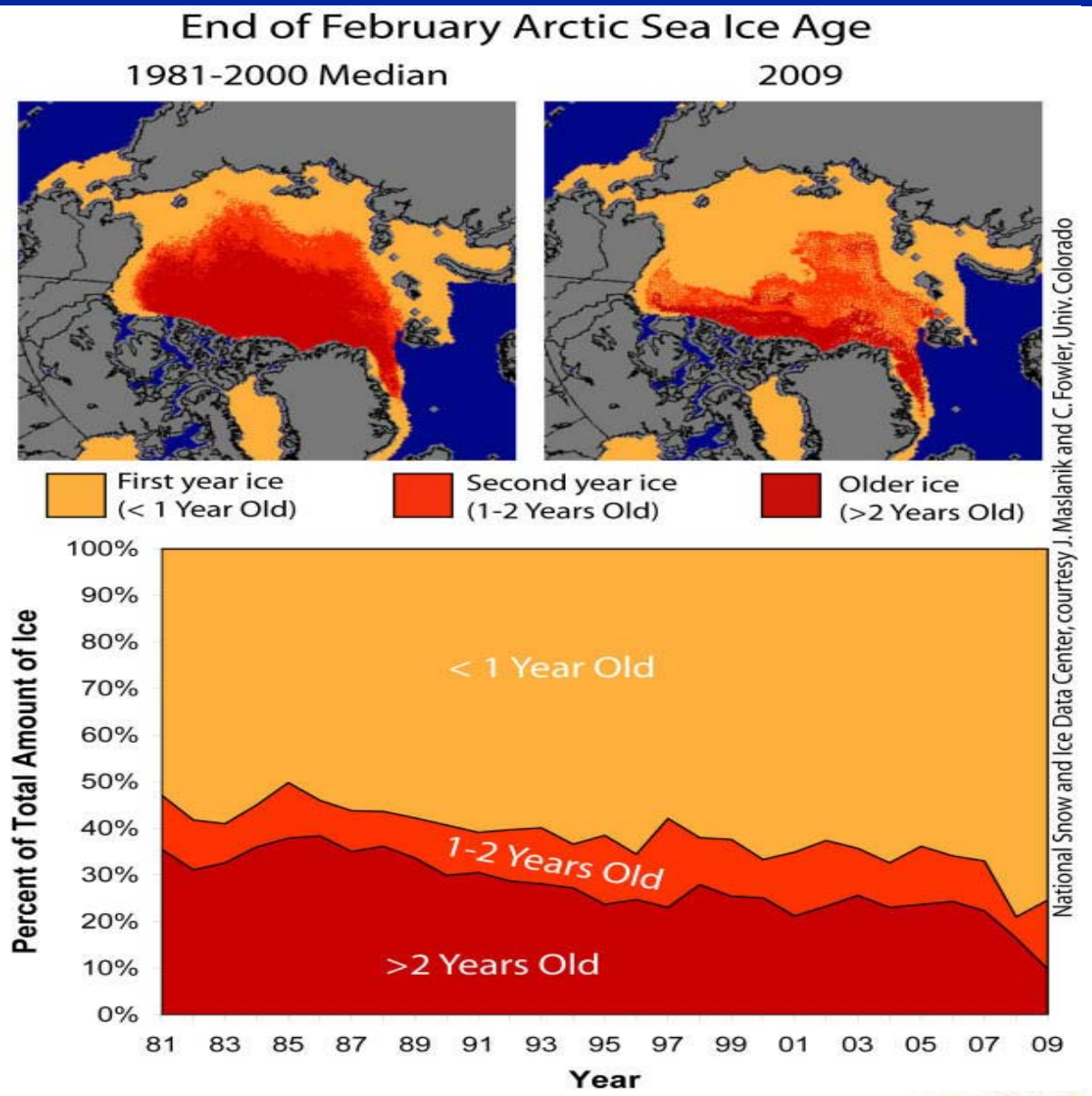
V. Ramanathan and Y. Feng, Scripps Institution of Oceanography, UCSD

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

GreenLight Project

Arctic Summer Ice is Rapidly Decreasing

"The Arctic Ocean will be effectively ice free sometime between 2020 and 2040, although it is possible it could happen as early as 2013."
--Walt Meier, Research Scientist at the National Snow and Ice Data Centre at the University of Colorado



http://news.cnet.com/8301-11128_3-10213891-54.html

The Hindu Kush/Himalayan Plateau Has the Most Snow and Ice Outside of the Polar Regions

Gordon and Betty MOORE FOUNDATION

UNIVERSITY OF CAMBRIDGE

UCSD

"Water Towers of Asia"
Impact
40% of the
World's Population

UCSD-Cambridge Workshop
May 4 – May 6, 2009
University of California San Diego
La Jolla, CA

Ice, Snow, and Water

Impacts of Climate Change on California and Himalayan Asia



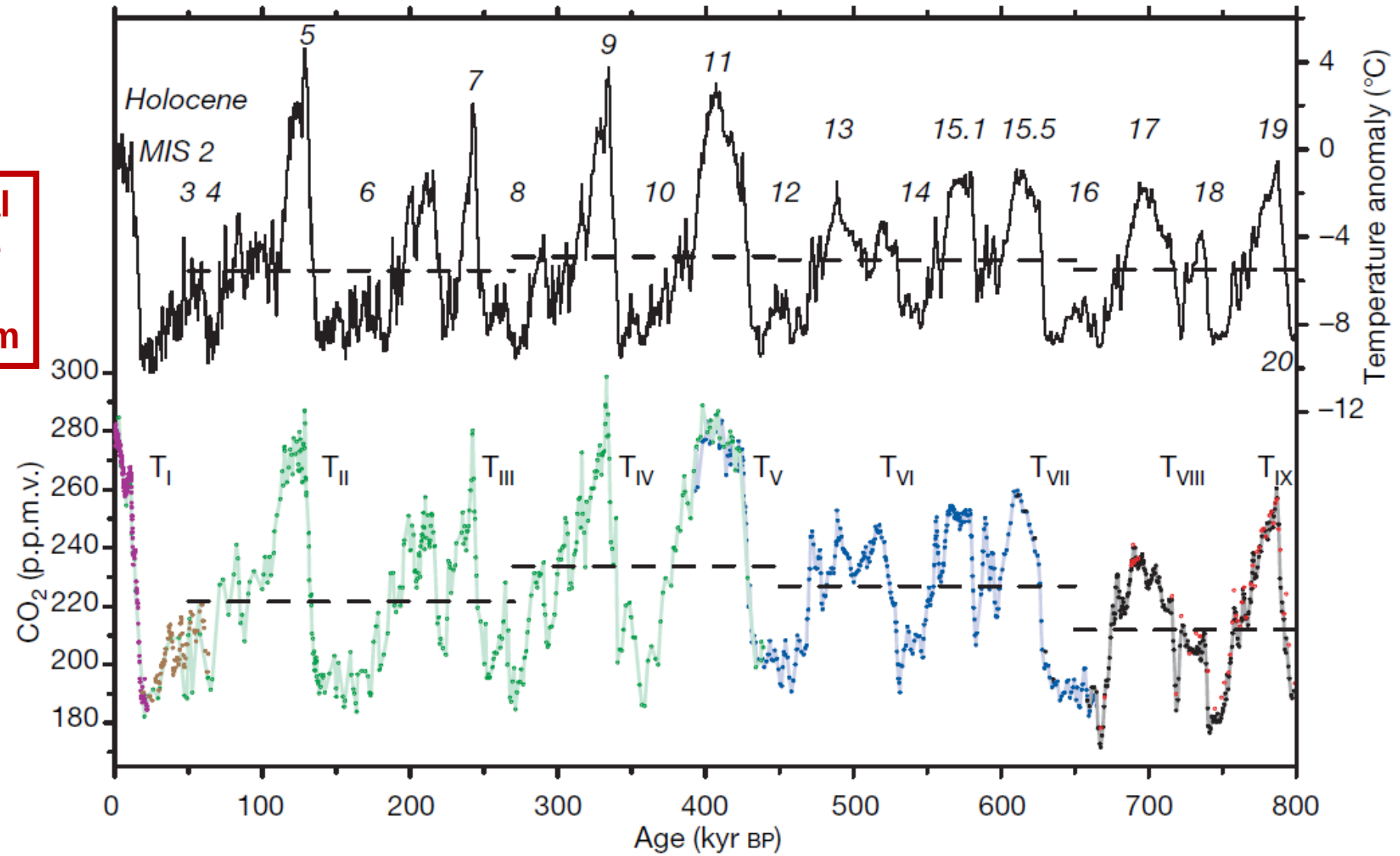
HKH Map with major river basins

GreenLight Project

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Antarctic Ice Cores Show CO^2 and Temperature Oscillations Over Last 800,000 Years

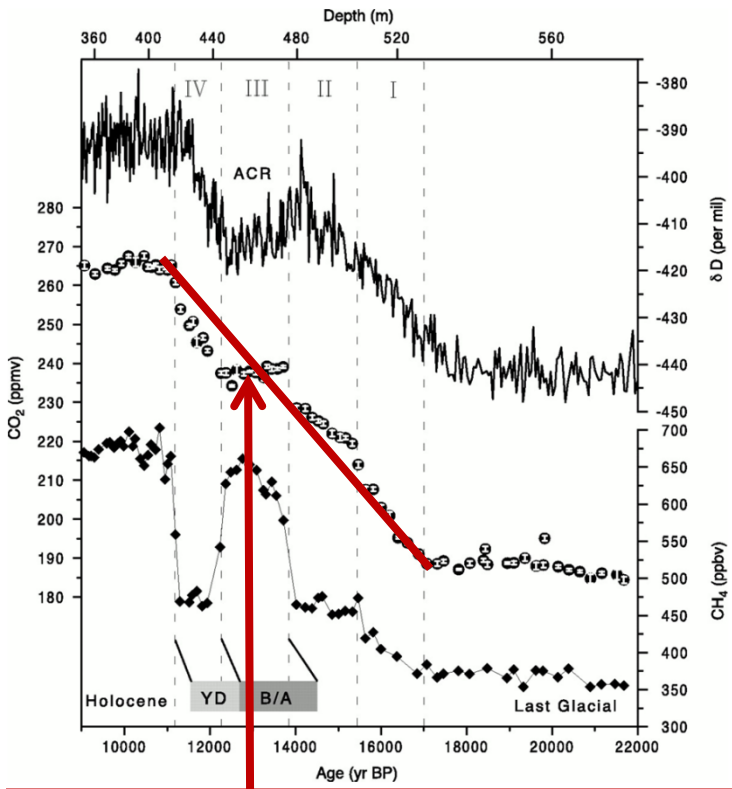
Vertical Range 170 to 300 ppm



GreenLight Project

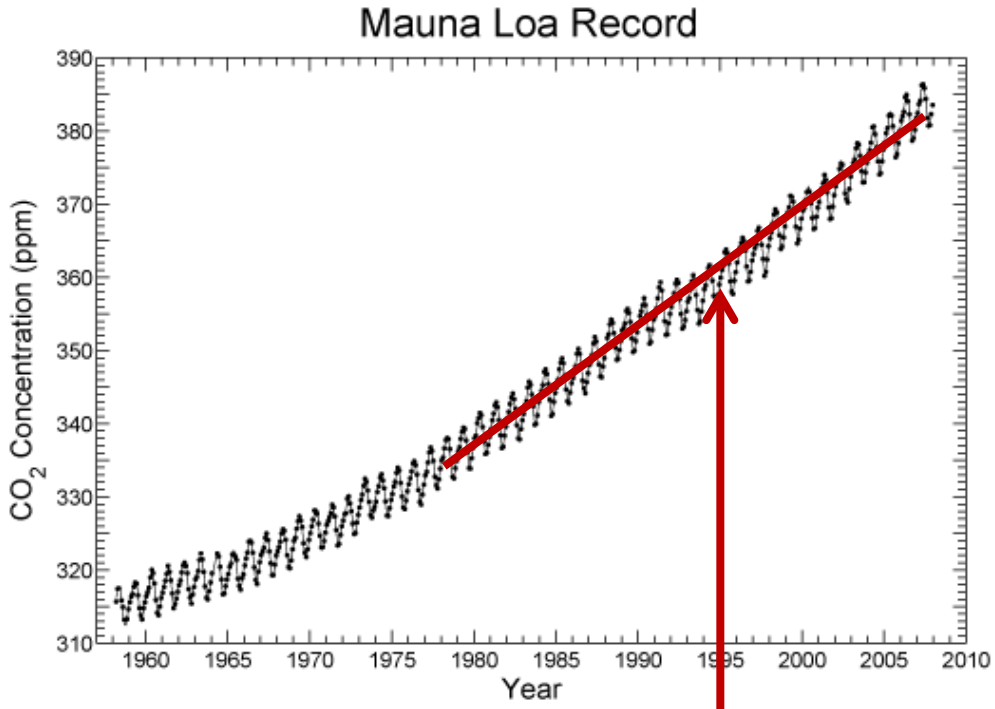
Luthi, et al. Nature may 15, 2008 v. 453 pp379-82

The Earth is Warming 200 Times Faster Today Than During the Last Ice Age Warming!



CO^2 Rose From 185 to 265ppm (80ppm) in 6000 years or 1.33 ppm per Century

http://scrippsco2.ucsd.edu/program_history/keeling_curve_lessons.html

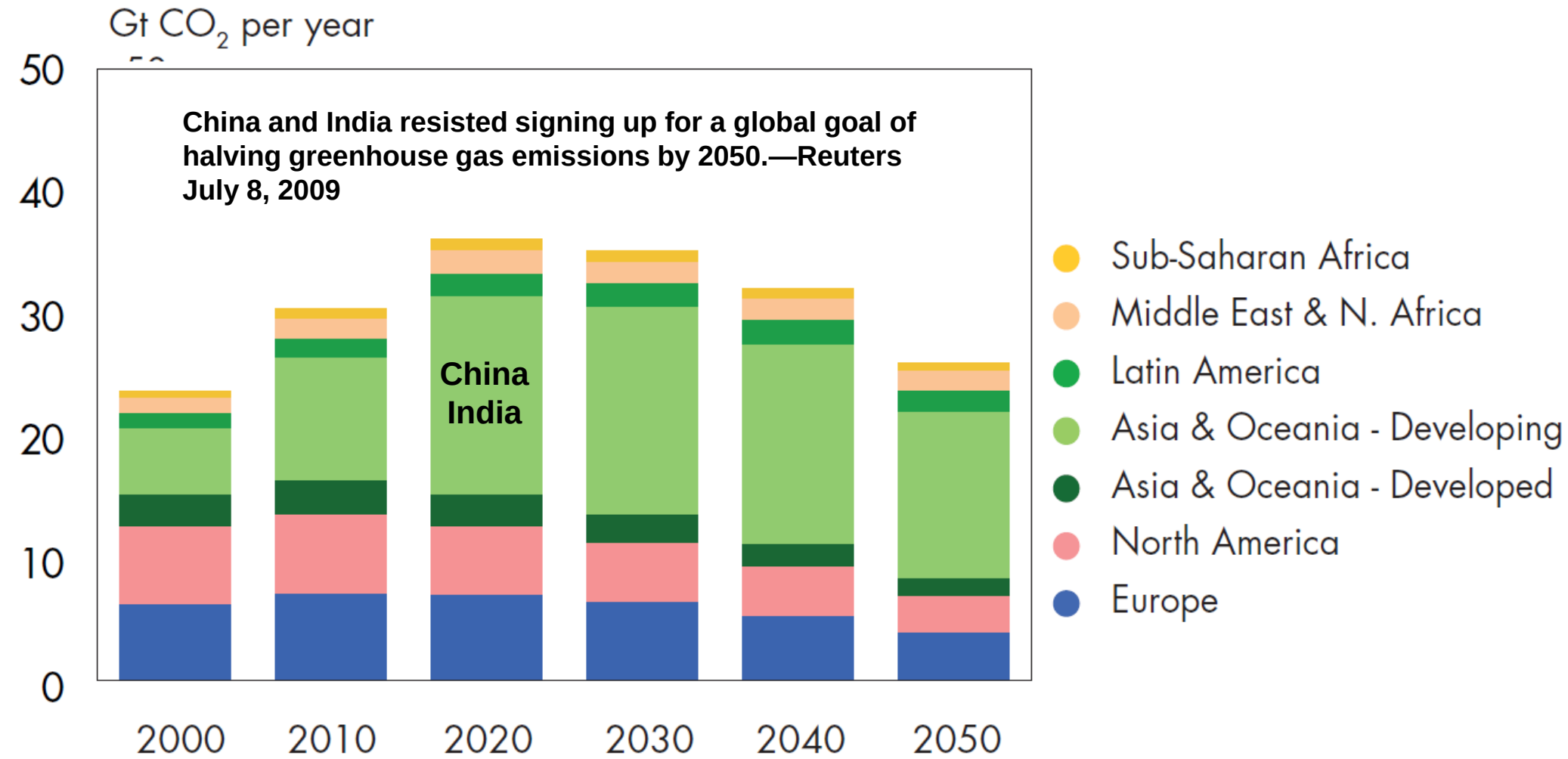


CO^2 Has Risen From 335 to 385ppm (50ppm) in 20 years or 2.5 ppm per Year

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CO^2 Emissions From Energy in an Aggressive CO^2 Emission Reduction Scenario

www-static.shell.com/static/public/downloads/brochures/corporate_pkg/scenarios/shell_energy_scenarios_2050.pdf

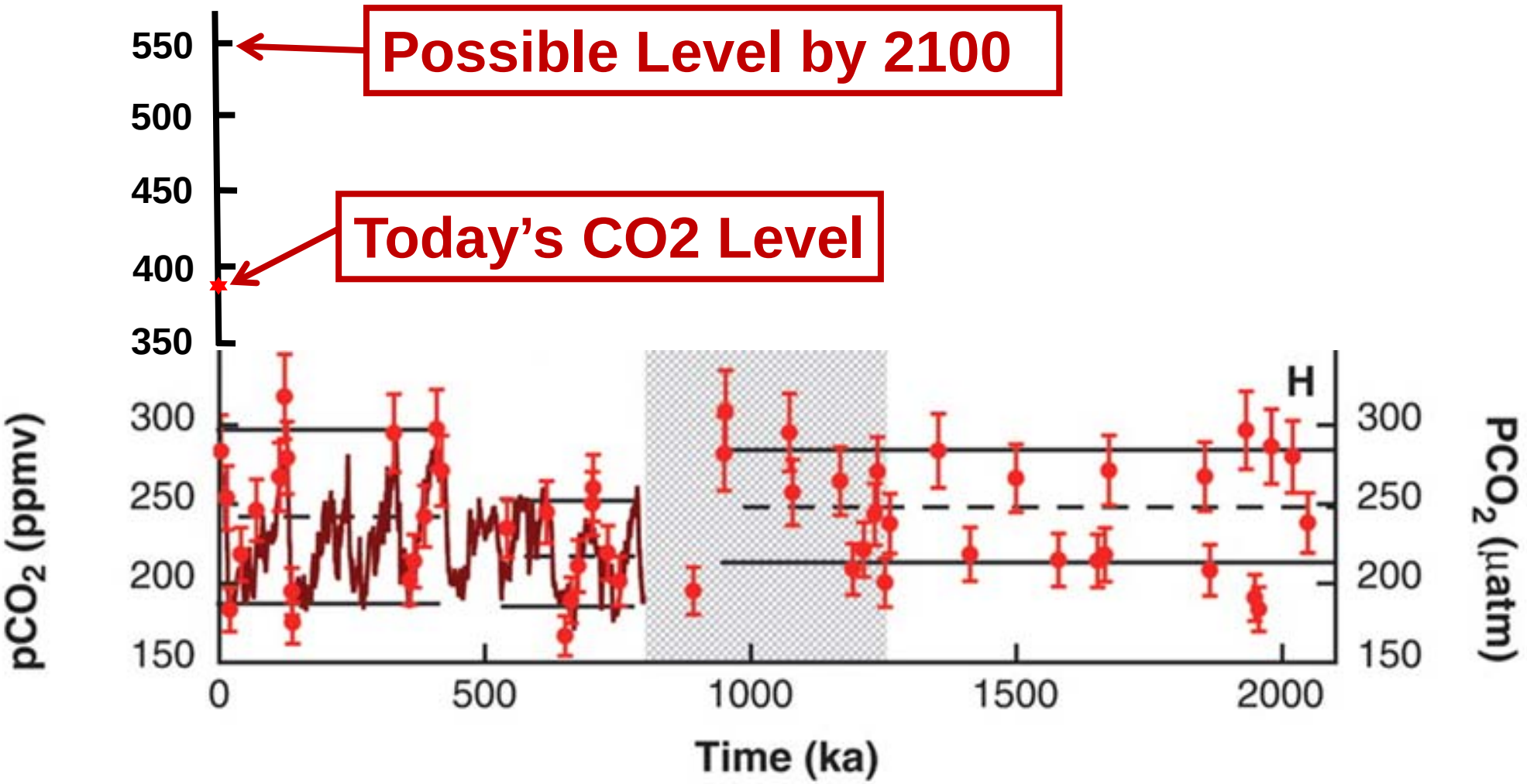


Estimated CO^2 Level in 2100 is 550ppm

GreenLight Project

Ice Core Record Has Been Extended Using Plankton: Today's CO^2 is Higher Than in Last 2 Million Years!

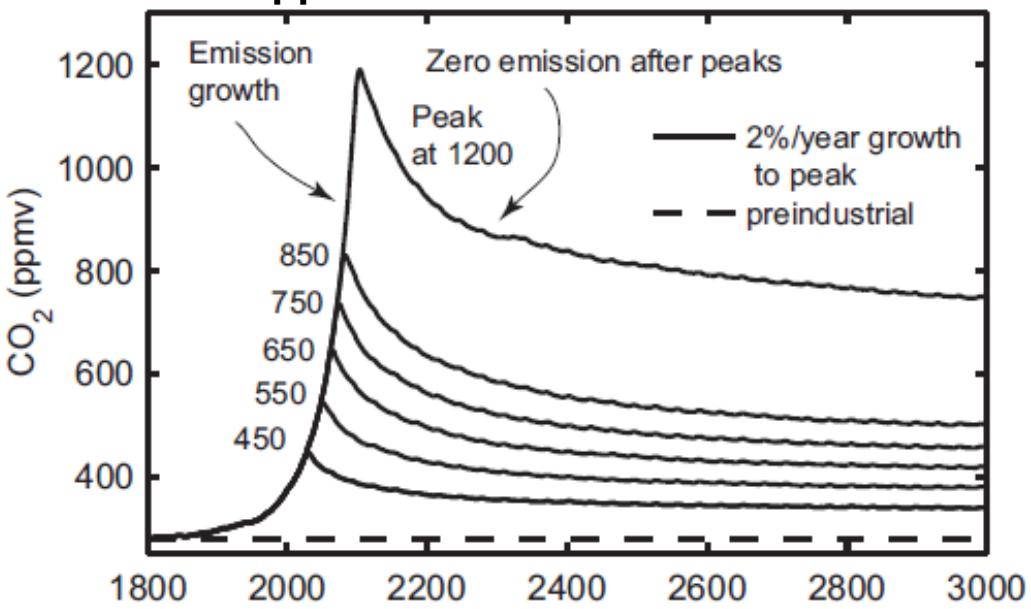
Hönisch, et al. Science Science 19 June 2009 Vol. 324. pp. 1551 - 1554

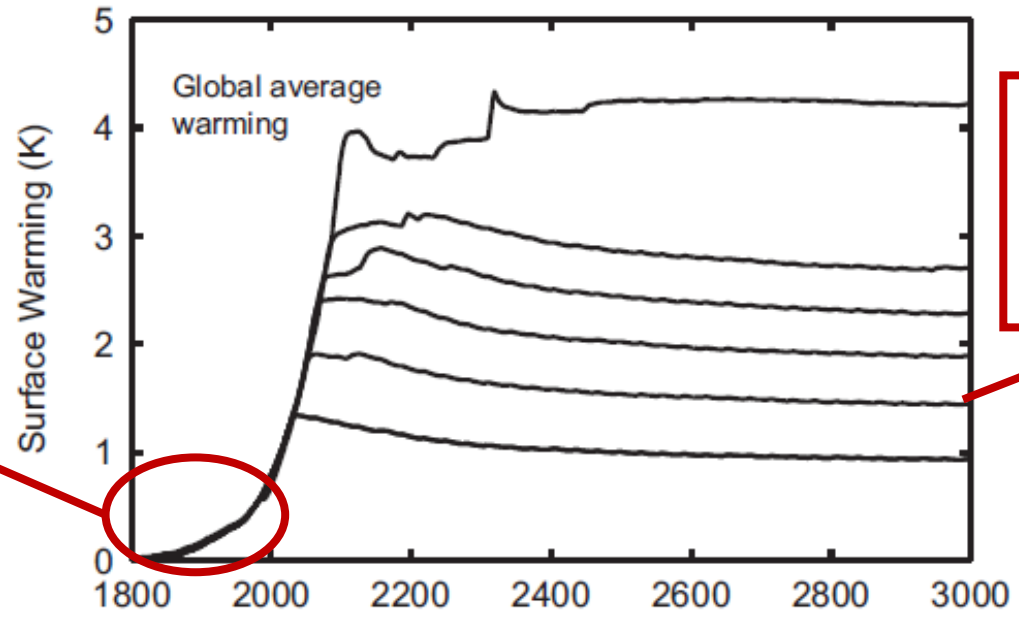


We Are Transitioning to a New Climate State -- Unlike the Rapid Recovery with Acid Rain or Ozone Hole

Susan Solomon, et al., PNAS 2/10/2009 v. 106 pp1704-9

Assumes CO^2 Increases to a Maximum and Then Emissions Abruptly Stop



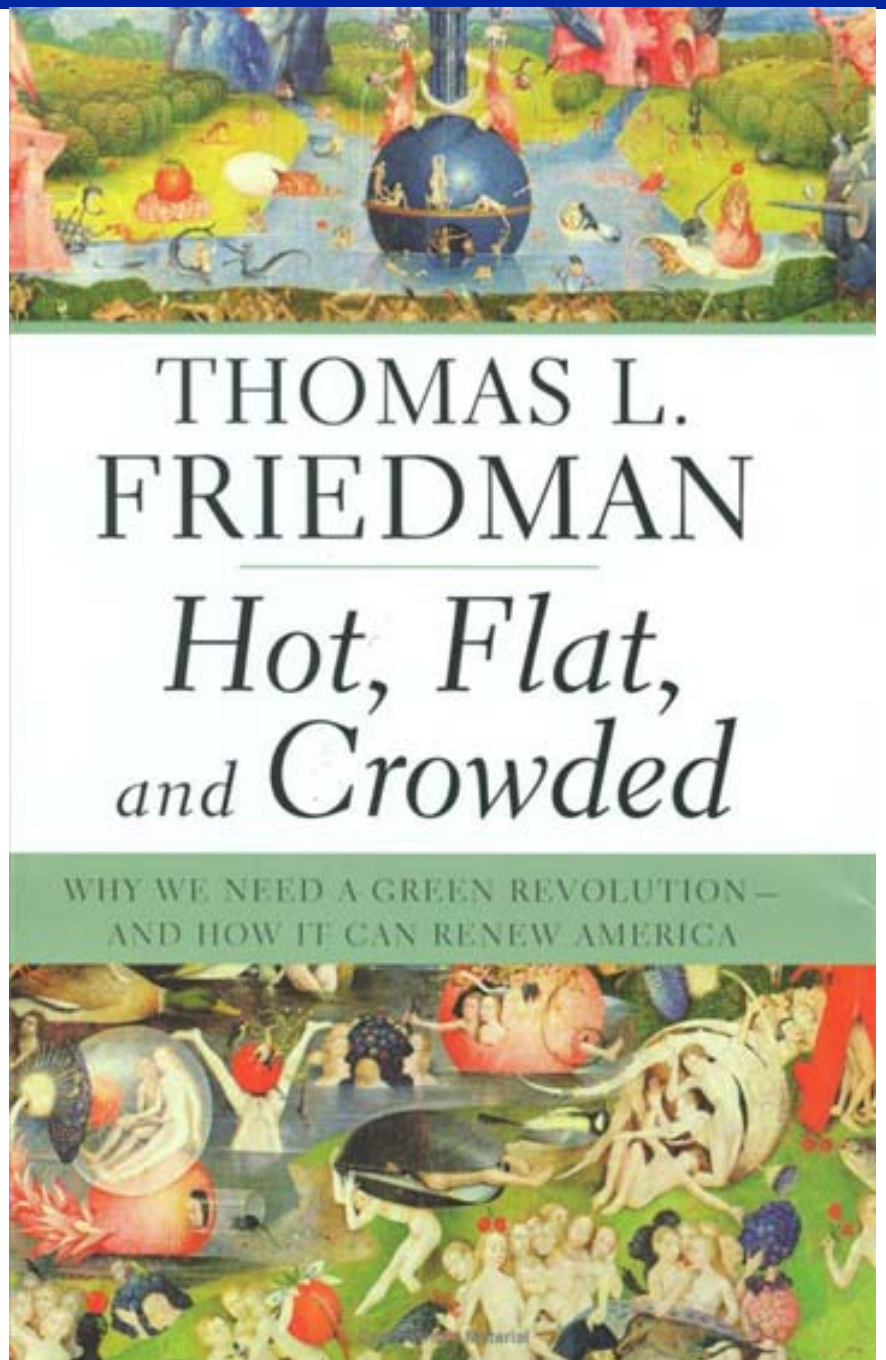


Warming During the Industrial Age -- Last 200 Years

Warming Persists for Over 1000 Years

GreenLight Project

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



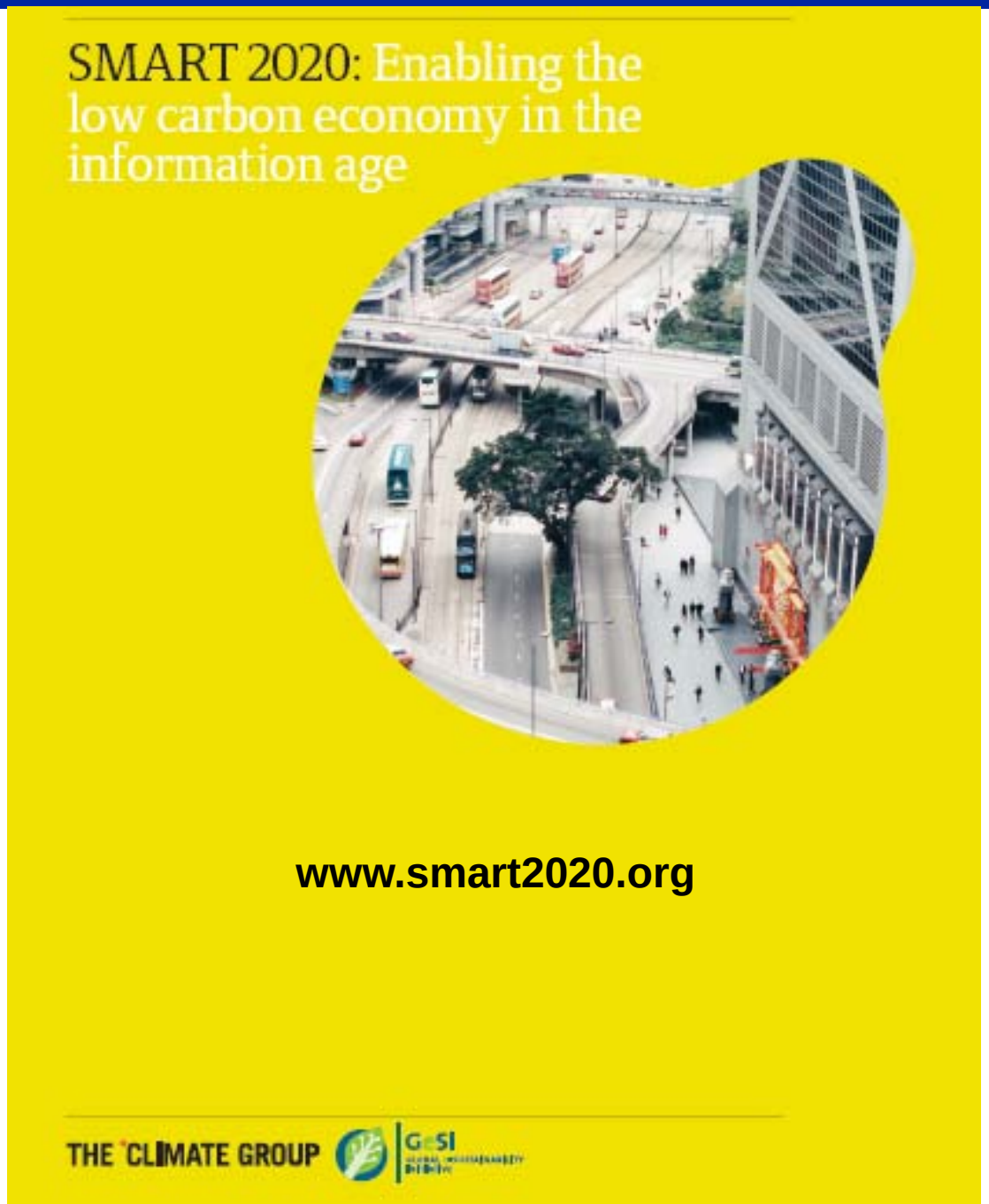
ICT is a Critical Element in Achieving Countries Greenhouse Gas Emission Reduction Targets

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:

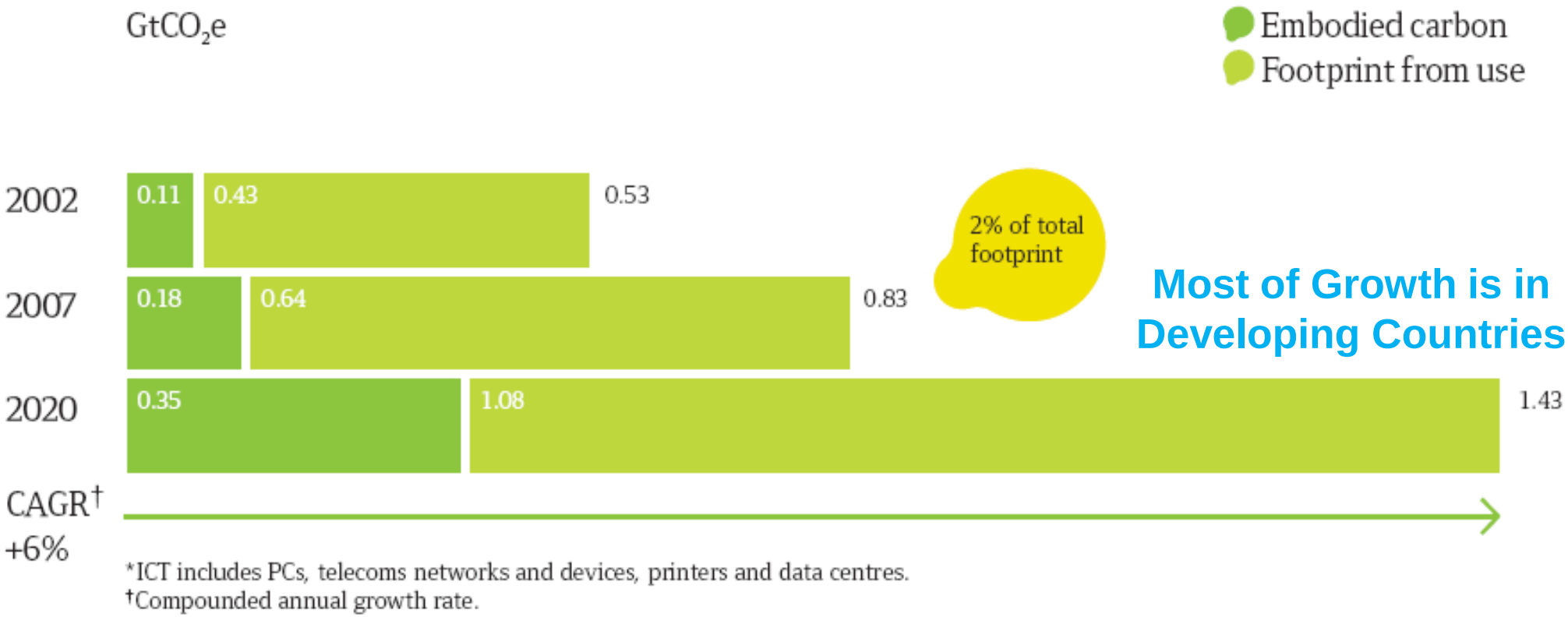
- **Dell, LG.**



GreenLight Project

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

But ICT Emissions are Growing at 6% Annually!



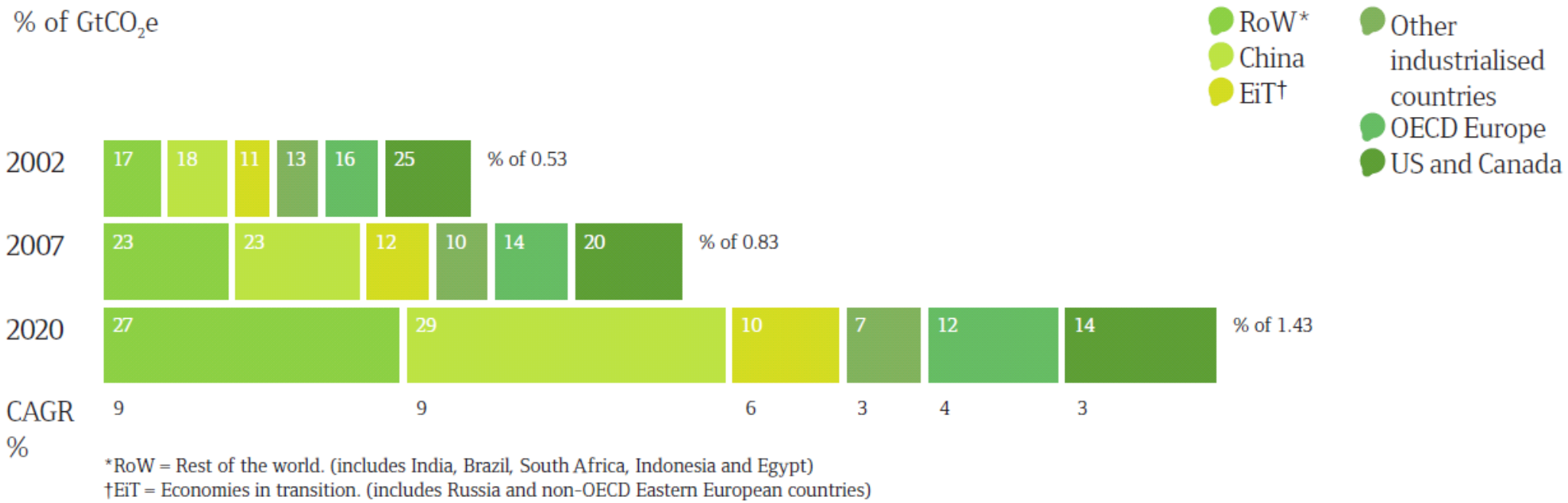
Most of Growth is in Developing Countries

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**

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

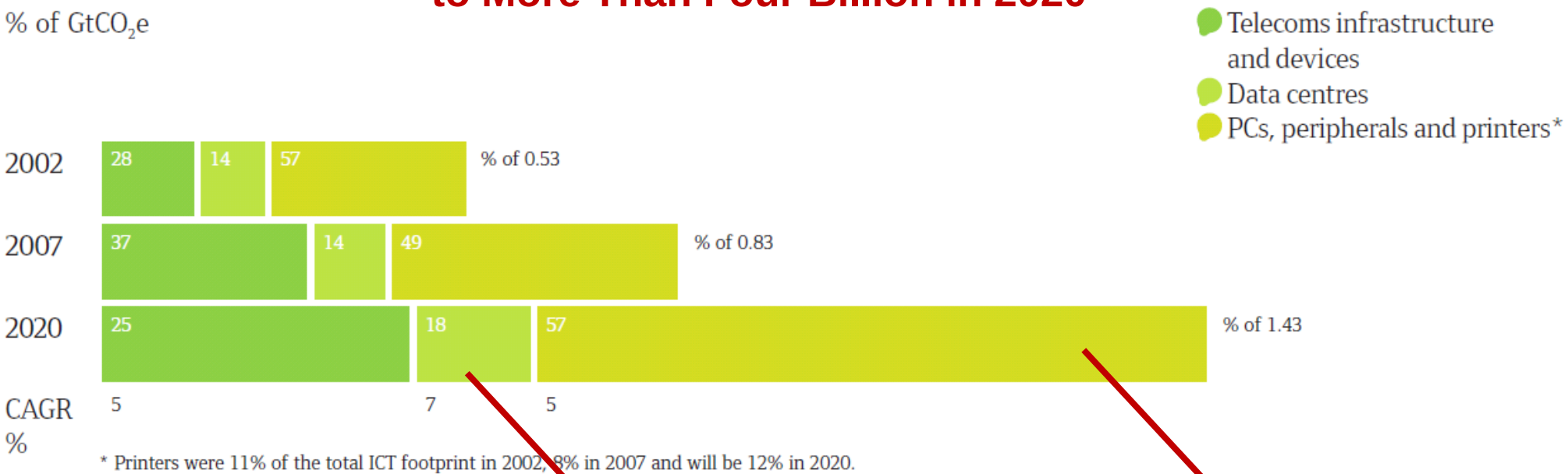
U.S. and Canada Together Fall From 25% to 14% of Global ICT Emissions by 2020



*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)

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

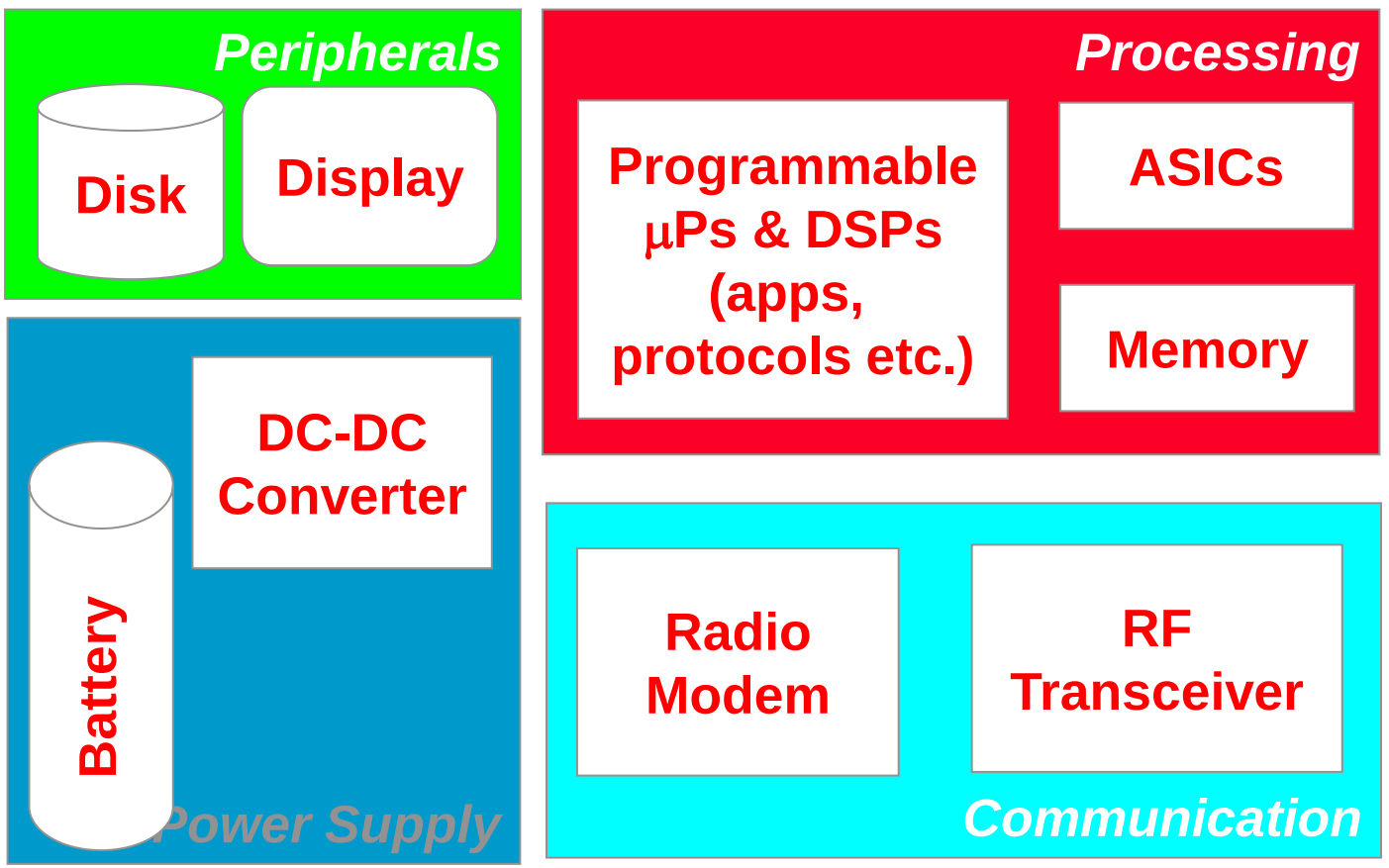


Data Centers Are Rapidly Improving

PCs Are Biggest Problem

Can We Make Laptops More Energy Efficient? This is a System Level Concern

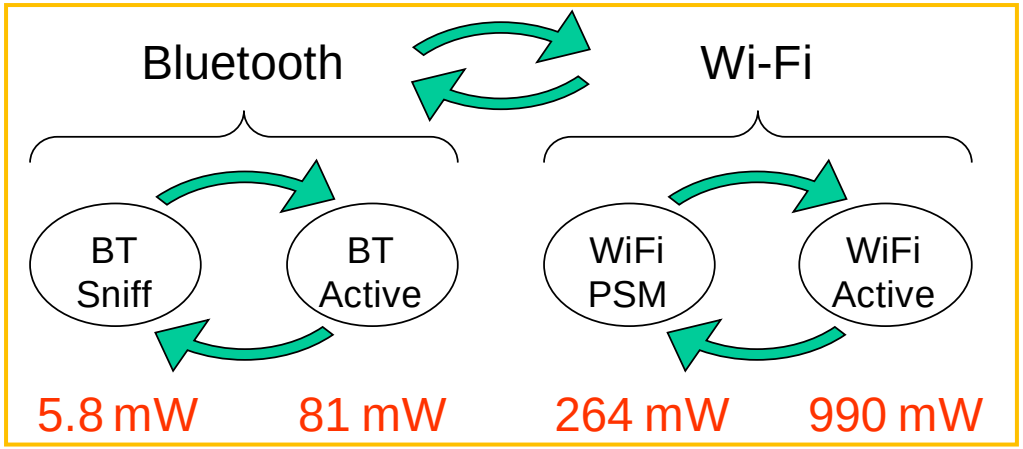
- **Requires Coordinated Strategies Across Processing, Communications and Networking**
- **6-10X Variation in Power from Sleep to Various Active Modes**
  - **Even Larger Variation in Radio Power, TX/RX Ratio**



Source: Rajesh Gupta, UCSD CSE; Calit2

Resource Coordination Can Lead to Energy Efficiencies

- **Coordinated Processing Can Improve Efficiency**
  - **Use Secondary Processor to Shutdown Main Processor**
- **Coordinating Radios Can:**
  - **Improve Efficiency (Spectral, Energy)**
    - **Use Radios to Page Other Radios,**
    - **Coordinate Radio Duty Cycles**
    - **Dynamically Match Radios to Range &Traffic**
  - **Use for Improving Performance, Reliability, Security**



Driven by Accurate and Timely Sensor Data That Push the Available Slack to Thermal Limits

Source: Rajesh Gupta, UCSD CSE; Calit2

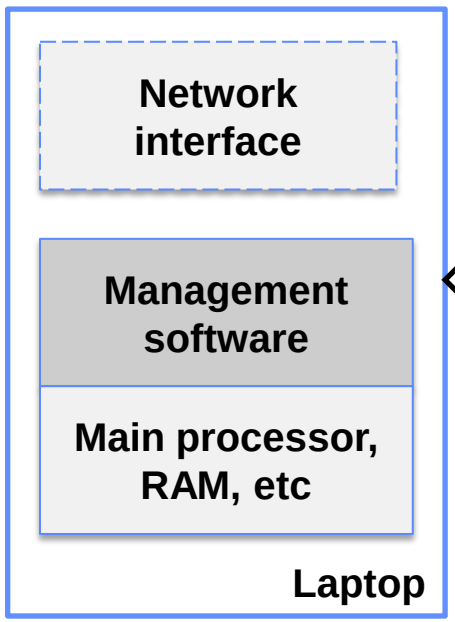
Algorithmically, Two Ways to Save Power Through Choice of Right System & Device States

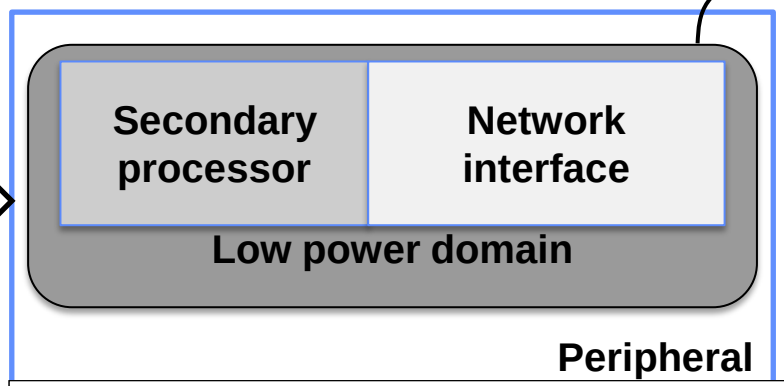
- **Shutdown**
  - Multiple Sleep States
  - Also Known as Dynamic Power Management (DPM)
- **Slowdown**
  - Multiple Active States
  - Also Known as Dynamic Voltage/Frequency Scaling (DVS)
- **DPM + DVS**
  - Choice Between Amount of Slowdown and Shutdown

Source: Rajesh Gupta, UCSD CSE; Calit2

Increasing Laptop Energy Efficiency: Putting Machines To Sleep Transparently

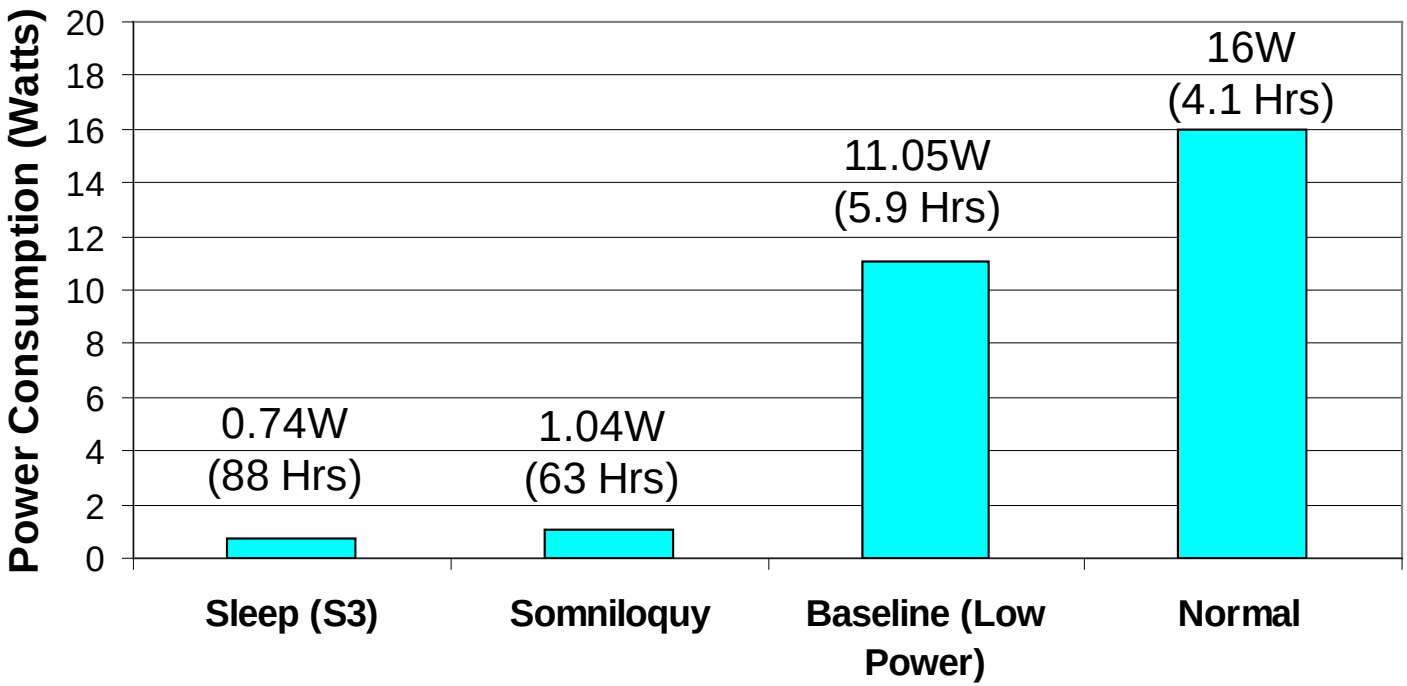
Rajesh Gupta, UCSD CSE; Calit2







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



GreenLight Project

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

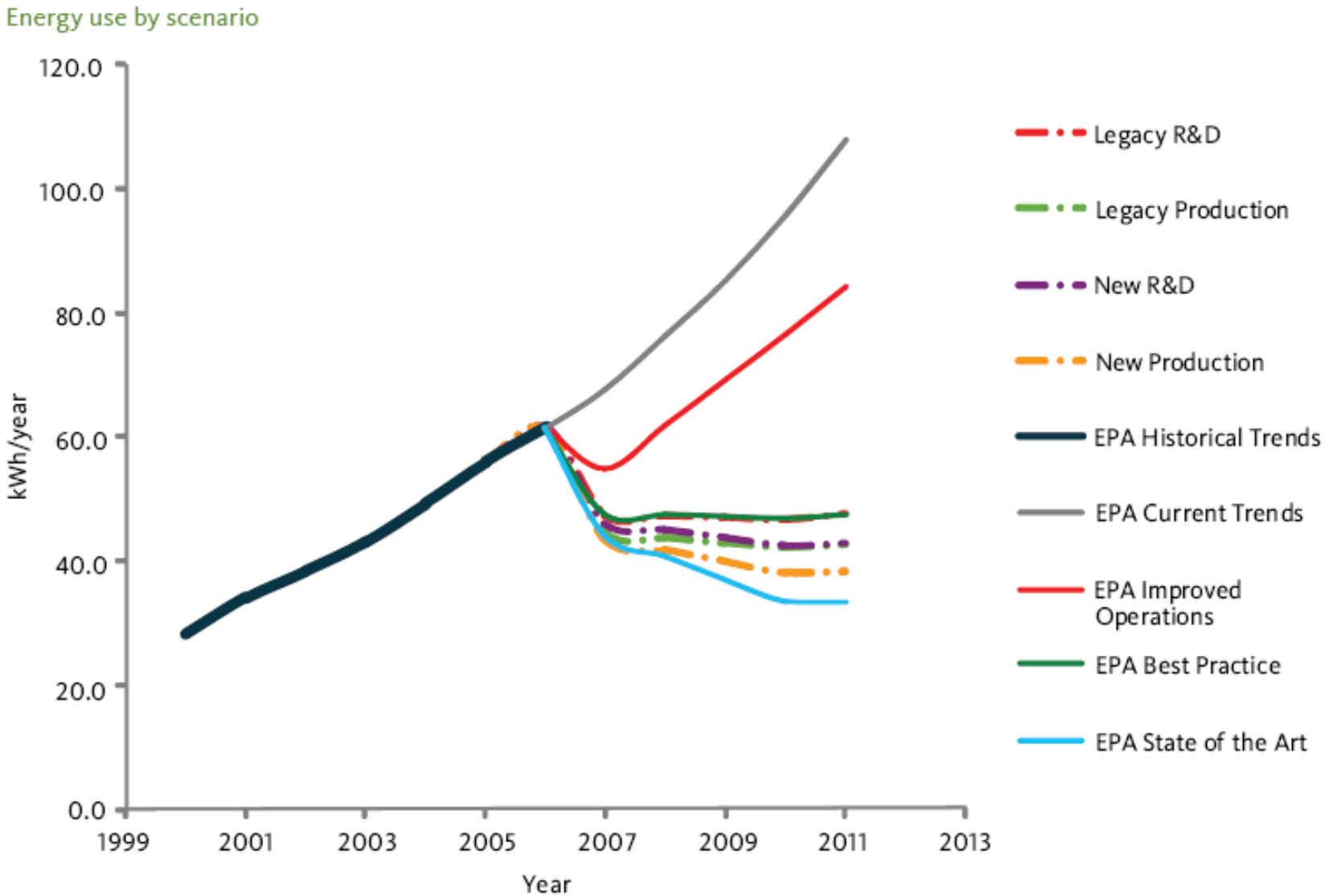
By John Fontana , Network World , 01/09/2008

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,

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



GreenLight Project

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

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**



Source: Tom DeFanti, Calit2; GreenLight PI

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

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**





CONVEY computer™ intel Sun microsystems
ARISTA NVIDIA World Leader in Visual Computing Technologies
KOI COMPUTERS Solutions Today with Tomarrow's Technology!

- **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**

NSF

GreenLight Project

it²

Source: Tom DeFanti, Calit2; GreenLight PI

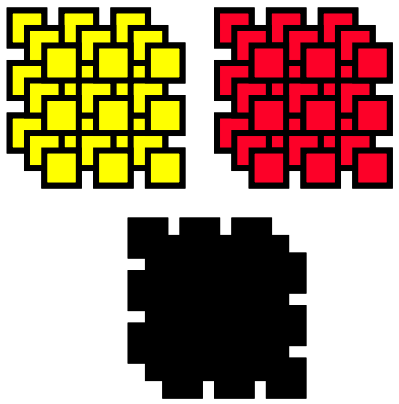
Research Needed on How to Deploy a Green CI



- **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

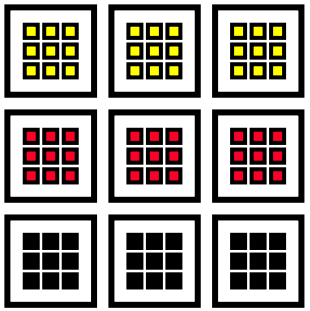
Virtualization at Cluster Level for Consolidation and Energy Efficiency

Source: Amin Vadhat, CSE, UCSD



Original Service

Usher



Virtualized Service

- 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

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)

- Optimal DPM for a 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
  - Measured Energy Savings of Up to 70% per Device

Dynamic Thermal Management (DTM)

- Workload Scheduling:
  - Machine learning for Dynamic Adaptation to get Best Temporal and Spatial Profiles with Closed-Loop Sensing
  - Proactive Thermal Management
  - Reduces Thermal Hot Spots by Average 60% with No Performance Overhead

GreenLight Project

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

Energy Efficiency by Exploiting Parallelism at the Processor Level

- **Multiprocessing as in Multiple Cores that can be Shutdown or Slowdown Based on Workloads**
- **Co-Processing that uses Specialized Functional Units for a Given Application**
- **The Challenge in Co-Processing is the Hand-Crafting that is Needed in Building such Machines**
  - **Application-Specific Co-Processor Constructed from Work-Load Analysis**
  - **The Co-Processor is Able to Keep up with the Host Processor in Exploiting Fine-Grain Parallel Execution Opportunities**

Source: Rajesh Gupta, UCSD CSE; Calit2

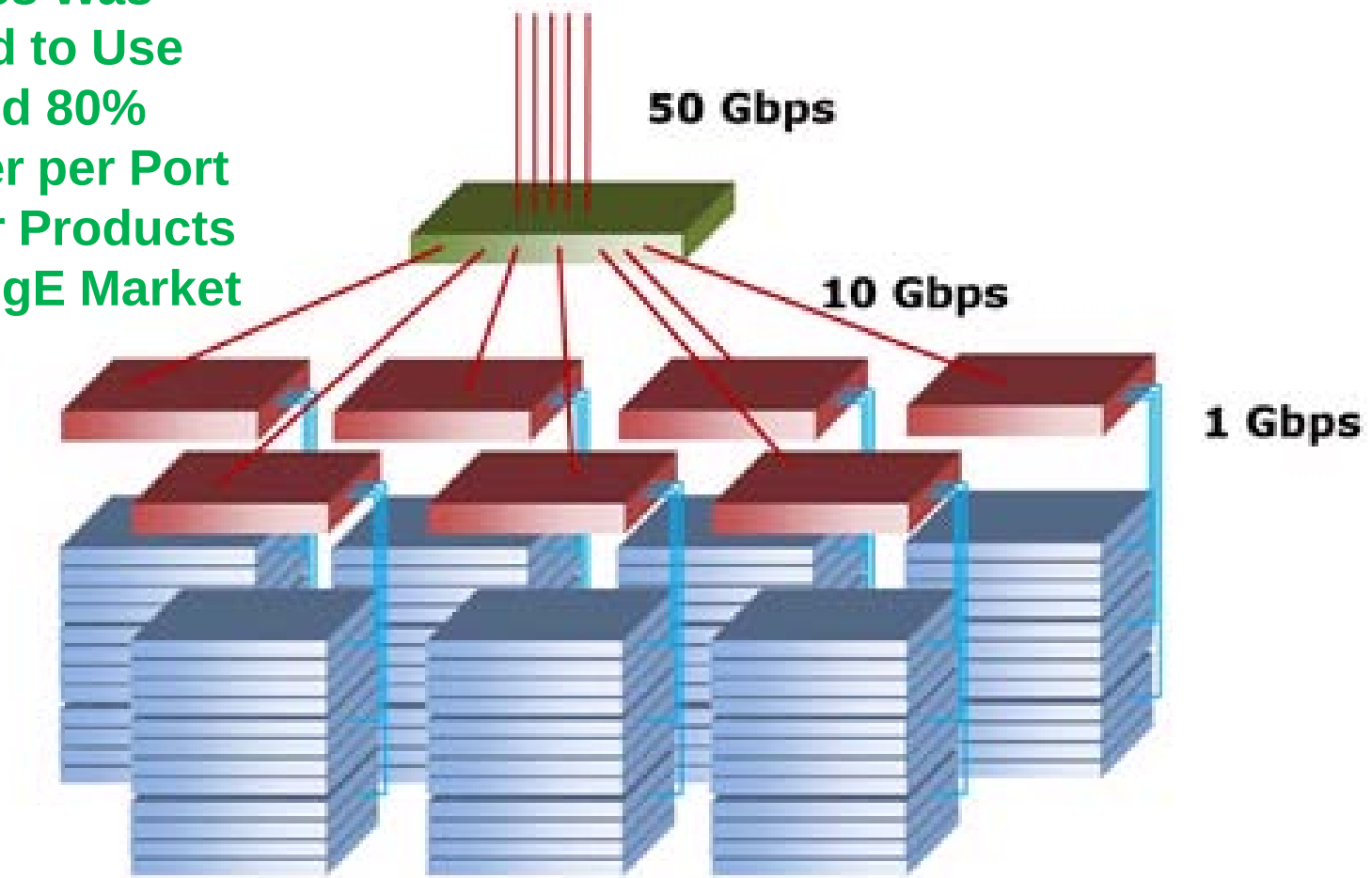
Improve Mass Spectrometry's Green Efficiency By Matching Algorithms to Specialized Processors

- **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

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).

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

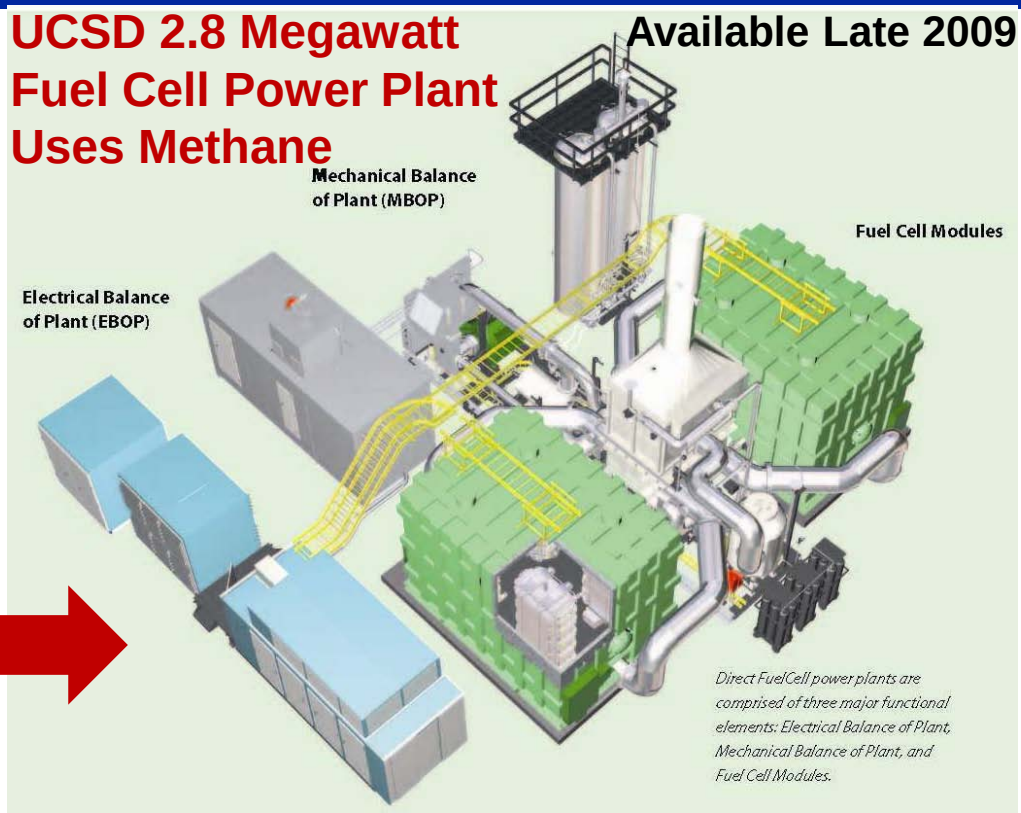
UCSD is Installing Zero Carbon Emission Solar and Fuel Cell DC Electricity Generators

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

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



Source: Tom DeFanti, Calit2; GreenLight PI

Toward "Zero Carbon" ICT
Green Cloud Computing and Storage

- **Purchasing Green Power Locally is Expensive with Significant Transmission Line Losses**
  - **Demand for Green Power Within Cities is Growing Dramatically**
  - **ICT Facilities Don't Need To Be Located In Cities**
- **But Most Renewable Energy Sites are Very Remote and Impractical to Connect to Electrical Grid**
  - **Can be Easily Reached by an Optical Network**
  - **Provide Independence from Electrical Utility**
  - **Savings in Transmission Line Losses (Up To 15% Alone)**
  - **Plus Carbon Offsets Can Pay for Moving ICT Facilities to Renewable Energy Site**
- **Calit2 is Discussing Partnering with Canada**
  - **Move a GreenLight Facility to Hydro Site in British Columbia**
  - **Link by 10Gbps Optical Fiber to Calit2—Offer to Remote Users**

GreenLight Project

Source: Bill St. Arnaud, CANARIE, Canada

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

Applying ICT – The Smart 2020 Opportunity for Reducing GHG Emissions by 7.8 $GtCO_2e$

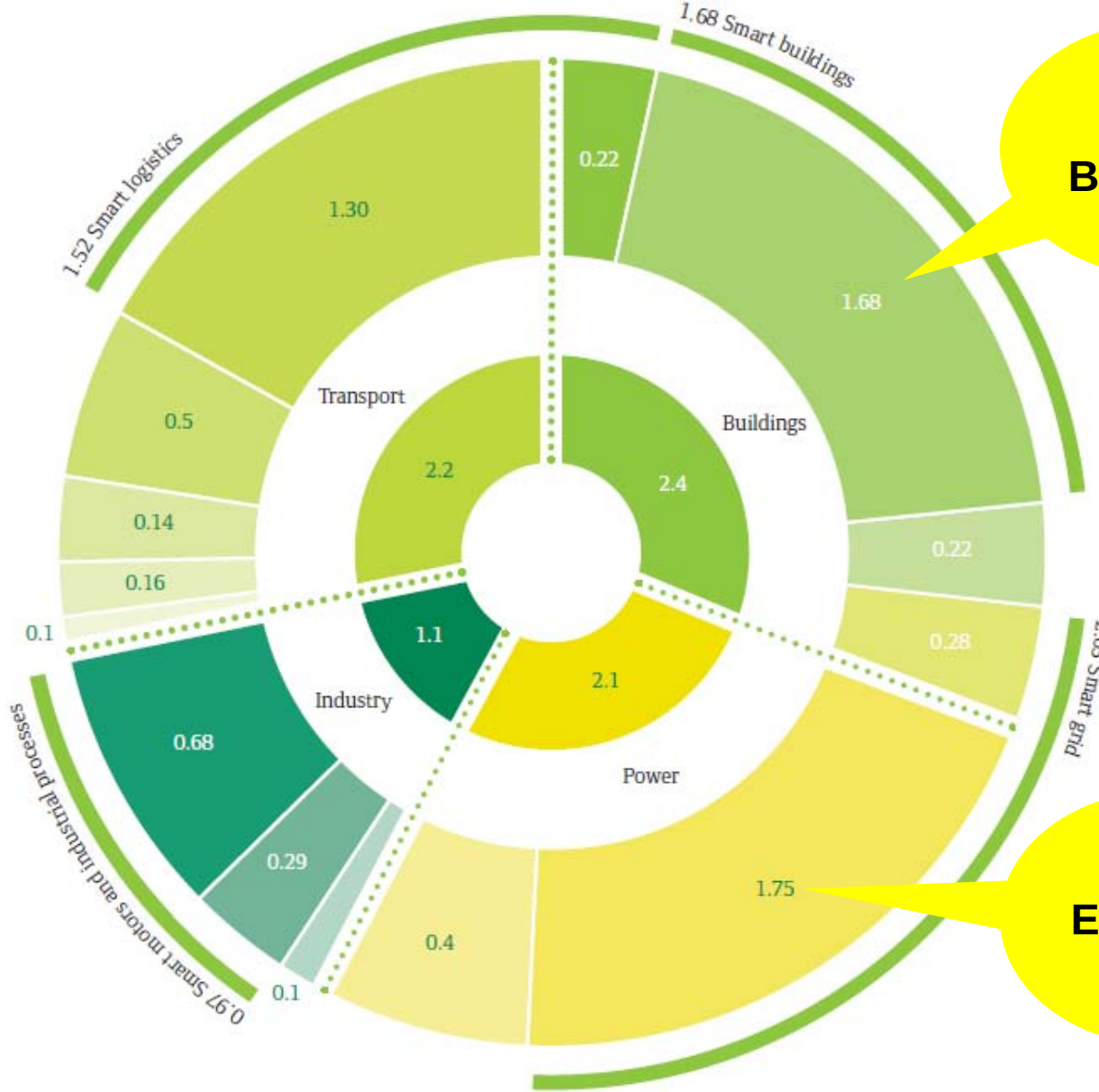
www.smart2020.org

Industry
- Smart motors
- Industrial process automation
- Dematerialisation* (reduce production of DVDs, paper)

Transport
- Smart logistics
- Private transport optimisation
- Dematerialisation (e-commerce, videoconferencing, teleworking)
- Efficient vehicles (plug-ins and smart cars)
- Traffic flow monitoring, planning and simulation

Buildings
- Smart logistics†
- Smart buildings
- Dematerialisation (teleworking)
- Smart grid‡

Power
- Smart grid
- Efficient generation of power, combined heat and power (CHP)



Smart Buildings

Smart Electrical Grid

Recall Total ICT 2020 Emissions are 1.43 $GtCO_2e$

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Next Stage: Developing Greener Smart Campuses Calit2 (UCSD & UCI) Prototypes

- **Coupling the Internet and the Electrical Grid**
  - Choosing non-GHG Emitting Electricity Sources
  - Measuring Demand at Sub-Building Levels
  - Reducing Local Energy Usage via User Access Thru Web
- **Transportation System**
  - Campus Wireless GPS Low Carbon Fleet
  - Green Software Automobile Innovations
  - Driver Level Cell Phone Traffic Awareness
- **Travel Substitution**
  - Commercial Teleconferencing
  - Next Generation Global Telepresence

Student Video -- UCSD Living Laboratory for Real-World Solutions
www.gogreentube.com/watch.php?v=NDc4OTQ1 on UCSD

UCI Named 'Best Overall' in Flex Your Power Awards
www.today.uci.edu/news/release_detail.asp?key=1859

International Symposia on Green ICT: Greening ICT and Applying ICT to Green Infrastructures

CUBIN

Symposium on Sustainability of the Internet and ICT

THE UNIVERSITY OF MELBOURNE

November 25 & 26, 2008, The University of Melbourne

Webcasts Available at:
www.calit2.net/newsroom/article.php?id=1456

Greening the Internet Economy
ICT & GLOBAL CHANGE

California Public Utilities Commission

Calit2

Co-Hosted By Calit2 & CPUC

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