EDUCAUSE CONFERENCE 2009
NOV. 3-6 DENVER
THE BEST THINKING IN HIGHER ED IT

Cyberinfrastructure in a Carbon-Constrained World

Bill St. Arnaud Larry Smarr

November 5, 2009

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EDUCAUSE

Abstract

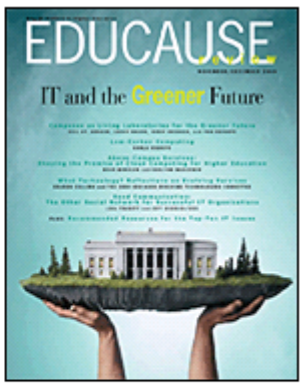
Greenhouse gas (GHG) emissions continue their relentless rise, even though the global CO2 level is already considerably higher than it has been on earth for over two million years. One of the significant contributors to increased GHG is the ITC industry itself, roughly equal to the emissions from the aviation industry. As universities researchers increasingly employ computational and cyberinfrastructure technologies, these very enablers of modern scientific discovery are coming into question because of their growing contributions to GHG emissions. As a result, some universities and R&E networks are starting to explore new types of computational and network architectures that not only benefit research, but also have reduced associated GHG emissions. Optical high speed research networks and distributed zero carbon cyberinfrastructure data centers with network virtualization, web services and grids will be a critical component of this emerging architecture. We review the trends and spotlight specific projects that offer hope for averting this cyber-carbon crisis.

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Based on an EDUCAUSE Review Article and Web Bonus

Current Issue — Volume 44, Number 6, November/December 2009

IT and the Greener Future



features

Campuses as Living Laboratories for the Greener Future

BILL ST. ARNAUD, LARRY SMARR, JERRY SHEEHAN, AND TOM DEFANTI

Institutional leaders need to reduce the campus carbon footprint by decreasing the emissions of their existing cyberinfrastructure while they simultaneously increase their use of cyberinfrastructure in areas such as intelligent infrastructure and dematerialization.

Web Bonus

For more on the science behind the current energy and climate change imperative and on the impact for colleges and universities from potential regulation, see:

Climate Change and Higher Education

BILL ST. ARNAUD, LARRY SMARR, JERRY SHEEHAN, AND TOM DEFANTI

Read online: http://www.educause.edu/library/erm0961

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http://net.educause.edu/ir/library/pdf/ERM0960.pdf

Science of Climate Change





Earth's Climate is Rapidly Entering a Novel Realm Not Experienced for Millions of Years

"Global Warming" Implies:

- **Gradual,**
- **Uniform,**
- **Mainly About Temperature,**
- **and Quite Possibly Benign.**

What's Happening is:

- **Rapid,**
- **Non-Uniform,**
- **Affecting Everything About Climate,**
- **and is Almost Entirely Harmful.**

John Holdren, Director Office of Science and Technology Policy
June 25, 2008

A More Accurate Term is 'Global Climatic Disruption'

This Ongoing Disruption Is:

- **Real Without Doubt**
- Mainly Caused by Humans
- Already Producing Significant Harm
- Growing More Rapidly Than Expected"

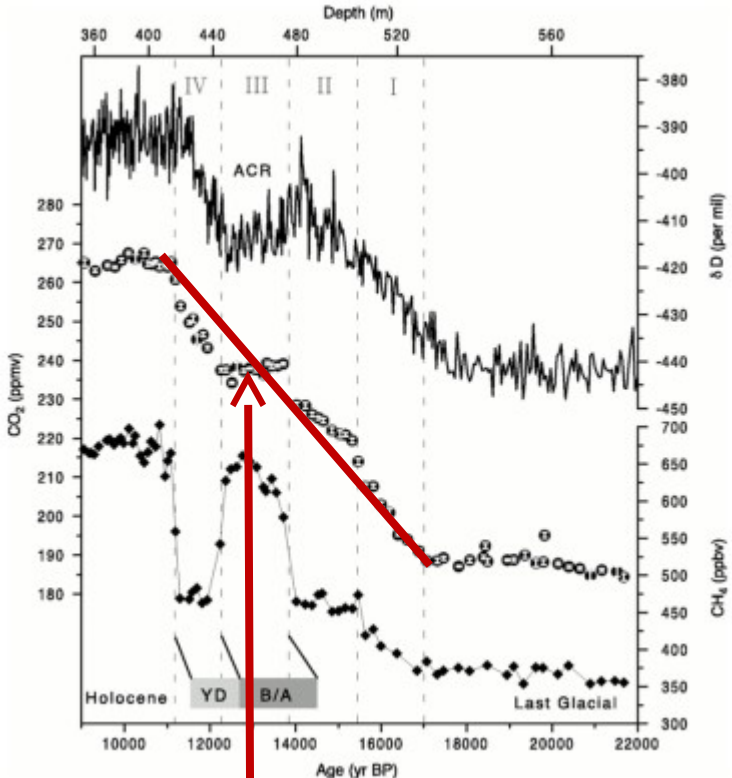


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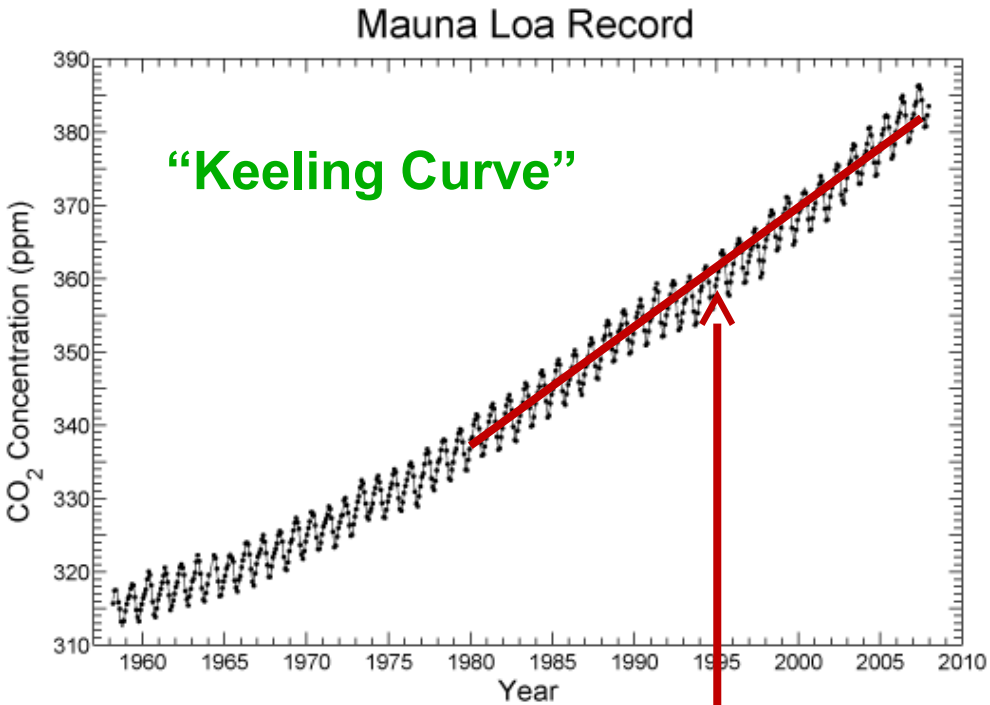
The Earth is Warming Over 100 Times Faster Today Than During the Last Ice Age Warming!

Monnin, et al., Science v. 291 pp. 112-114, Jan. 5, 2001.



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

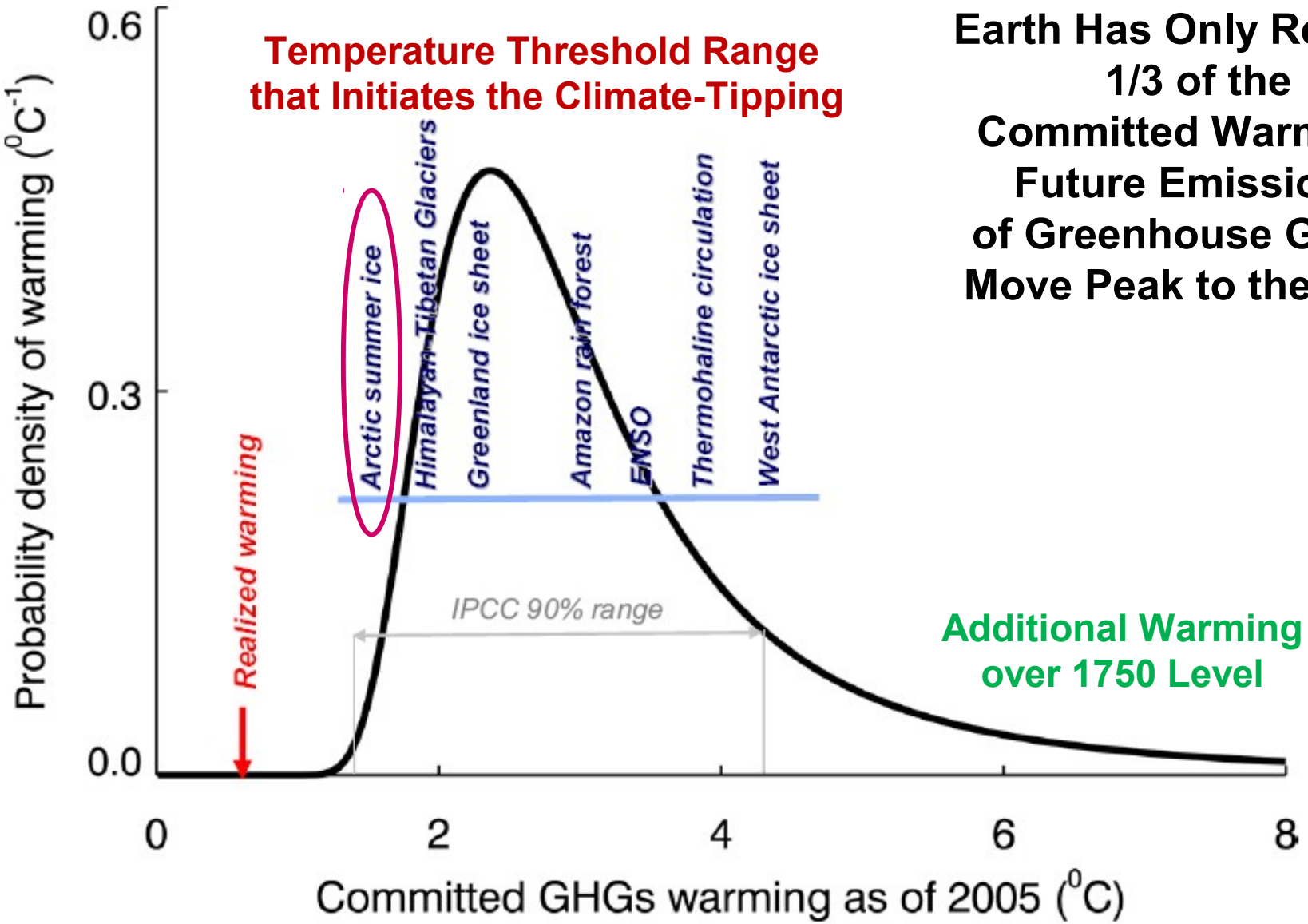


CO_2 Has Risen From 335 to 385ppm (50ppm) in 30 years or 1.6 ppm per Year

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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

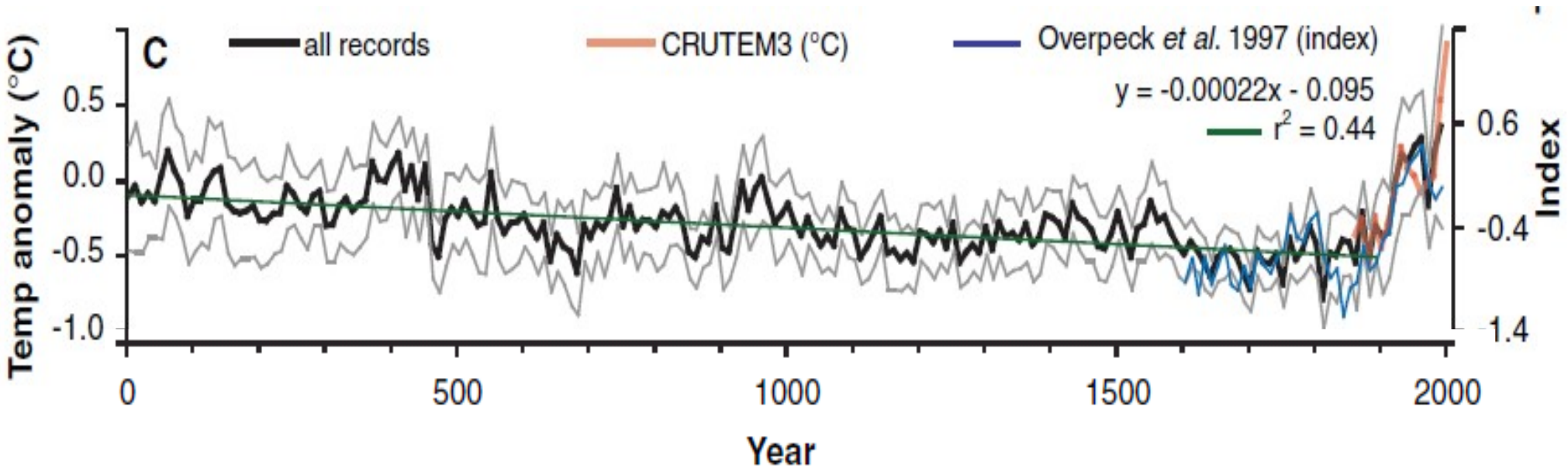
Additional Warming over 1750 Level

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

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

Global Climatic Disruption Example: The Arctic Sea Ice

"A pervasive cooling of the Arctic in progress 2000 years ago continued through the Middle Ages and into the Little Ice Age. It was reversed during the 20th century, with four of the five warmest decades of our 2000-year-long reconstruction occurring between 1950 and 2000. The most recent 10-year interval (1999–2008) was the warmest of the past 200 decades."



Mean of all records transformed to summer temperature anomaly relative to the 1961–1990 reference period, with first-order linear trend for all records through 1900 with 2 standard deviations

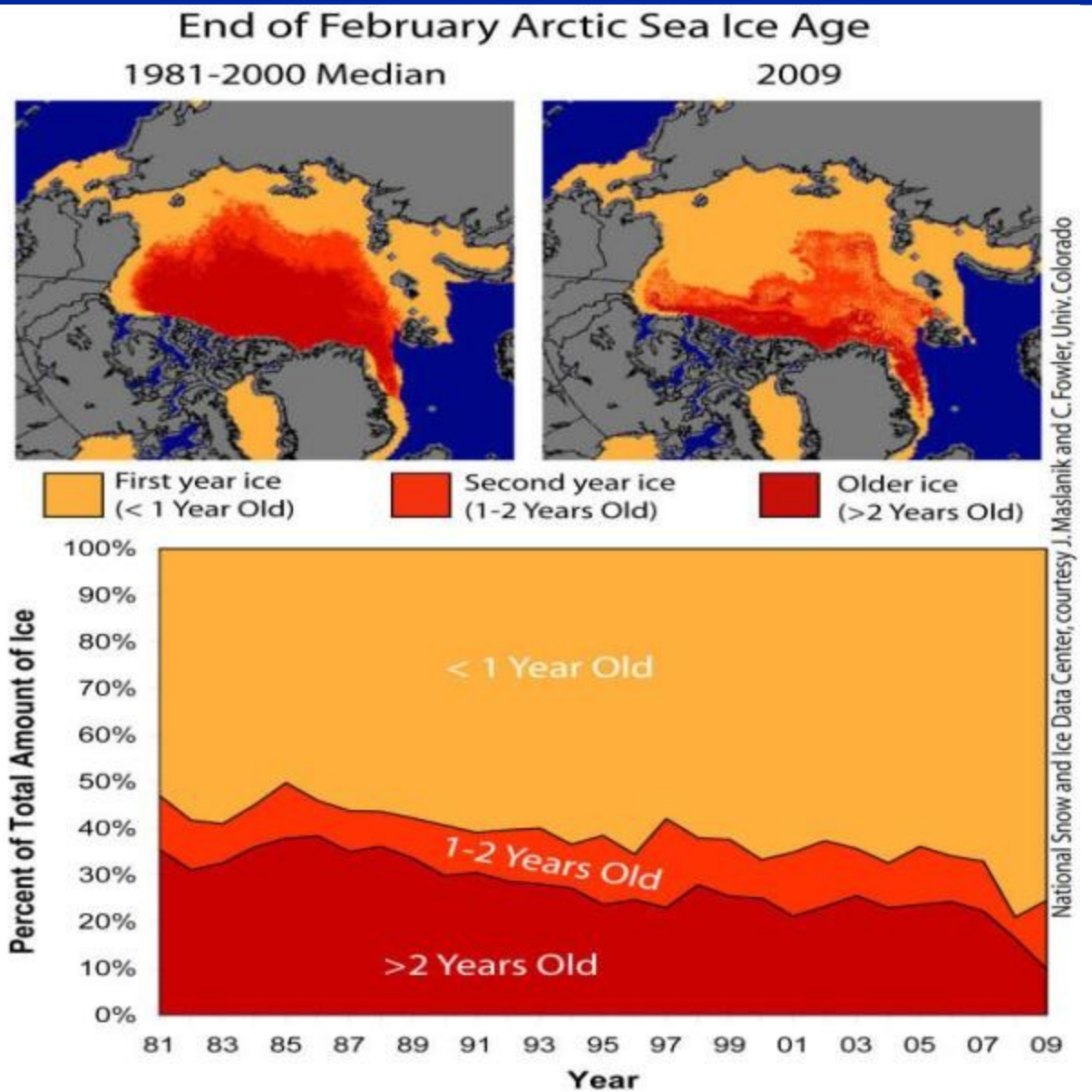
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Science v. 325 pp 1236 (September 4, 2009)

Global Climatic Disruption Early Signs: Arctic Summer Ice is Rapidly Decreasing

"We are almost out of multiyear sea ice in the northern hemisphere-- I've never seen anything like this in my 30 years of working in the high Arctic."
--David Barber, Canada's Research Chair in Arctic System Science at the University of Manitoba
October 29, 2009

http://news.yahoo.com/s/nm/20091029/sc_nm/us_climate_canada_arctic_1

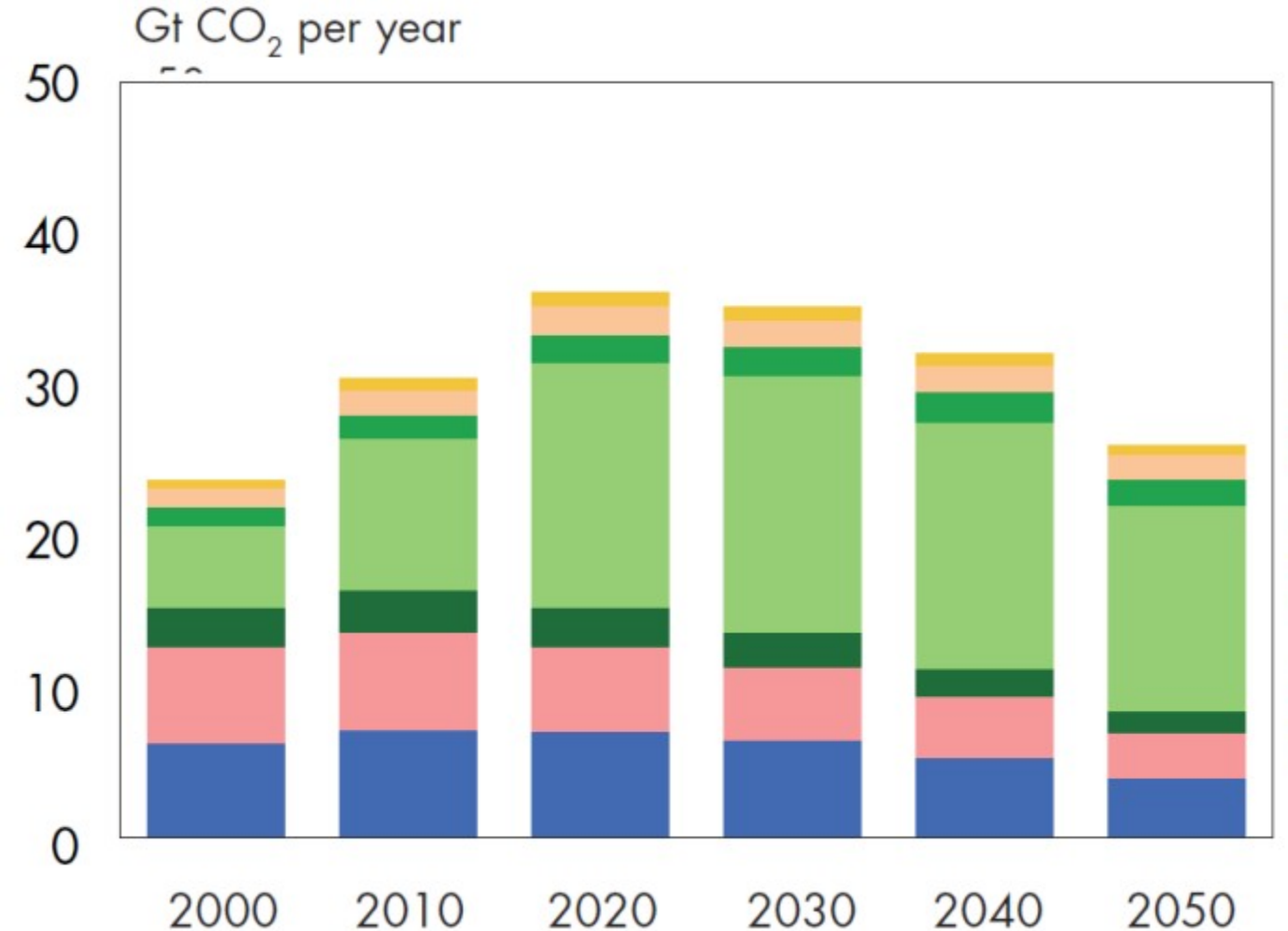


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http://news.cnet.com/8301-11128_3-10213891-54.html

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Future Estimates of CO_2 Emissions From Energy: In an Aggressive CO_2 Emission Reduction Scenario



Carbon Emissions Continue to Build CO_2 Level

- Sub-Saharan Africa
- Middle East & N. Africa
- Latin America
- Asia & Oceania - Developing
- Asia & Oceania - Developed
- North America
- Europe

Current CO_2 Level is ~390 ppm

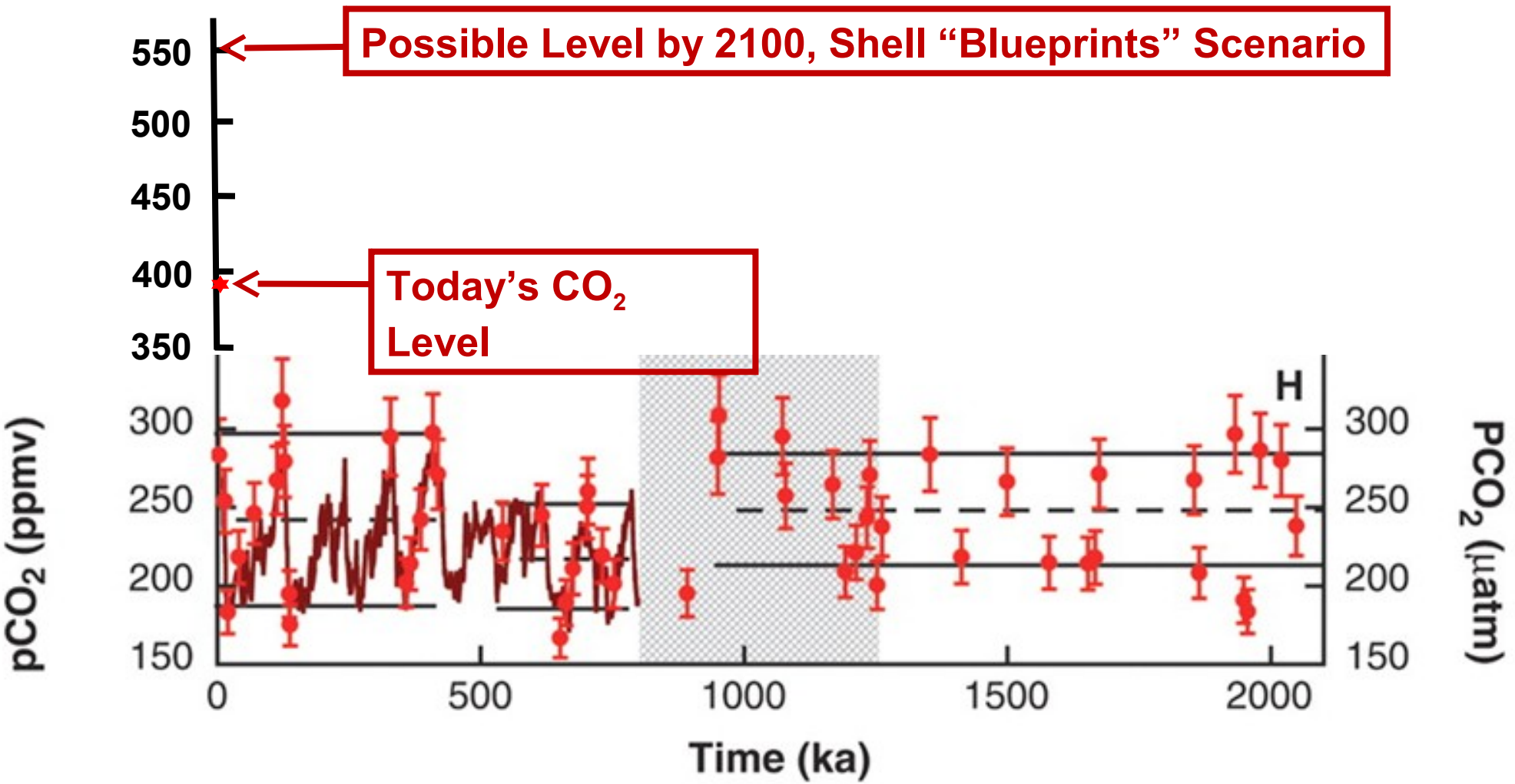
Estimated CO_2 Level in 2100 is 550ppm -- 40% Higher!

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www.shell.com/scenarios

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Today's CO_2 is Already Higher Than in Last 2 Million Years!

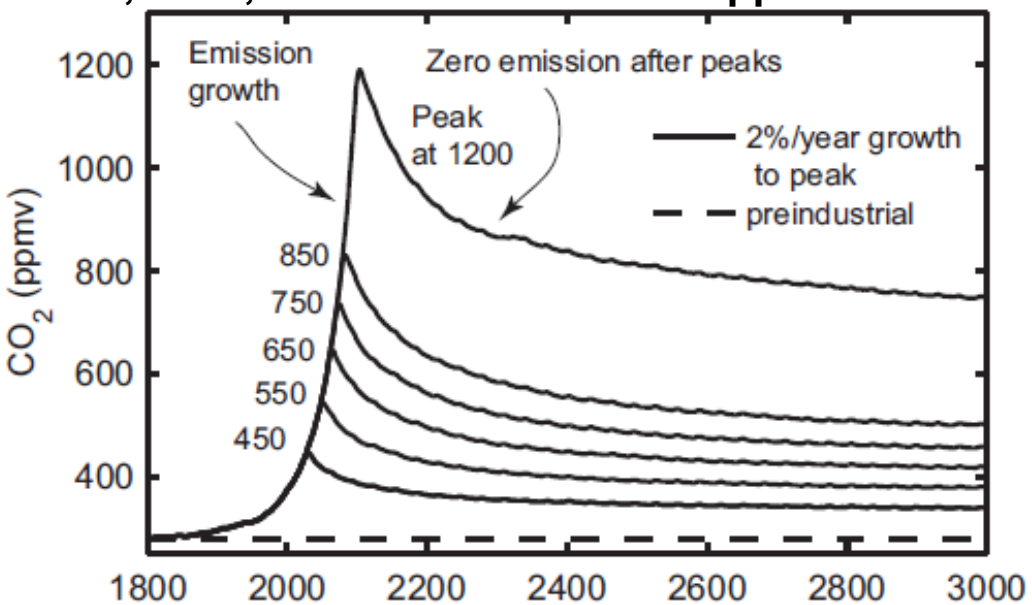


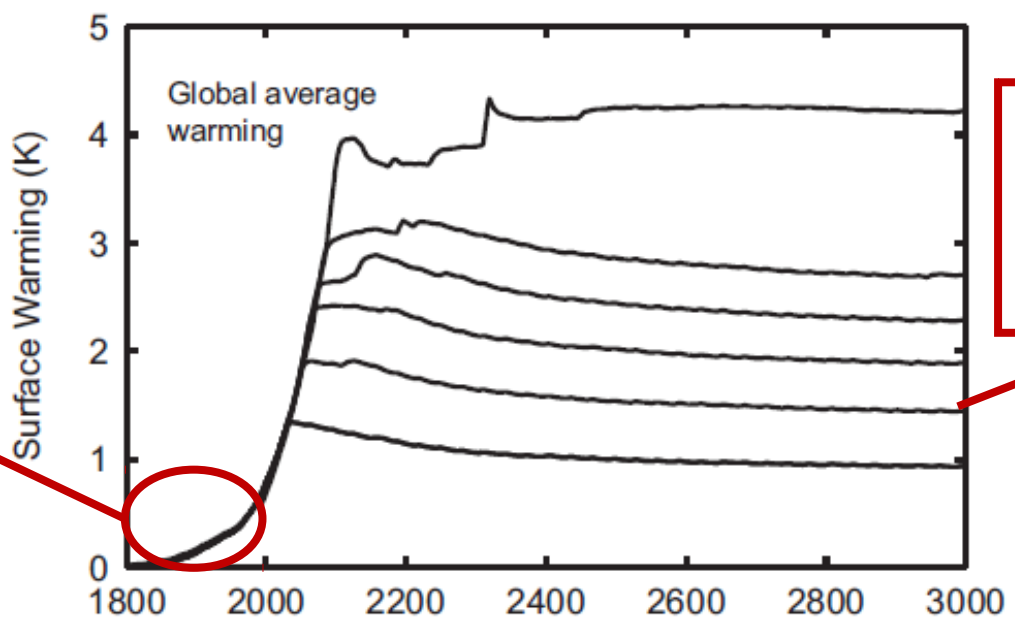
Hönisch, et al. Science 19 June 2009 Vol. 324. p. 1551

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

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How Can We Slow Down the Rate of Carbon Emissions? What is the Role for Colleges and Universities?

- Campus IT Testbeds for the Greener Future
- Can We Transition to Zero-Carbon Data Centers?
- Carbon Legislation and Implications for Campuses

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Campus IT Testbeds for the Greener Future





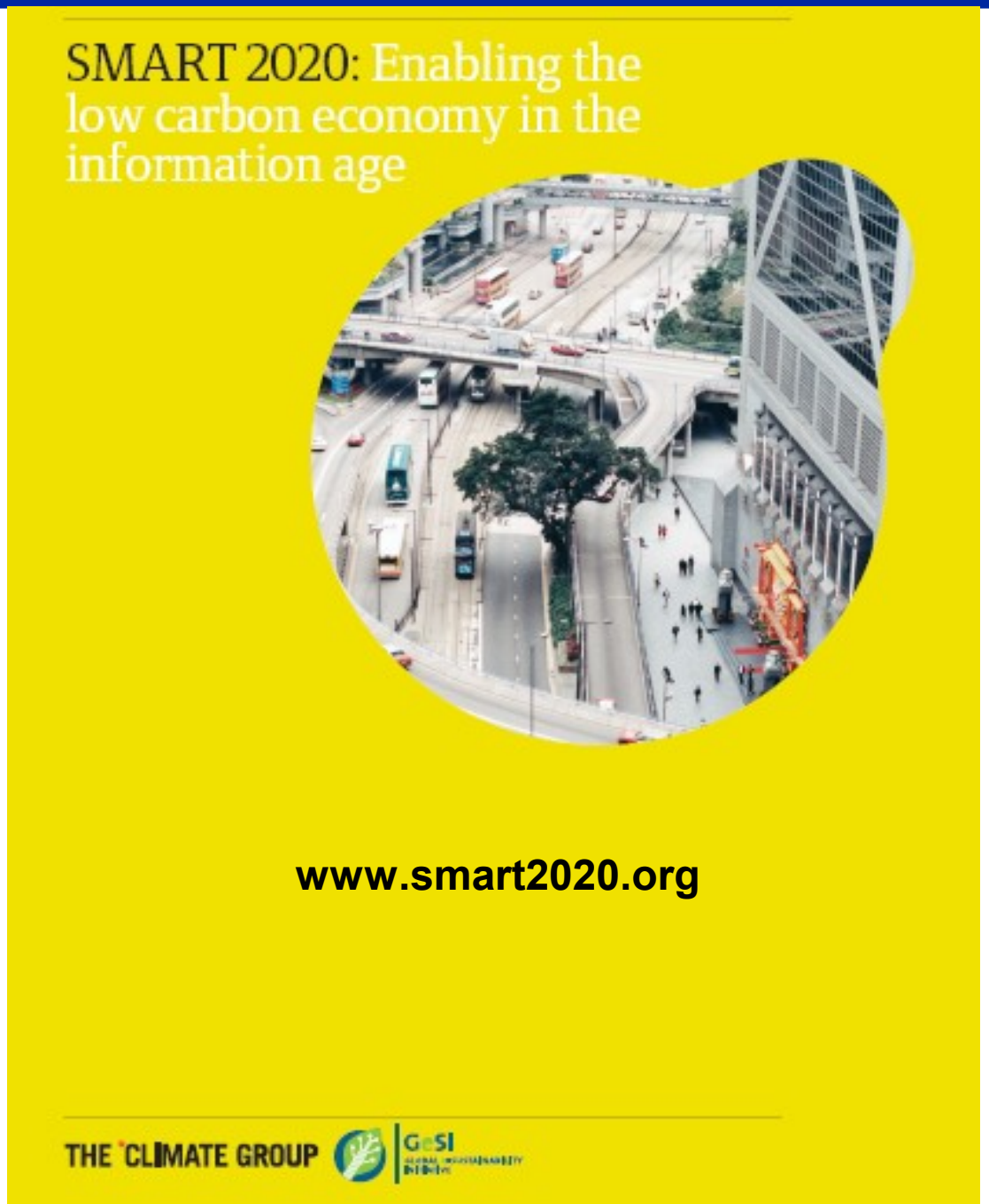
ICT is a Critical Element in Achieving Countries Greenhouse Gas Emission Reduction Targets

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.**

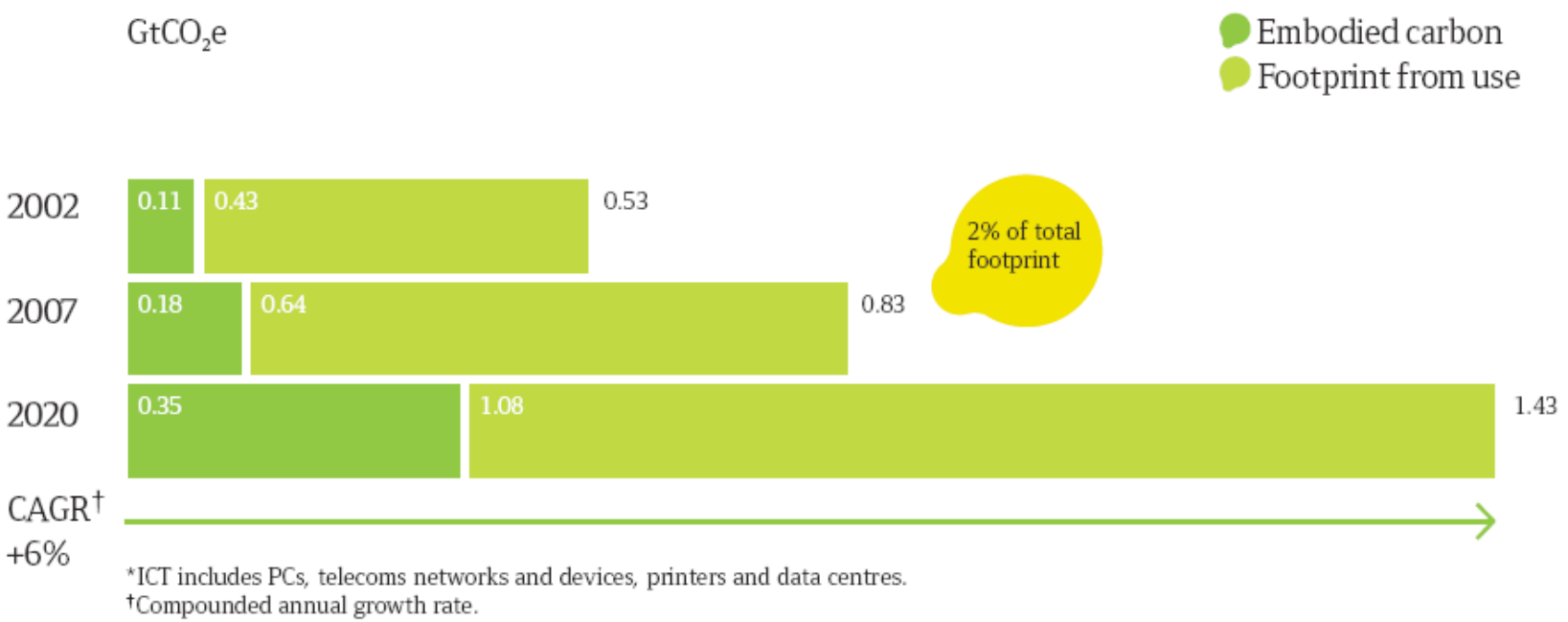
Additional support:

- **Dell, LG.**



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**

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www.smart2020.org

But, If IT is Used in New Ways Carbon Savings Can Be Much Larger!

While the sector plans to significantly step up the energy efficiency of its products and services, IT'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*

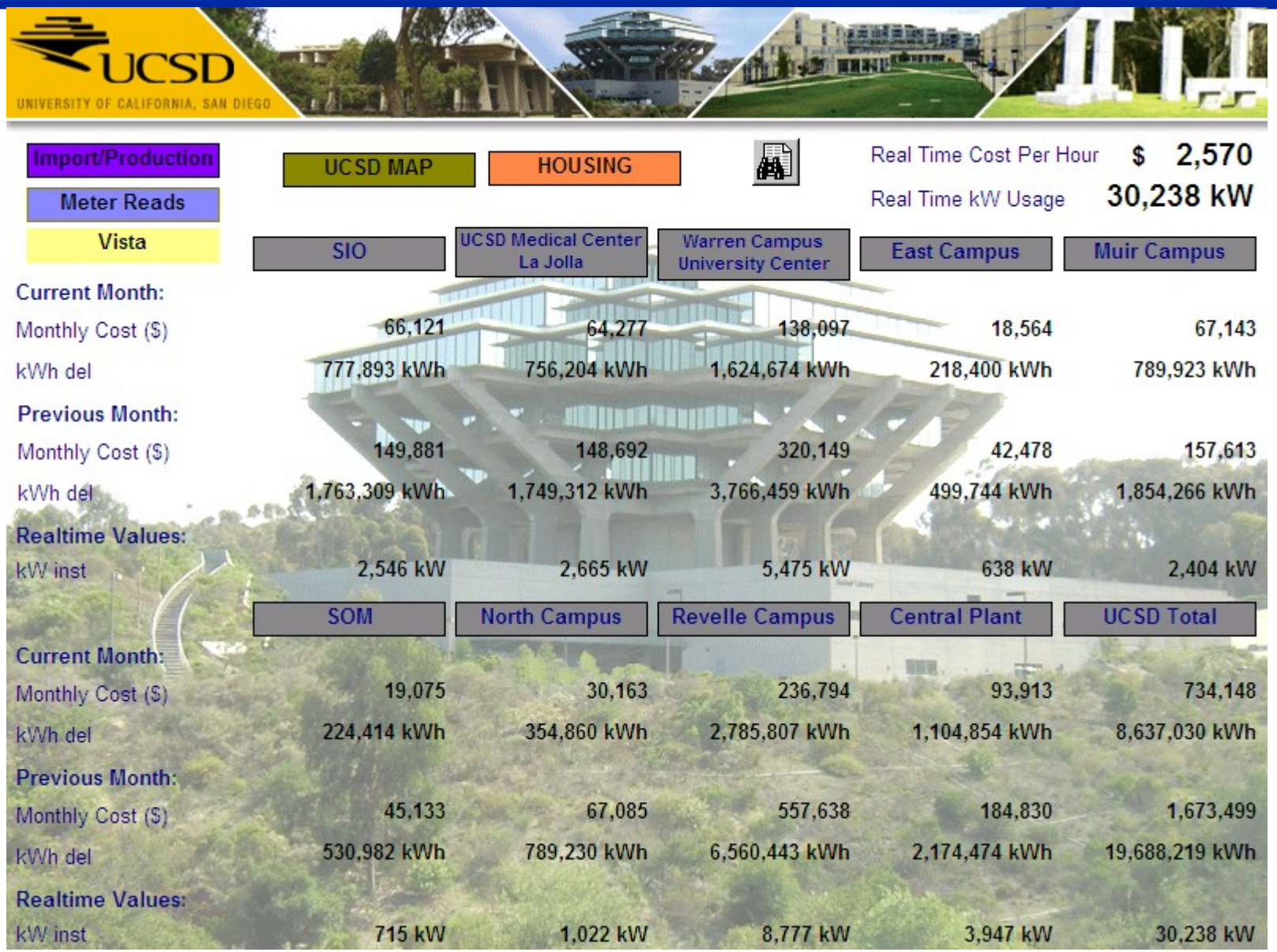
- Smart Buildings
- Virtual Meetings
- Smart Transportation Systems
- Smart Electrical Grids

*** Smart 2020 United States Report Addendum**

www.smart2020.org

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Real-Time Monitoring of Building Energy Usage: UCSD Has 34 Buildings On-Line



	SIO	UCSD Medical Center La Jolla	Warren Campus University Center	East Campus	Muir Campus
Current Month:					
Monthly Cost ($)	66,121	64,277	138,097	18,564	67,143
kWh del	777,893 kWh	756,204 kWh	1,624,674 kWh	218,400 kWh	789,923 kWh
Previous Month:					
Monthly Cost ($)	149,881	148,692	320,149	42,478	157,613
kWh del	1,763,309 kWh	1,749,312 kWh	3,766,459 kWh	499,744 kWh	1,854,266 kWh
Realtime Values:					
kW inst	2,546 kW	2,665 kW	5,475 kW	638 kW	2,404 kW

	SOM	North Campus	Revelle Campus	Central Plant	UCSD Total
Current Month:					
Monthly Cost ($)	19,075	30,163	236,794	93,913	734,148
kWh del	224,414 kWh	354,860 kWh	2,785,807 kWh	1,104,854 kWh	8,637,030 kWh
Previous Month:					
Monthly Cost ($)	45,133	67,085	557,638	184,830	1,673,499
kWh del	530,982 kWh	789,230 kWh	6,560,443 kWh	2,174,474 kWh	19,688,219 kWh
Realtime Values:					
kW inst	715 kW	1,022 kW	8,777 kW	3,947 kW	30,238 kW

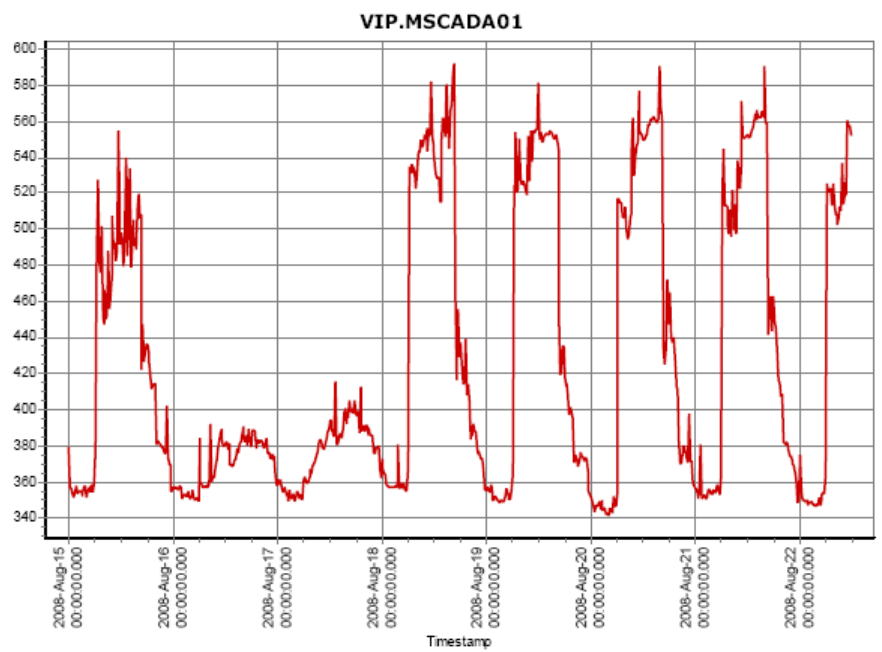
http://mscada01.ucsd.edu/ion/

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Power Management in Mixed Use Buildings: The UCSD CSE Building is Energy Instrumented

- 500 Occupants, 750 Computers
- Detailed Instrumentation to Measure Macro and Micro-Scale Power Use
  - 39 Sensor Pods, 156 Radios, 70 Circuits
  - Subsystems: Air Conditioning & Lighting
- Conclusions:
  - Peak Load is Twice Base Load
  - 70% of Base Load is PCs and Servers
  - 90% of That Could Be Avoided!

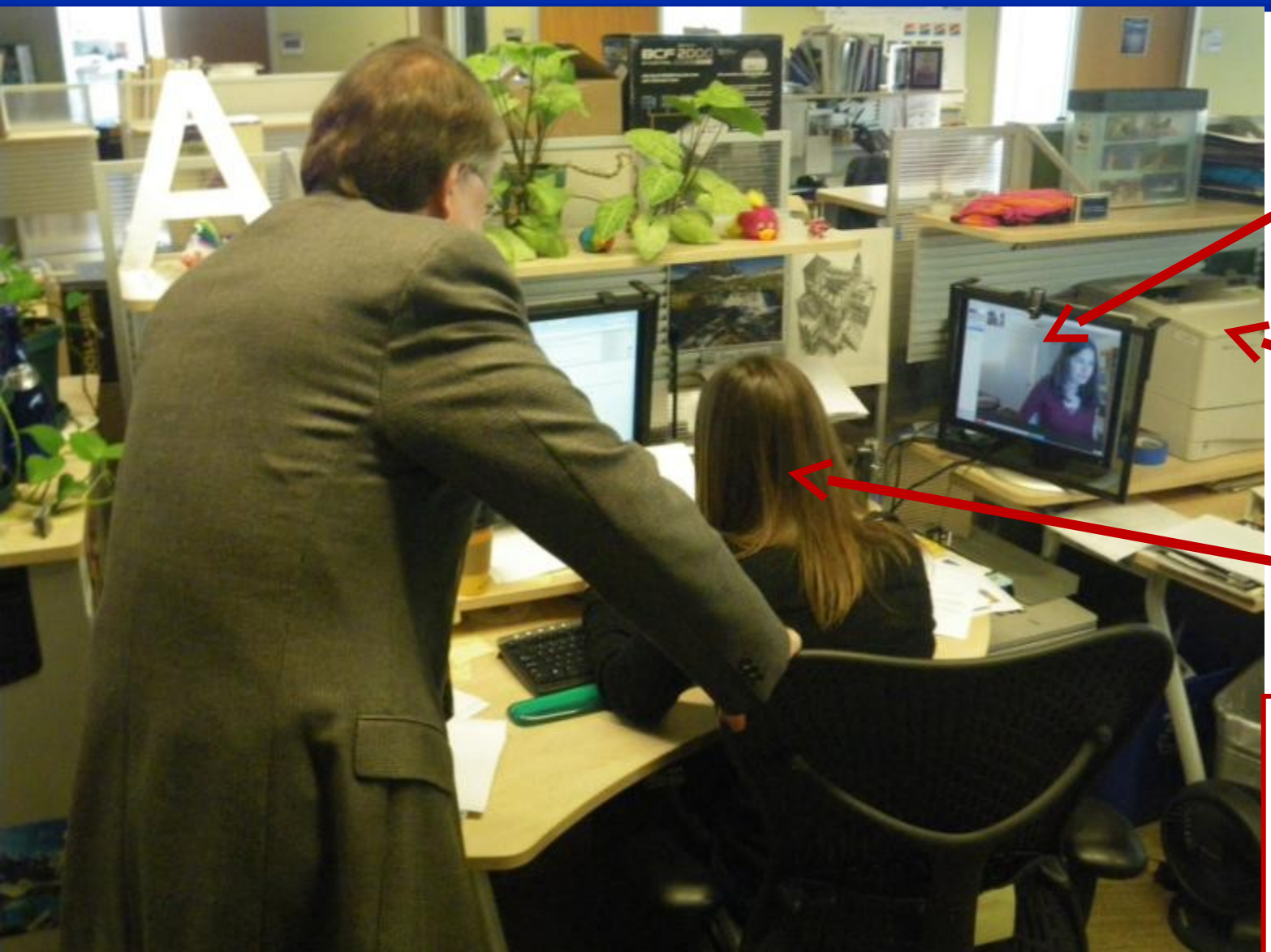




Source: Rajesh Gupta, CSE, Calit2

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Dematerialization—
Working in Mixed Virtual/Physical Spaces



Virtual Kristen

Kristen
Prints Here
For Amy

Real Amy

Kristen
Reads My Email,
Sets My Calendar.
Works With Amy
on My Trips

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We Run Video Sykpe Continuously
During Office Hours

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Linking the Calit2 Auditoriums at UCSD and UCI with HD for Shared Seminars



Avoiding Travel Between Campuses

Photo by Erik Jepsen, UC San Diego

High Definition Video Connected OptIPortals: Virtual Working Spaces for Data Intensive Research



CGLX
CROSS-PLATFORM CLUSTER GRAPHICS LIBRARY

LifeSize HD

NASA Ames
Lunar Science Institute
Mountain View, CA

NASA Interest in Supporting Virtual Institutes

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Source: Falko Kuester, Kai Doerr Calit2; Michael Sims, NASA

Multi-User Global Workspace: San Diego, Chicago, Saudi Arabia



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Source: Tom DeFanti, KAUST Project, Calit2

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UCSD and UCI Intelligent Transportation System and Renewable Energy Campus Fleets

- **Calit2@UCSD Developed the California Wireless Traffic Report**
  - http://traffic.calit2.net/
  - Deployed in San Diego, Silicon Valley, and San Francisco
  - Thousands/Day Reduce Congestion
- **UCSD Campus Fleet 45% Renewables**
  - 300 Small Electric Cars
  - 50 Hybrids
  - 20 Full-Size Electrics by 2011
- **UCI First U.S. campus to Retrofit its Shuttle system for B100 (Pure Biodiesel),**
  - Reducing Campus Carbon Emissions ~480 Tons Annually

Toyota Delivers Plug-in Prius to UC Irvine and UC Berkeley as Part of Clean Mobility Partnership



Nov. 2007

- **EPA Environmental Achievement Award for its Sustainable Transportation Program,**
  - Eliminates >18,000 $mTCO_2e$ Annually by Promoting Alternative Transportation
  - 2008 Governor's Environmental and Economic Leadership Award

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How Your Campus Can Lower Carbon Emissions —UCI Example

- **"Best Overall" Category of California's "Flex Your Power" Statewide Energy-Efficiency Campaign in December 2008**
  - **Saving 3.7 GWh of Electricity FY 2007–8**
  - **Reducing Peak Demand by up to 68 Percent**
    - **A 62,000 Ton-Hour Chilled-Water Thermal Energy Storage System Can Reduce up to 6 MW of Electrical Peak Demand**
  - **Annually:**
    - **Saving Nearly 4 Million Gallons of Water**
    - **Eliminates 62,000 $mTCO_2e$**
    - **Saves the Campus $28.9 Million**
- **All New Campus Buildings Will Be Gold LEED**
- **Highest % On-Campus Students In UC System**

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Source: Arnaud, Smarr, DeFanti, Sheehan, EDUCAUSE Review

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Sustainable Data Centers





The NSF-Funded UCSD GreenLight Project: Instrumenting the Energy Cost of Cluster Computing

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





- **Goal: 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**

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Machine Learning 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

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

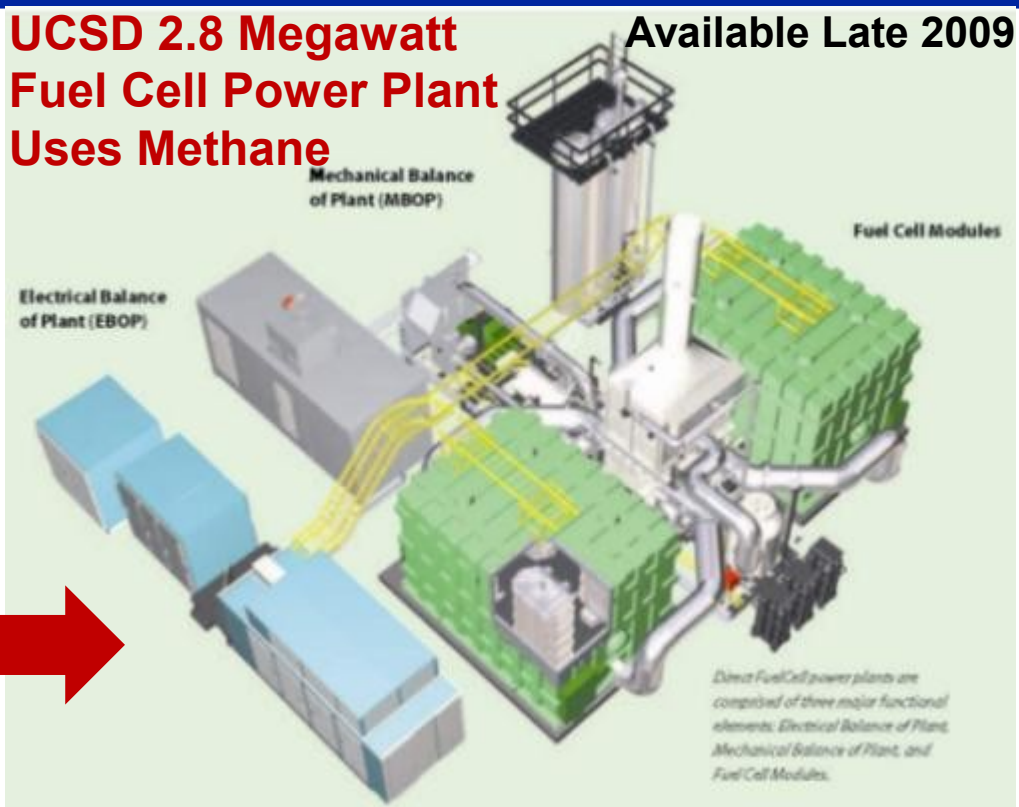
UCSD is Installing Zero Carbon Emission Solar and Fuel Cell DC Electricity Generators

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



UCSD 2.8 Megawatt Fuel Cell Power Plant Uses Methane

Available Late 2009



Use to Power Local Data Centers



2 Megawatts of Solar Power Cells Being Installed

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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)?

UCSD DC Fuel Cell 2800kW
Sun MDC <100-200kW

- **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

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Source: Tom DeFanti, Calit2; GreenLight PI

MIT to Build Zero Carbon Data Center in Holyoke MA

- **The Data Center Will Be Managed and Funded by the Four Main Partners In The Facility:**
  - **MIT**
  - **Cisco Systems**
  - **University Of Massachusetts**
  - **EMC**



- **A High-performance Computing Environment That Will Help Expand the Research and Development Capabilities of the Companies and Schools in Holyoke**

www.greenercomputing.com/news/2009/06/11/cisco-emc-team-mit-launch-100m-green-data-center

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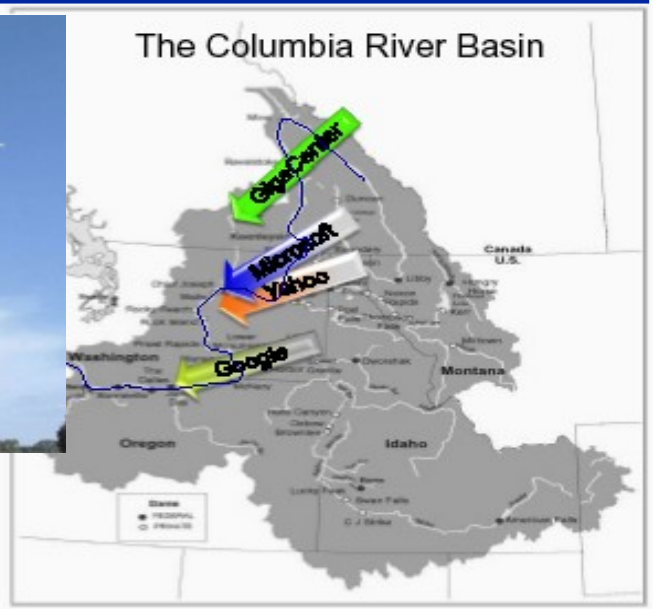
Many Zero Carbon Data Centers Exist Worldwide



Wind Powered Data Centers



Ecotricity in UK Builds Windmills at Data Center Locations with No Capital Cost to User



Hydro-Electric Powered Data Centers



Data Islandia Digital Data Archive



ASIO Solar Powered Data Centers

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Zero Carbon Leadership in British Columbia: BCNET



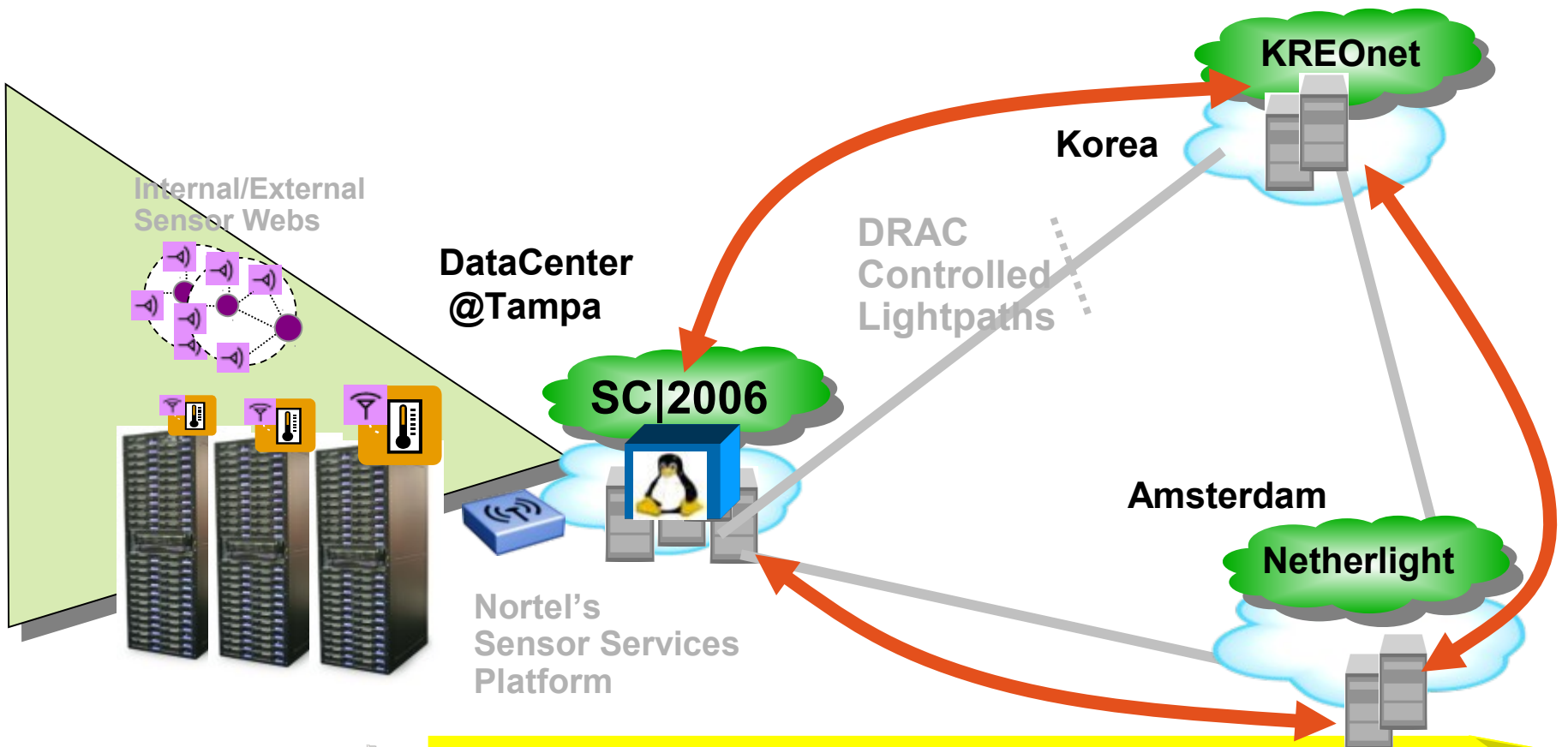
The Concept

- Use cyber infrastructure to combat global warming by reducing computing infrastructure's carbon footprint
- Find efficient ways to share computing facilities that are close to sources of green power by utilizing BCNET's advanced network infrastructure within the Province
- Make it possible for BC's Universities to reduce their carbon footprint by relocating their existing ICT infrastructure to "greener facilities"
- Build a zero carbon data centre and use the BCNET/CANARIE ROADM network to connect users to it

CANARIE Green Cyberinfrastructure Pilot -- $3M Allocation

- **Two Objectives:**
  - **Technical Viability and Usability for Relocating Computers to Zero Carbon Data Centers and "Follow the Sun/Follow the Wind" Network**
  - **Business Case Viability of Offering Carbon Offsets (and/or Equivalent in Services) to IT Departments and University Researchers Who Reduce Their Carbon Footprint by Relocating Computers and Instrumentation to Zero Carbon Data Centers**
- **International Partnership with Possible Zero Carbon Nodes Using Virtual Router/Computers in Spain, Ireland, California, Australia, British Columbia, Ottawa, Quebec and Nova Scotia**

The SC06
VMT Demonstrator





Computation at the Right Place & Time!
We Migrate Live Virtual Machines, Unbeknownst to Applications and Clients, for Data Affinity, Business Continuity / Disaster Recovery, Load Balancing, or Power Management

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CO2 Regulations and Universities





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 Only 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)**

- **Neither the U.S. or Canada has an Official Target Yet**
  - **President Obama Has Endorsed the AB32 2020 Goal**

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US EPA *Requires* GHG Reporting for Any Entity Emitting Over 25,000 Metric Tons CO_2e



U.S. ENVIRONMENTAL PROTECTION AGENCY

Climate Change - Regulatory Initiatives

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- Proposed GHG Permitting Requirements on Large Industrial Facilities
- Comment Requested on GHG Permitting Guidance under Reconsideration
- Final Mandatory

Final Mandatory Reporting of Greenhouse Gases Rule

Final Mandatory Reporting of Greenhouse Gases Rule | Resources and Tools | Training Opportunities | Background | Rule Help Center

In response to the FY2008 Consolidated Appropriations Act (H.R. 2764; Public Law 110-161), EPA has issued the Final Mandatory Reporting of Greenhouse Gases Rule. The rule requires reporting of greenhouse gas (GHG) emissions from large sources and suppliers in the United States, and is intended to collect accurate and timely emissions data to inform future policy decisions.

Under the rule, suppliers of fossil fuels or industrial greenhouse gases, manufacturers of vehicles and engines, and facilities that emit 25,000 metric tons or more per year of GHG emissions are required to submit annual reports to EPA. The gases covered by the proposed rule are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFC), perfluorocarbons (PFC), sulfur hexafluoride (SF_6), and other fluorinated gases including nitrogen trifluoride (NF_3) and hydrofluorinated ethers (HFE).

What's New

- Final Mandatory Reporting of Greenhouse Gases Rule Published in Federal Register
- Training Slides Now Available on GHG Rulemaking Web Site
- EPA Offers Training on GHG Reporting Applicability Tool
- EPA Administrator Lisa Jackson Signs Final Mandatory Reporting of Greenhouse Gases Rule

First Measurements January 2010
First Reports Due January 2011

SOURCE: US Environmental Protection Agency, www.epa.gov/climatechange/emissions/ghgrulemaking.html

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Most US Universities Will Become Regulated Entities -- Emitting Over 25,000 Metric Tons CO_2e

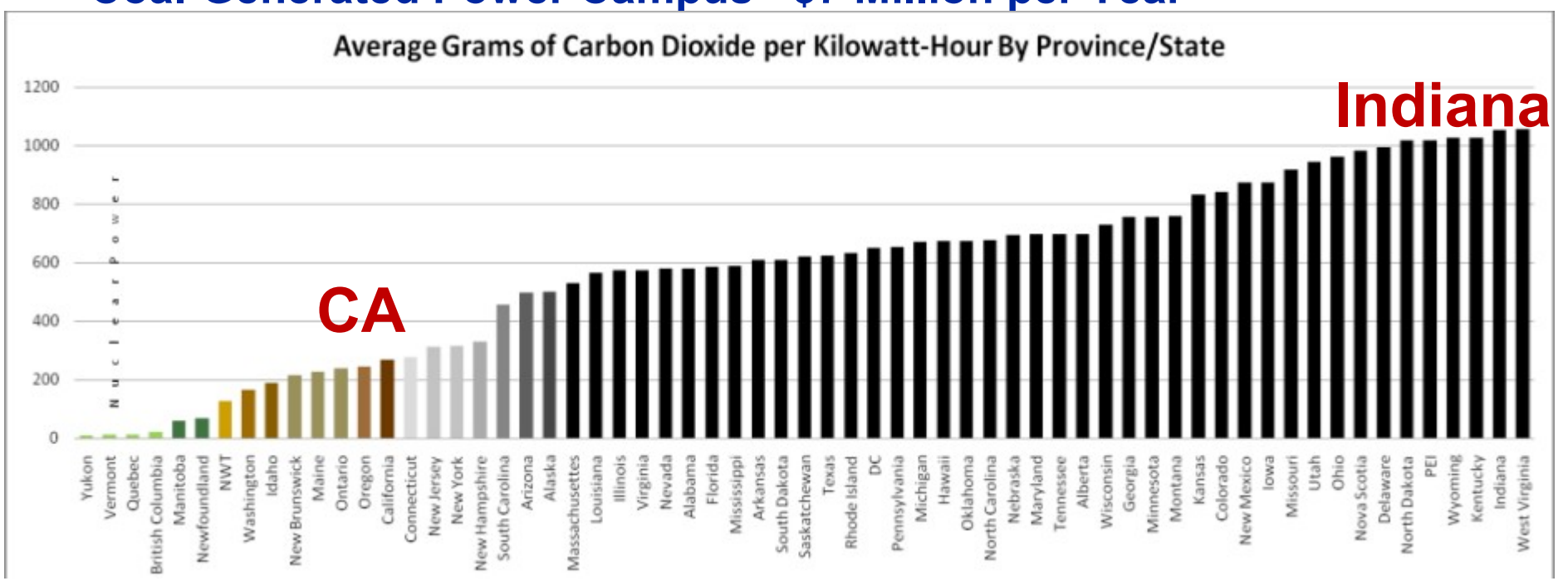
Gross Emissions Scope 1 & 2 (CO_2e)	Year	US EPA GHG Rule Requires Reporting in 2011?
491,258	2008	YES!
52,2709	2008	YES!
80,498	2007	YES!
234,000	2008	YES!
309, 117	2008	YES!
192,862	2008	YES!

SOURCE: American College and University Presidents Climate Commitment, http://acupcc.aashe.org/

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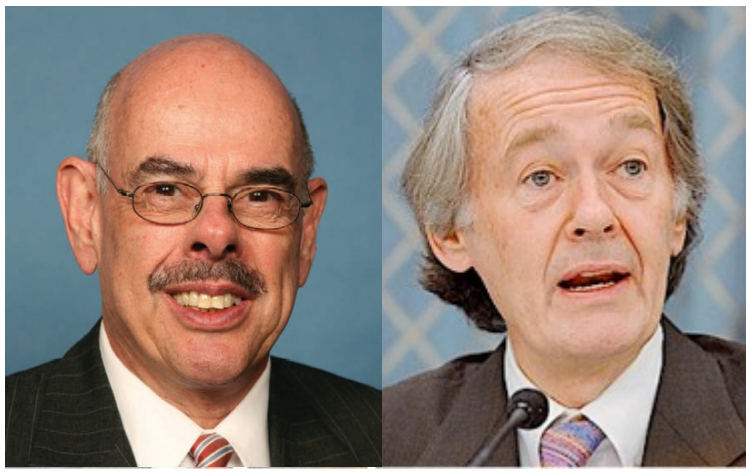
How Much Will Carbon Cap & Trade Cost Your Campus? Assume a 40MW Campus Like UCSD

- **Depends on How Carbon-Rich Your Electricity Production Is**
  - **88,000 $mTCO_2e$ on California Campus**
  - **348,000 $mTCO_2e$ on a Coal-Generated Electricity Campus**
- **Assume that Carbon Trades at $20 per Metric Ton--the Cost to**
  - **A California Campus ~$1.8 Million/Year**
  - **Coal-Generated Power Campus ~$7 Million per Year**



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Proposed Federal Cap & Trade Legislation



Waxman-Markey

- CO_2 Reduction Targets of 17% Below 2005 Level by 2020
- Cap and Trade Requires Offsets ($11-$15 /Ton in 2012, Double in Price by 2025)
- Passed U.S. House in July



Kerry-Boxer

- CO2 Reduction Targets of 20% Below 2005 Level by 2020
- Similar “Cap and Trade” System to Waxman-Markey
- Being Considered US Senate Now

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GHG Regulation in British Columbia
Public Sector Institutions MUST Be Carbon Neutral!

- **Greenhouse Gas Reductions Target Act Became Law 2008**
- **Establishes GHG Emission Target Levels for the Province**
  - **2020 BC GHG will be 33% Less than 2007**
  - **2050 BC GHG will be 80% Less than 2007**
- **Bill Mandates that by 2010 Each Public Sector Organization Must be Carbon Neutral**
- **If a Public Sector Organization Cannot Achieve Carbon Neutrality Then They are Required to Purchase Offsets at $24/Ton**

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Source: Jerry Sheehan UCSD

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Implications for Carbon Costs for the University of British Columbia

University of British Columbia Greenhouse Gas Liability 2010-2012			
	2010	2011	2012
Carbon Offset	$1,602,750	$1,602,750	$1,602,750
Carbon Tax	$1,179,940	$1,474,925	$1,769,910
Total	**$2,782,690**	**$3,077,675**	**$3,372,660**

SOURCE: UBC Sustainability Office, August 2009

Achieving Carbon Targets May Become A Requirement for Federal Funding



U.K. Universities Secretary John Denham

HIGHER EDUCATION FUNDING COUNCIL FOR ENGLAND hefce

- **Higher Education Funding Council for England Asked to Develop Strategy to Curb Emissions by 80% by 2050**
- **Increase in Emissions Reduction Target by 20% Was In Support of England's Climate Strategy**
- **Capital Funding Will Be Linked to Performance in Reducing Emissions**

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SOURCE: Carbon Offsets Daily, www.carbonoffsetsdaily.com/global/government-funding-to-reward-greenest-universities-3996.htm

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We Need to Bring Together the Stakeholders To Cross-Educate and Seek Common Ground

SOUTHERN CALIFORNIA SMART GRID SYMPOSIUM
APRIL 7, 2009

Calit2
UNIVERSITY of CALIFORNIA IRVINE



January 22-23, 2009

Greening the Internet Economy
ICT & GLOBAL CHANGE

California Public Utilities Commission

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Co-Hosted By Calit2 & CPUC

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The College & University Leadership Opportunity

- **American College and University Presidents' Climate Commitment**
  - **659 Presidents Have Signed So Far**
  - **Commitment for Taking Steps Toward Climate Neutrality**

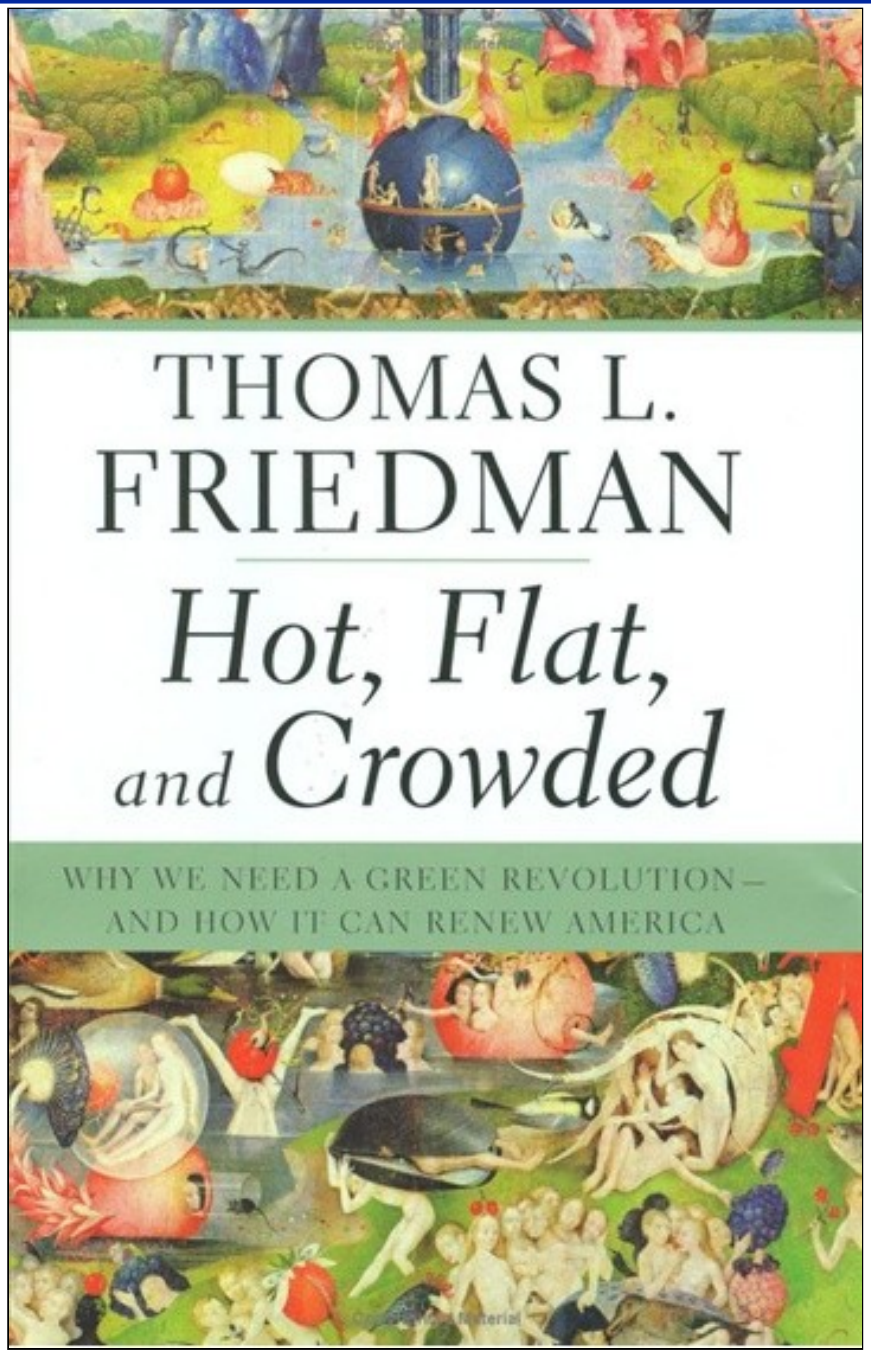
We believe colleges and universities must exercise leadership in their communities and throughout society by modeling ways to minimize global warming emissions…



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www.presidentsclimatecommitment.or

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



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Let's Keep The Conversation Going



Bill St. Arnaud



Larry Smarr

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