

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

**Director, California Institute for Telecommunications and Information
Technology**

Harry E. Gruber Professor,

**Dept. of Computer Science and Engineering
Jacobs School of Engineering, UCSD**



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 CO₂e 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.

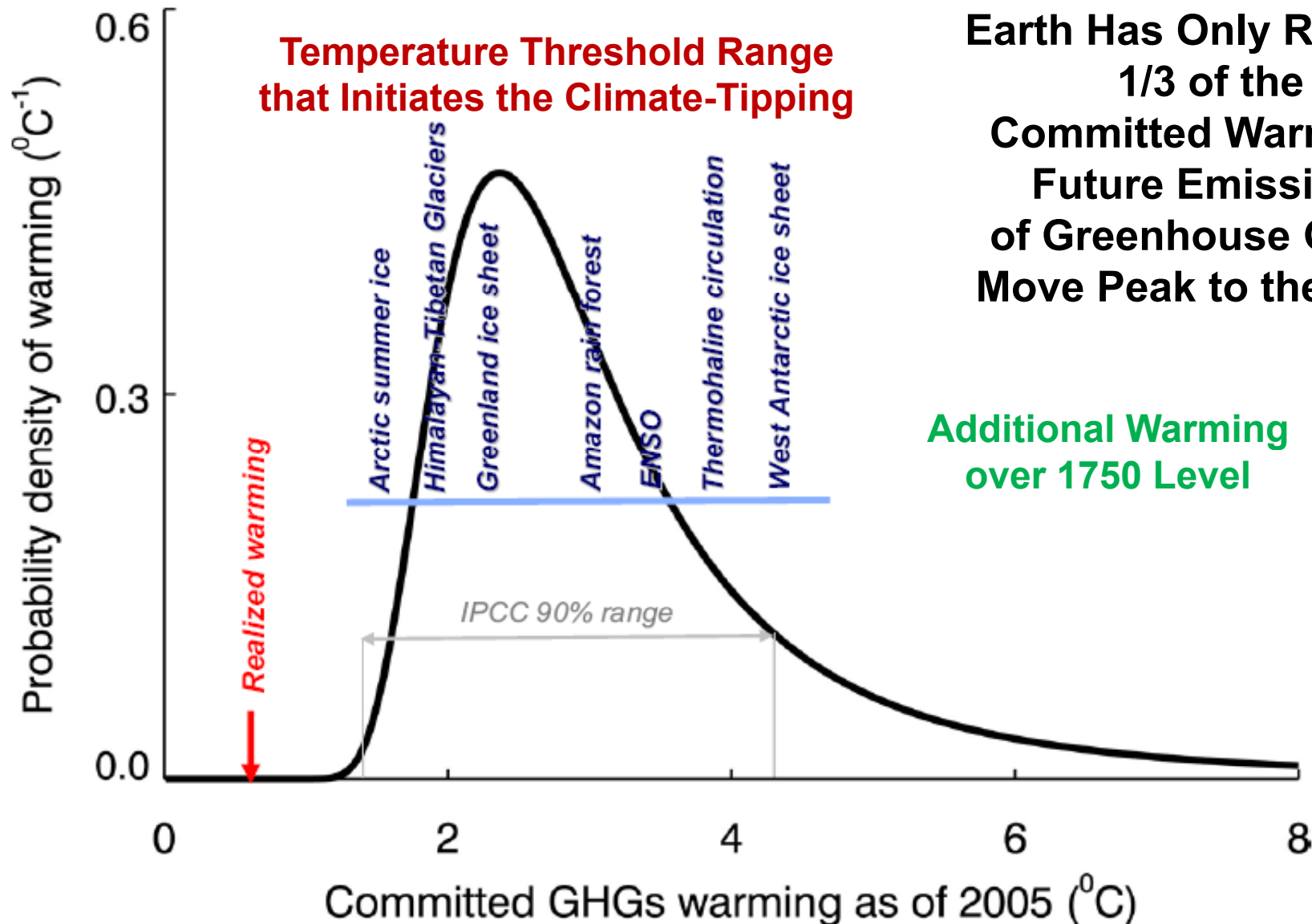
SMART 2020: Enabling the
low carbon economy in the
information age

THE CLIMATE GROUP



GeSI
GLOBAL e-SUSTAINABILITY
INITIATIVE

The Planet is Already Committed to a Dangerous Level of Warming



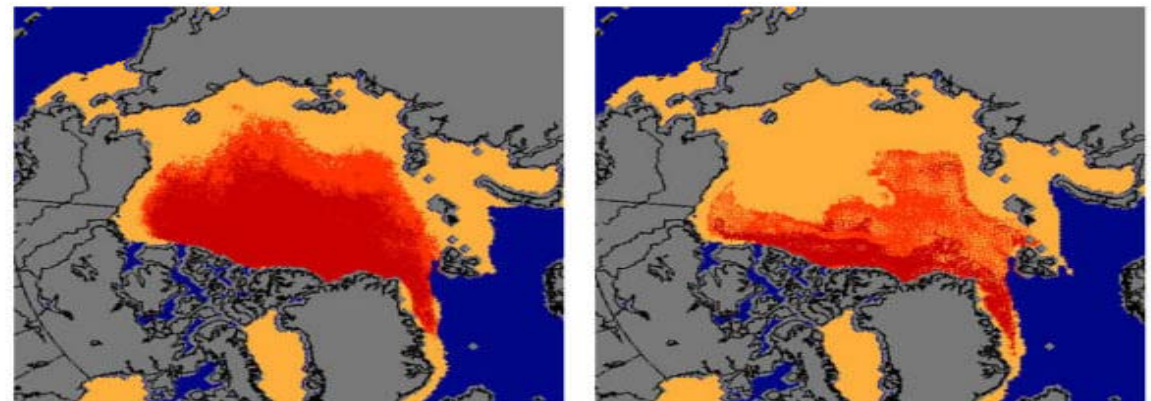
V. Ramanathan and Y. Feng, Scripps Institution of Oceanography, UCSD
September 23, 2008

www.pnas.org/cgi/doi/10.1073/pnas.0803838105

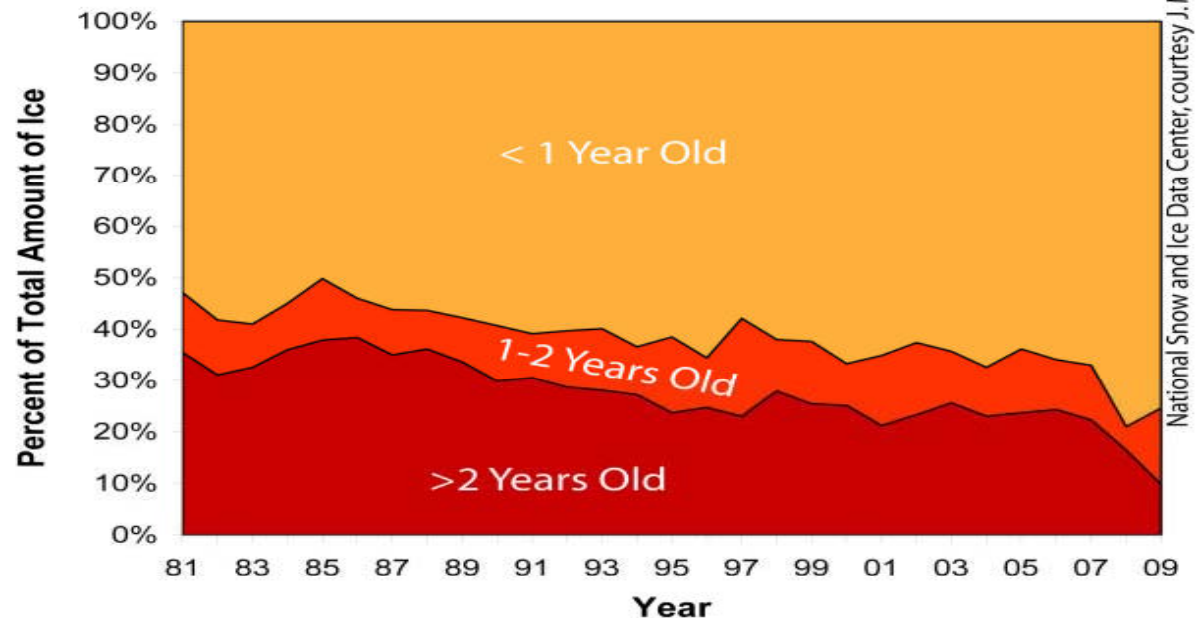
Arctic Summer Ice is Rapidly Decreasing

“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

End of February Arctic Sea Ice Age
1981-2000 Median 2009



Legend for ice age categories:
Yellow: First year ice (< 1 Year Old)
Orange: Second year ice (1-2 Years Old)
Red: Older ice (> 2 Years Old)



National Snow and Ice Data Center, courtesy J. Maslanik and C. Fowler, Univ. Colorado

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

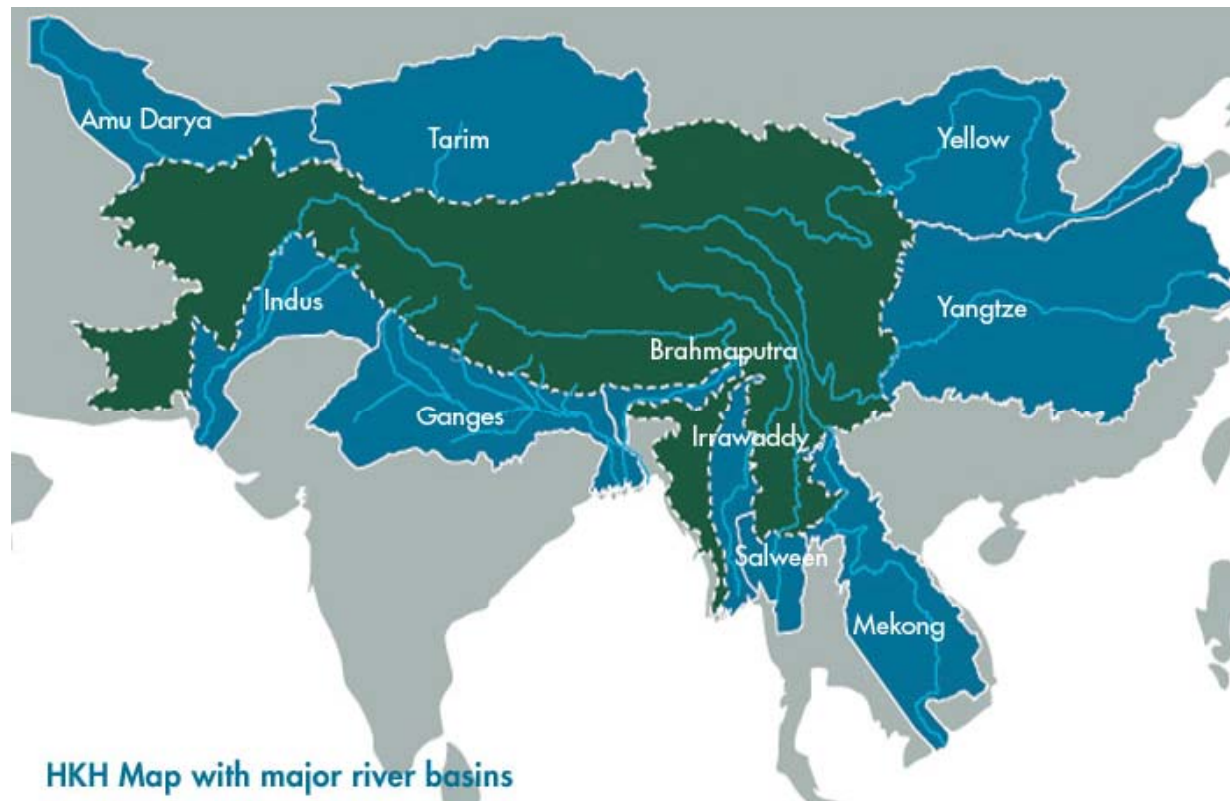


**“Water Towers of Asia”
Impact
40% of the
World’s Population**

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

Ice, Snow, and Water

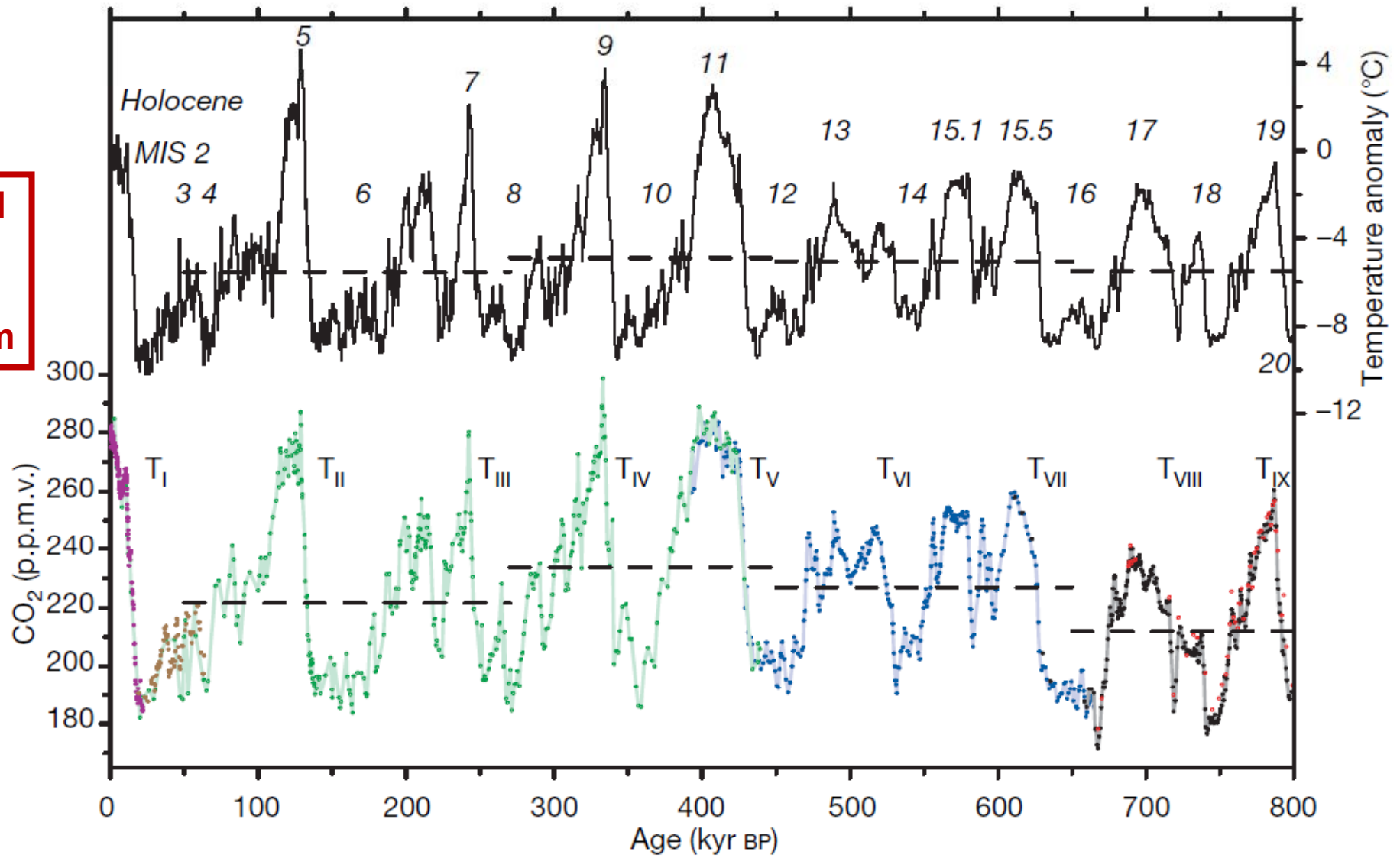
Impacts of Climate Change on California and Himalayan Asia



HKH Map with major river basins



Antarctic Ice Cores Show CO₂ and Temperature Oscillations Over Last 800,000 Years

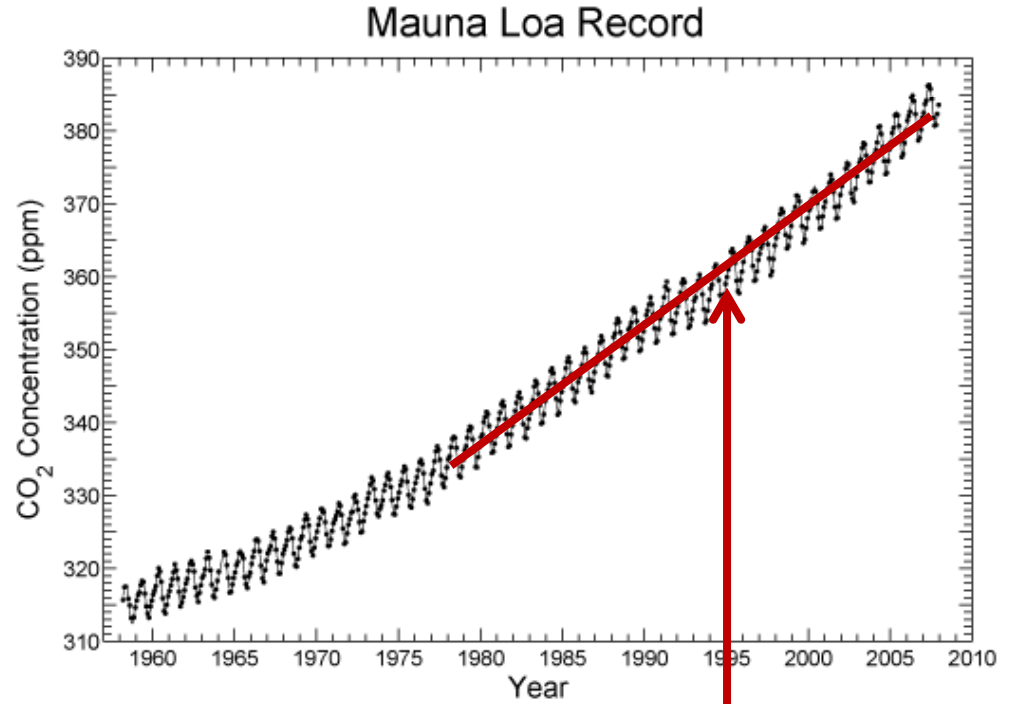
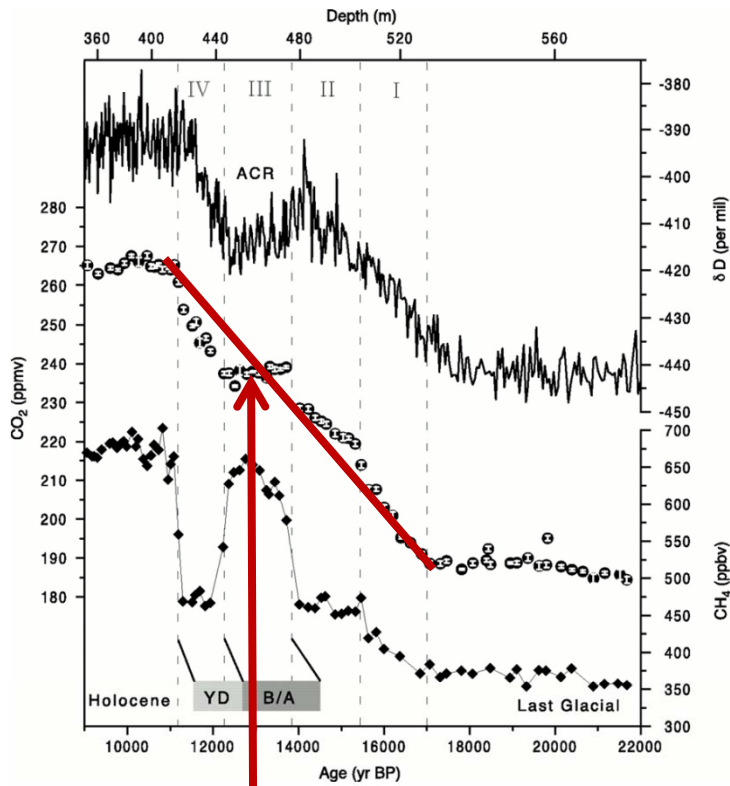


Vertical Range
170 to
300 ppm



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

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

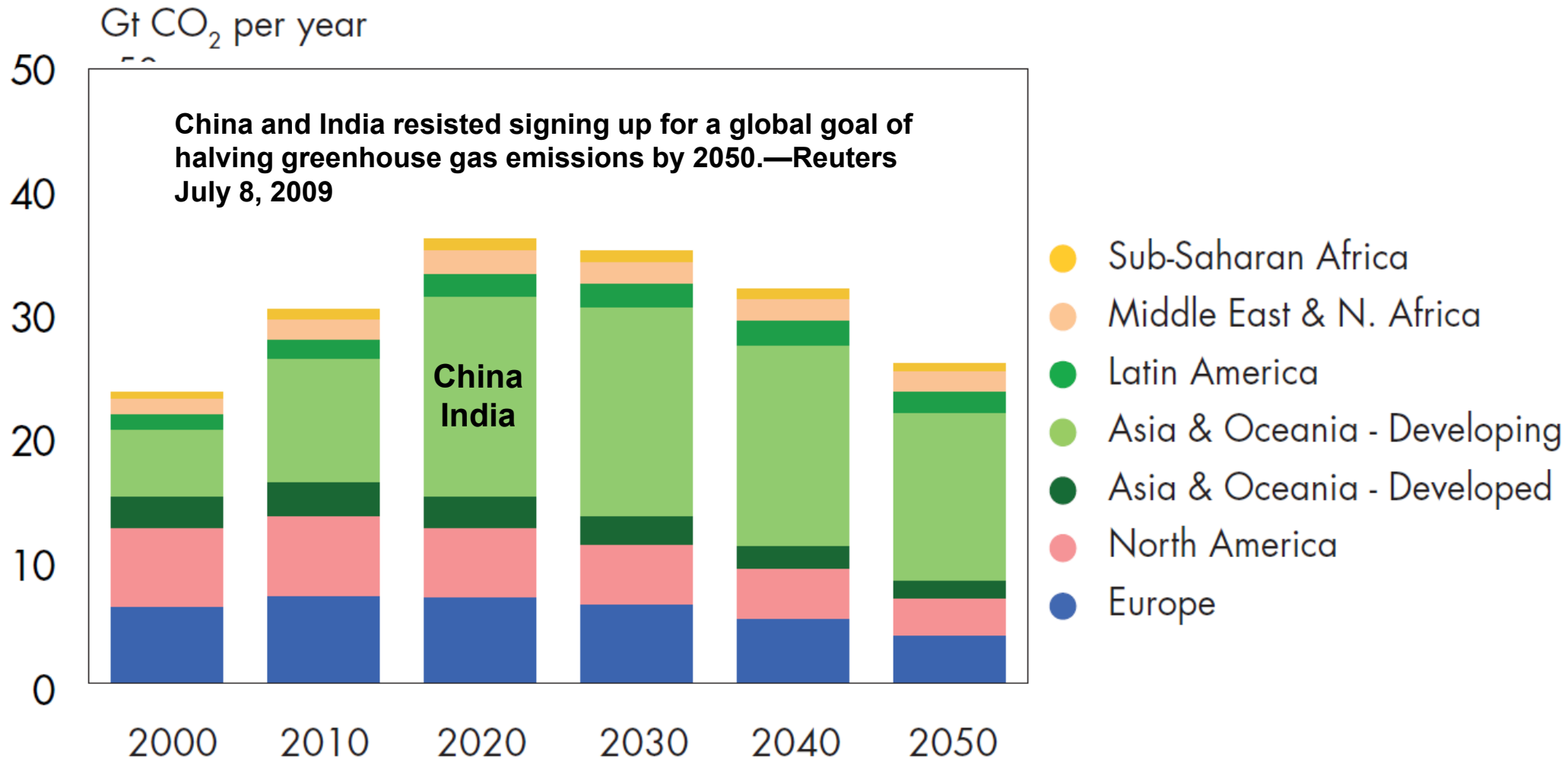


CO² Rose From 185 to 265ppm (80ppm) in 6000 years or 1.33 ppm per Century

CO² Has Risen From 335 to 385ppm (50ppm) in 20 years or 2.5 ppm per Year

CO₂ Emissions From Energy in an Aggressive CO₂ Emission Reduction Scenario

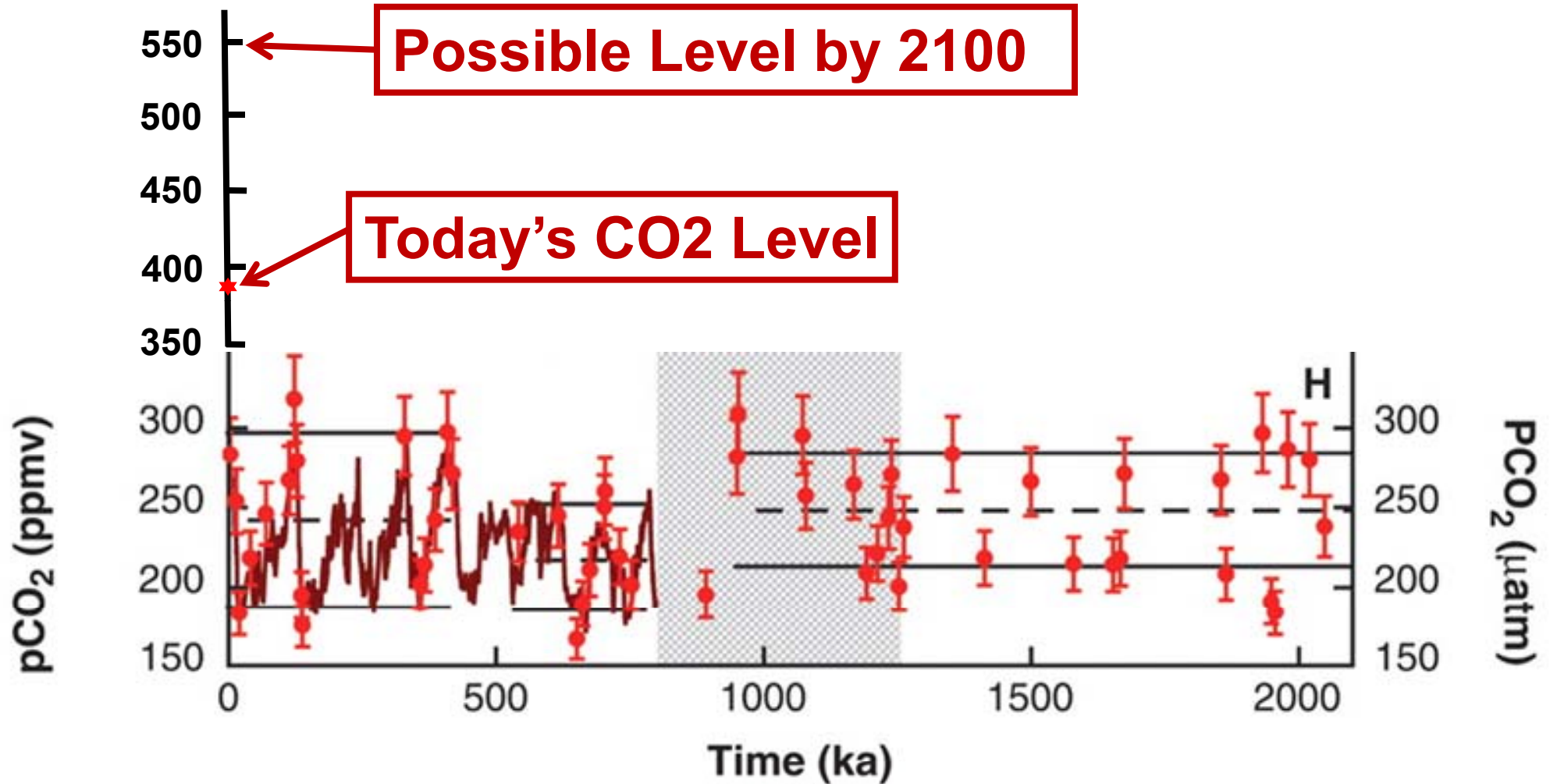
www-static.shell.com/static/public/downloads/brochures/corporate_pkg/scenarios/shell_energy_scenarios_2050.pdf



Estimated CO₂ Level in 2100 is 550ppm

Ice Core Record Has Been Extended Using Plankton: Today's CO₂ is Higher Than in Last 2 Million Years!

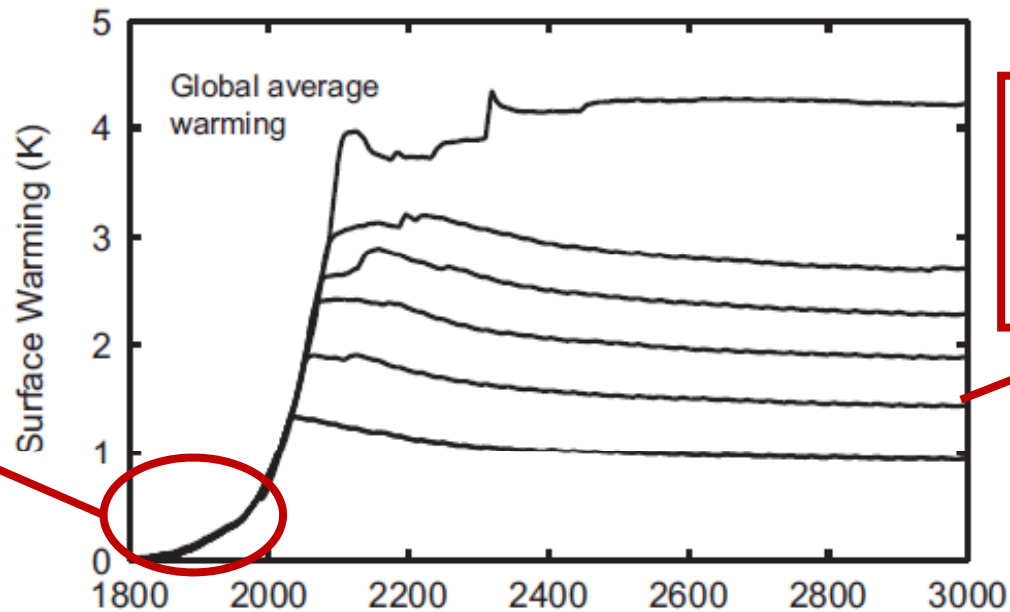
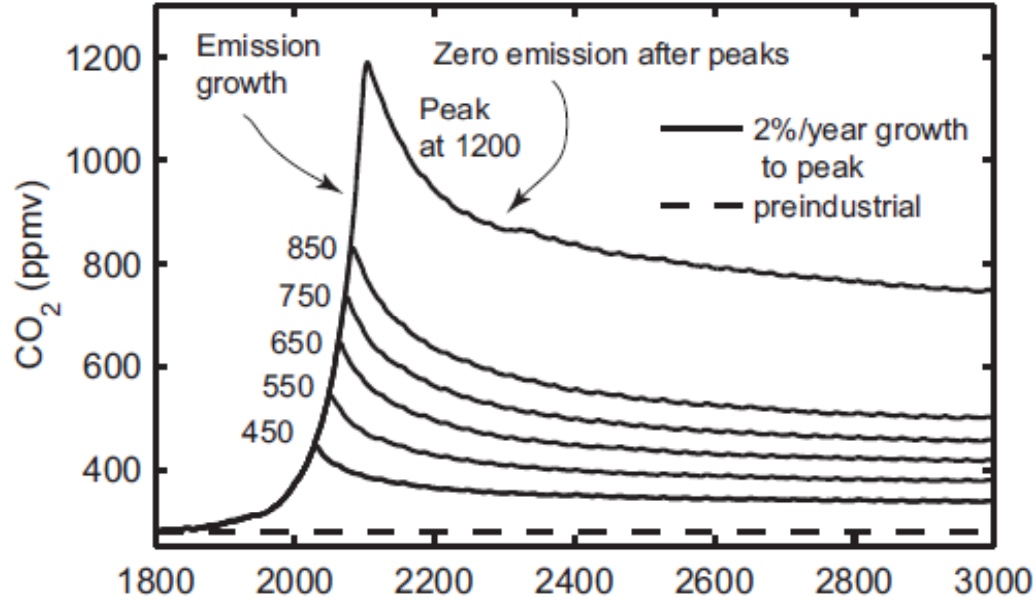
Hönisch, et al. Science Science 19 June 2009 Vol. 324. pp. 1551 - 1554



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
CO₂ Increases
to a Maximum
and Then Emissions
Abruptly Stop**



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



THOMAS L.
FRIEDMAN

*Hot, Flat,
and Crowded*

WHY WE NEED A GREEN REVOLUTION —
AND HOW IT CAN RENEW AMERICA



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.

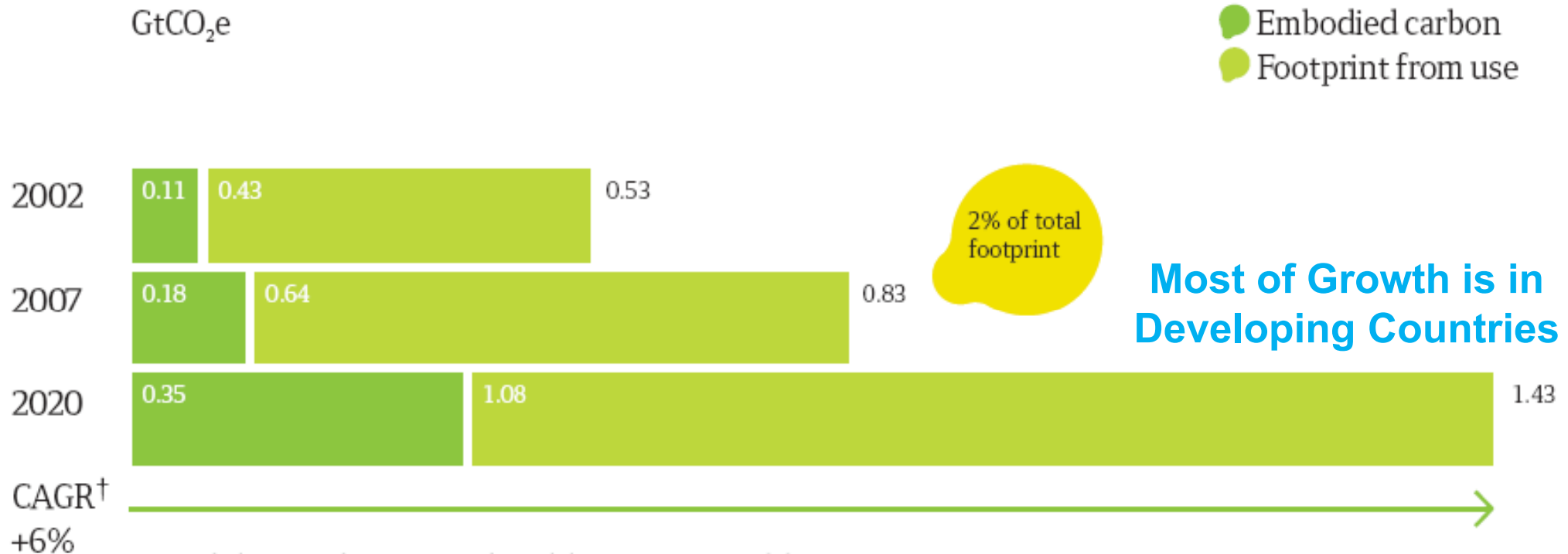
SMART 2020: Enabling the low carbon economy in the information age



www.smart2020.org

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

But ICT Emissions are Growing at 6% Annually!



*ICT includes PCs, telecoms networks and devices, printers and data centres.

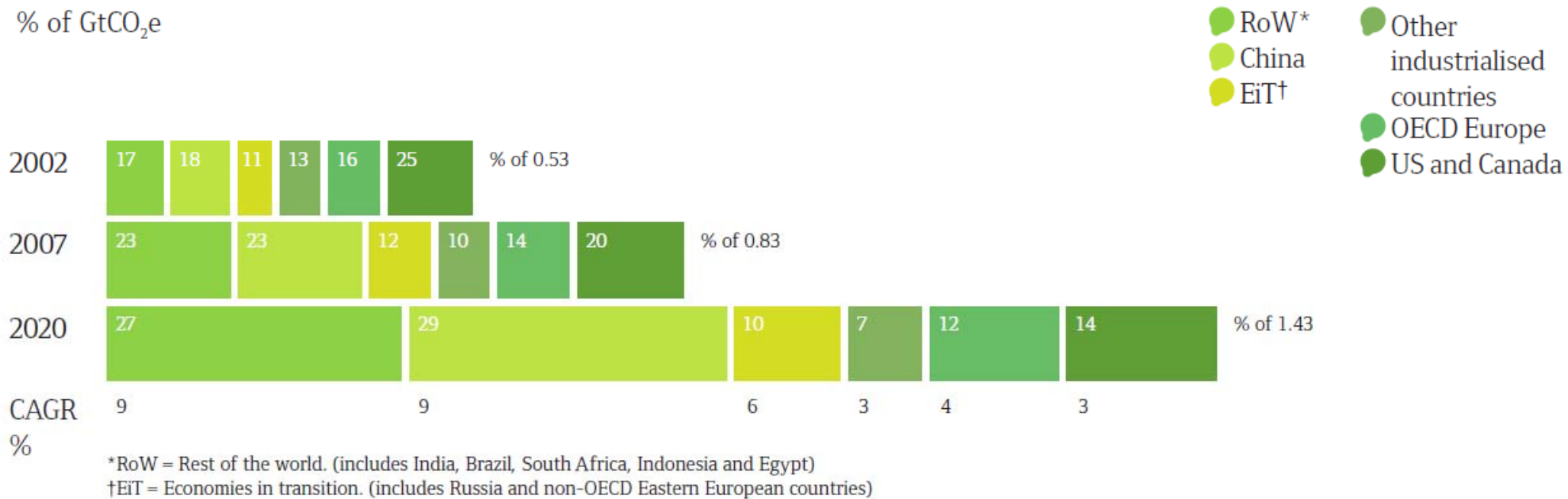
†Compounded annual growth rate.

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

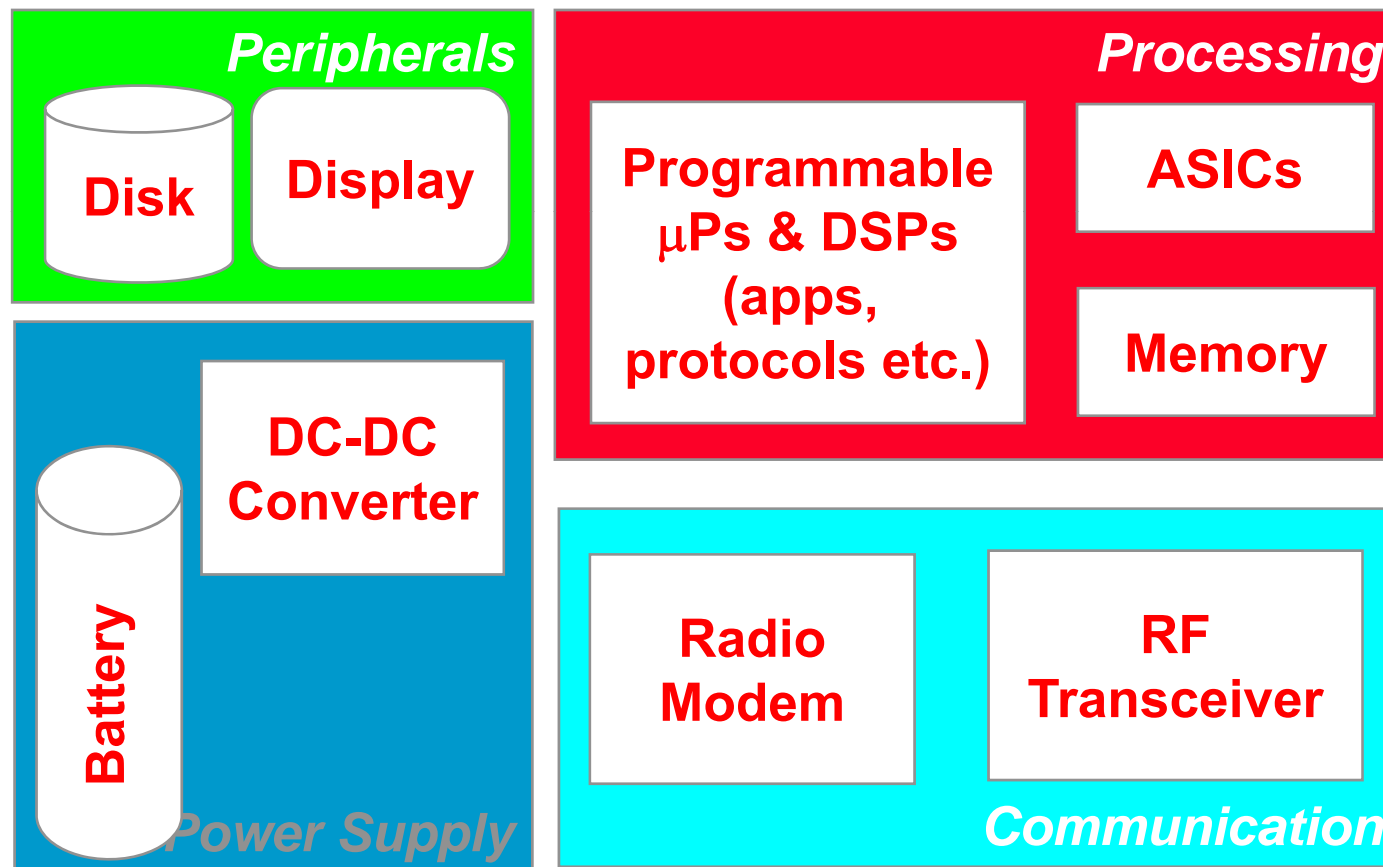
U.S. and Canada Together Fall From 25% to 14% of Global ICT Emissions by 2020



Can We Make Laptops More Energy Efficient?

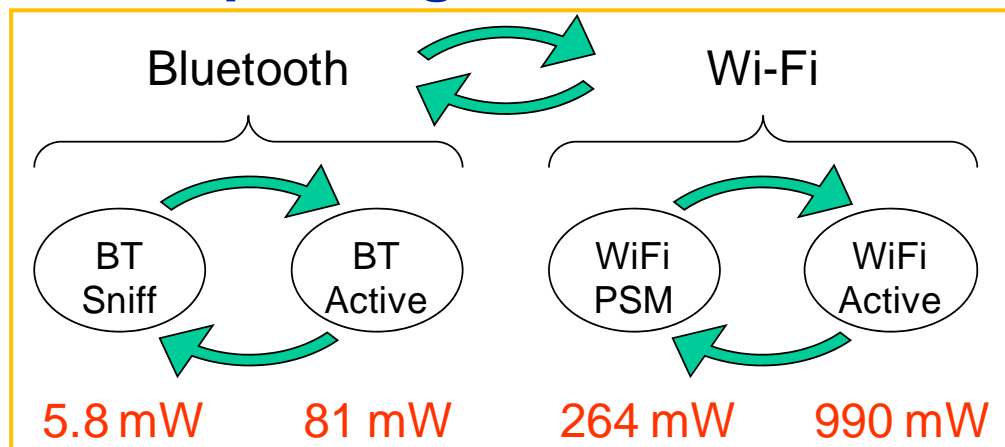
This is a System Level Concern

- 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



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



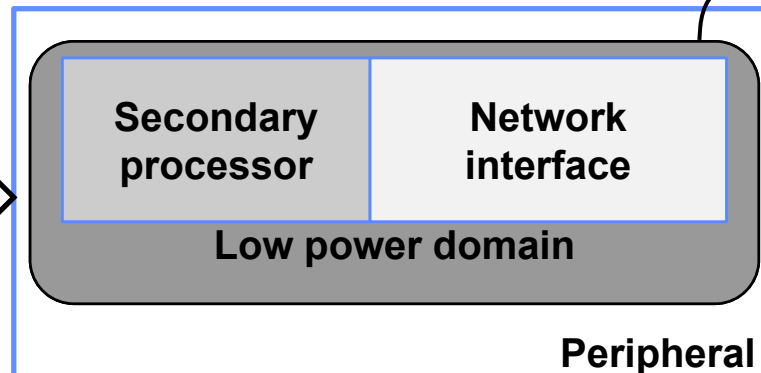
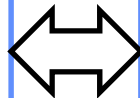
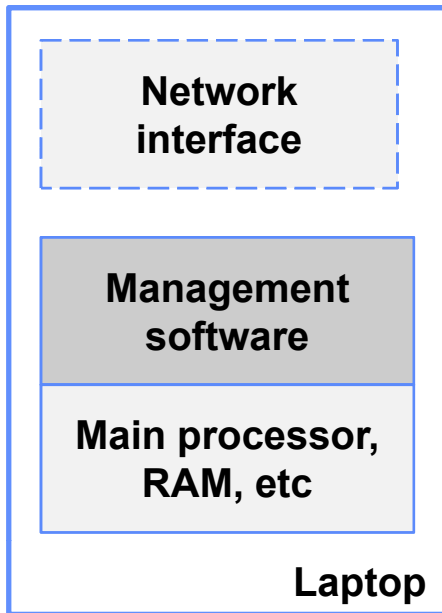
**Driven by
Accurate and Timely
Sensor Data
That Push
the Available Slack
to Thermal Limits**

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

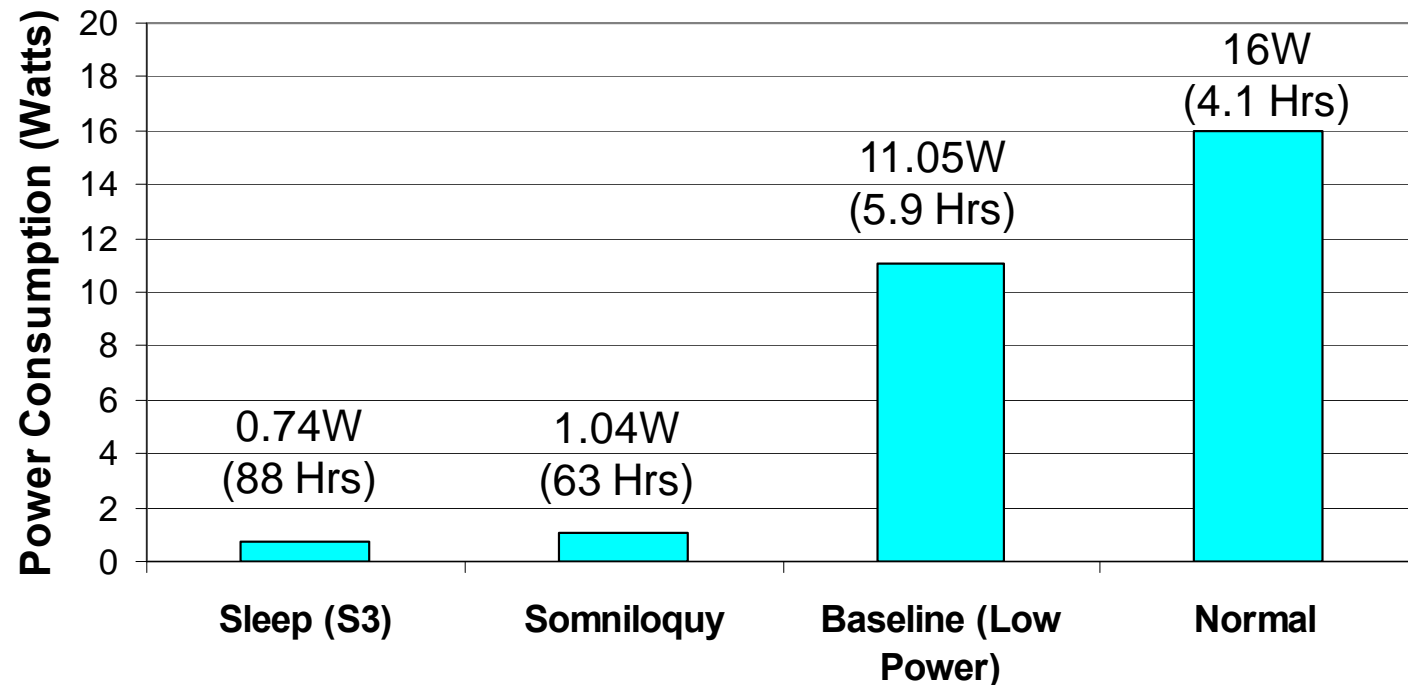
Increasing Laptop Energy Efficiency: Putting Machines To Sleep Transparently

Rajesh Gupta, UCSD CSE; Calit2



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

IBM X60 Power Consumption



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

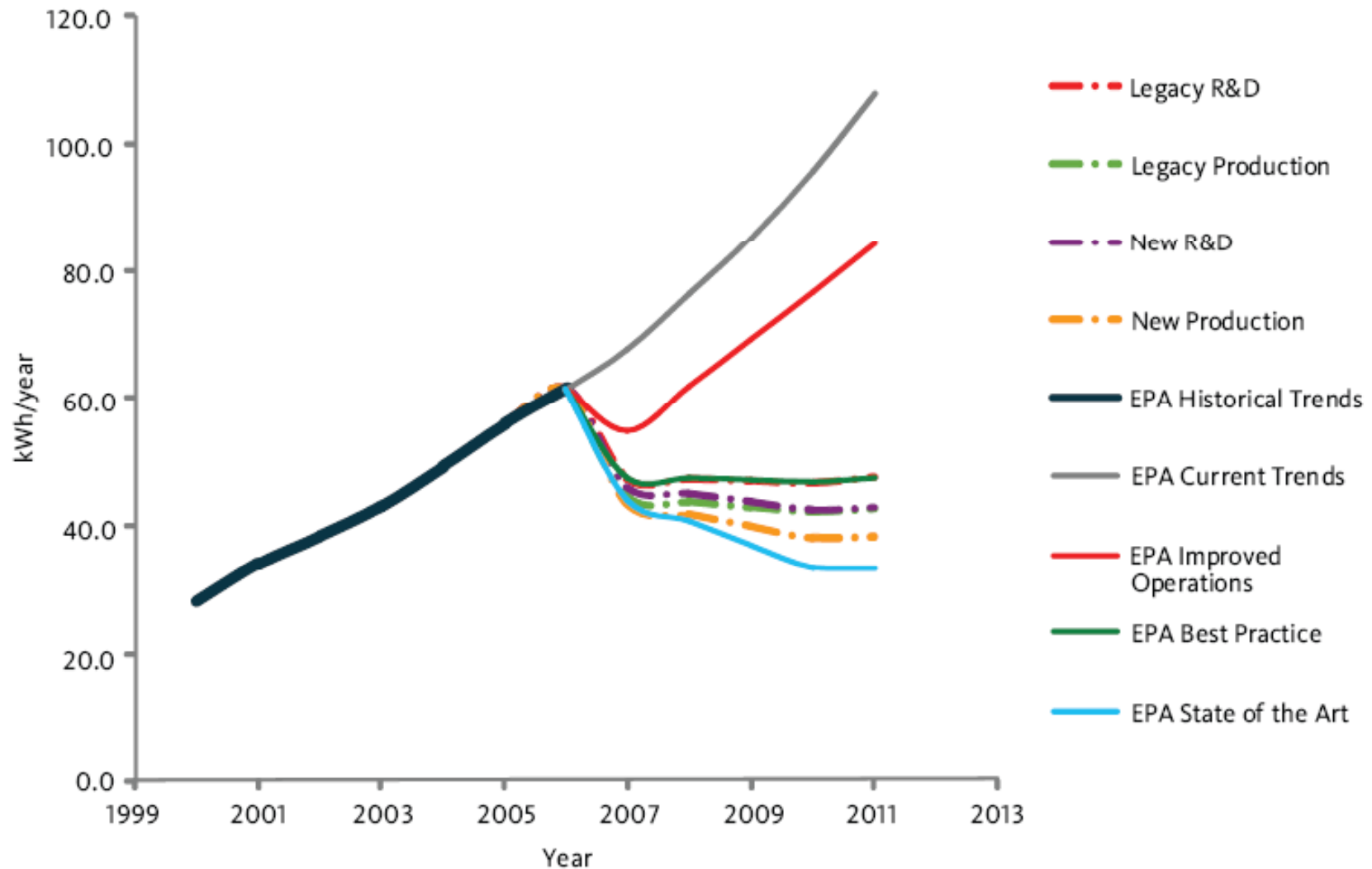
IBM Project Big Green

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

Energy use by scenario



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



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



Research Needed on How to Deploy a **Green CI**



GreenLight Project



MRI

University of California, San Diego

Home Instrument Research Projects People Learn More

Upcoming Events

Sept 19, 2008
California-Canada Summit on
Green IT and Next Generation
Internet

October 27, 2008
Third Summit of the Canada-
California Strategic Innovation
Partnership, Montreal, Quebec,
Canada

January 22-23rd
Greening of the Internet
Economy hosted by Calit2 - TBA

Project and Community Slides

Calit2: Tom DeFanti's GreenLight
Project Overview

Community: McKinsey Report on
Revolutionizing Data Center
Efficiency

Instrument

The GreenLight Instrument will enable 'green' data decisions by offering a suite of physical-layer architectures, exposed via advanced middleware to our domain science users in biology and geoscience.

There are 5 levels of possible green optimization in the GreenLight Instrument:

1. **The container as the controlled environment:** Black Box with instrumented rack space unlike any found on campuses, different from and more "contained" than is typical for conventional computer centers and faculty "closet" clusters. It can measure temperature at 40 points in the air stream (5 spots on 8 racks), internal humidity and temperature at the Sensor module, external temperature and humidity, incoming and exiting water temperature and power utilization in each of the 8 racks;



- **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

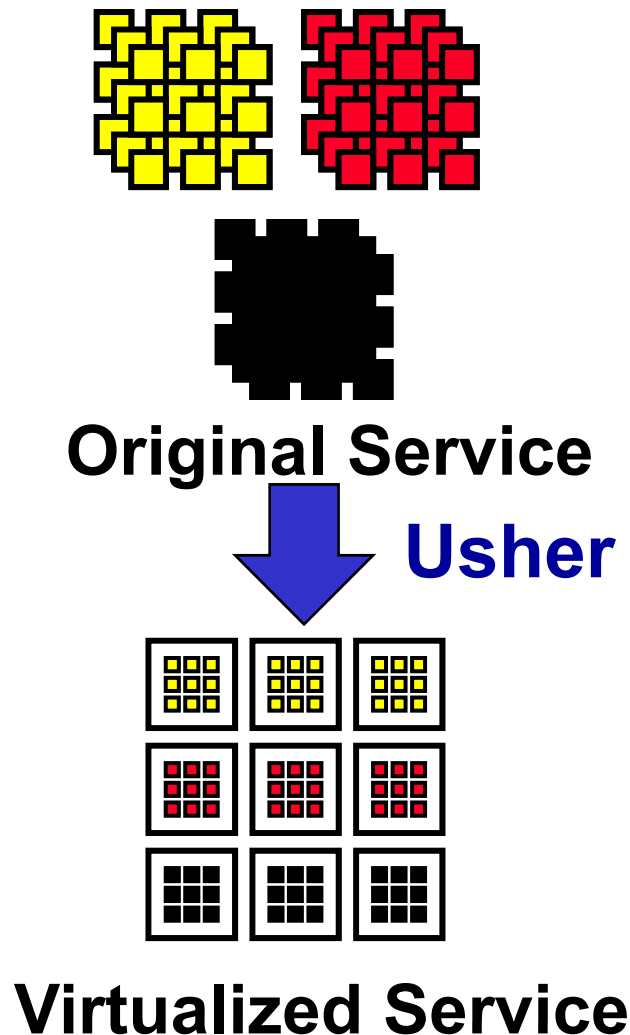


GreenLight Project

<http://greenlight.calit2.net>

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

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



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

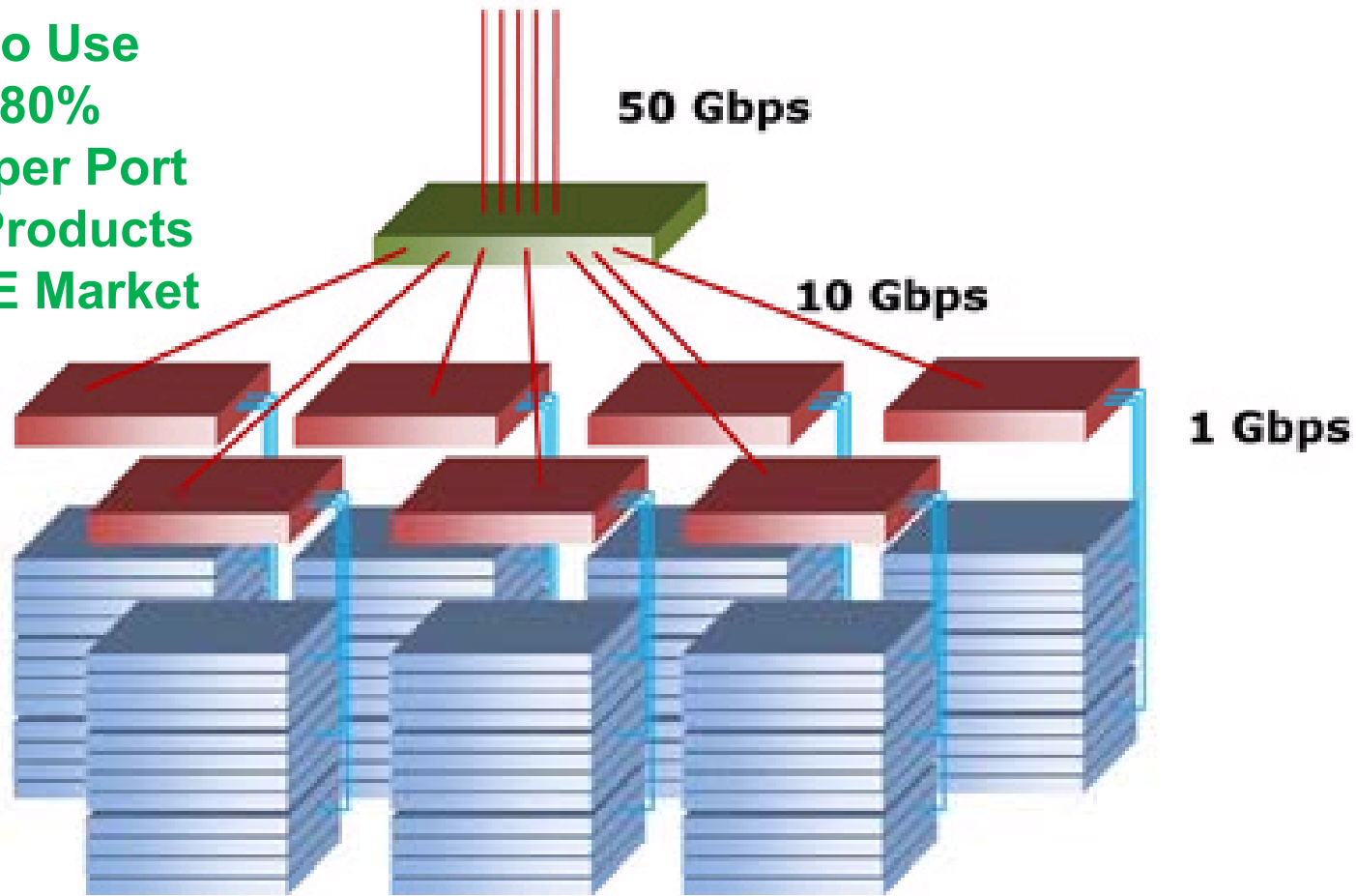
Improve Mass Spectrometry's Green Efficiency By Matching Algorithms to Specialized Processors

- 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).

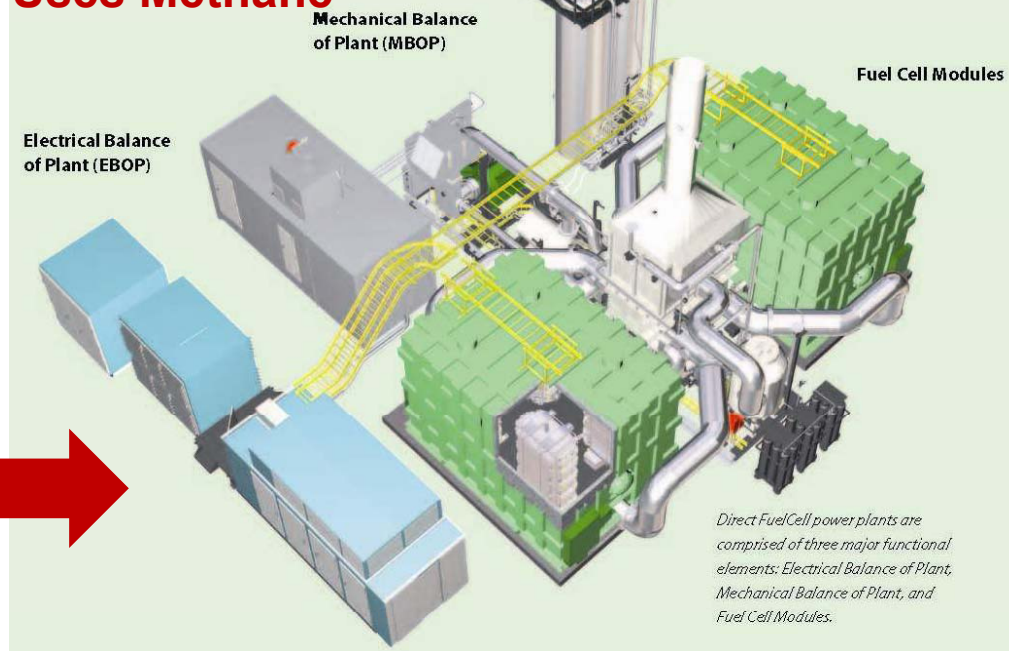
UCSD is Installing Zero Carbon Emission Solar and Fuel Cell DC Electricity Generators

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



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** **Sun Box <200kWatt**
 - **Both Plug into the AC Power Grid**
 - **Can We Use DC Directly (With or Without the AC Grid)?**
- **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**



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

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**

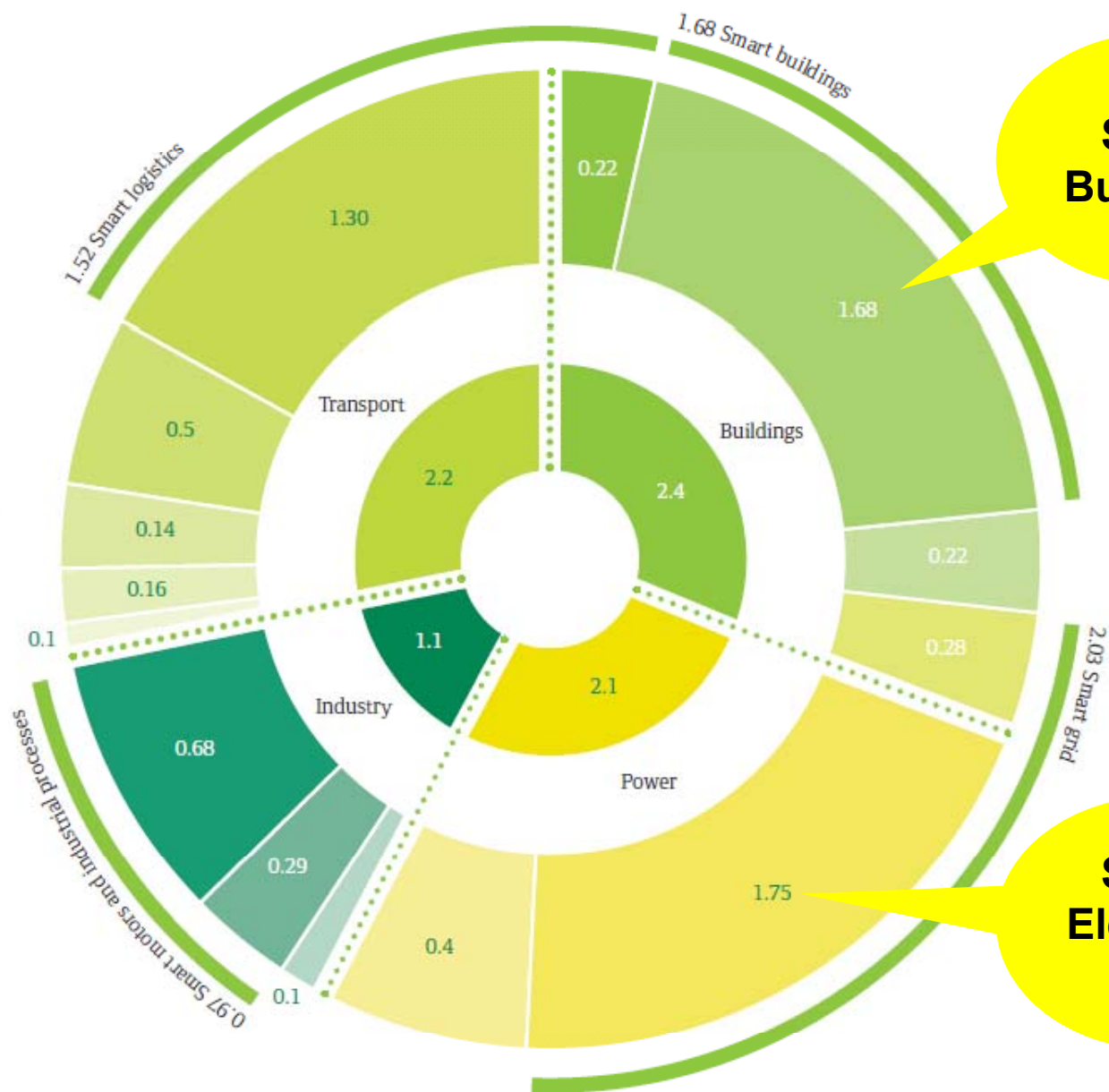
* Smart 2020 United States Report Addendum

www.smart2020.org

Applying ICT – The Smart 2020 Opportunity for Reducing GHG Emissions by 7.8 GtCO₂e

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 GtCO₂e



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



Symposium on Sustainability of the Internet and ICT

November 25 & 26, 2008, The University of Melbourne



Webcasts Available at:

www.calit2.net/newsroom/article.php?id=1456

January 22-23, 2009



Greening the
Internet Economy
ICT & GLOBAL CHANGE

California Public
Utilities Commission



Co-Hosted By Calit2 & CPUC



Calit2@UCSD

