The Role of University Energy Efficient Cyberinfrastructure in Slowing Climate Change

Energy Leadership Lecture
The Institute for Energy Efficiency
University of California, Santa Barbara
April 14, 2010

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
Twitter: lsmarr

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Abstract

The continuing rise in greenhouse gases (GHG) in Earth's atmosphere caused by human activity is beginning to alter the delicately balanced climate system. Means to slow down the rate of GHG emissions are needed to avoid catastrophic climate change in the future. While moving from a high-carbon to a low-carbon energy system is the long term solution, more energy efficient cyberinfrastructure can provide some relief in the short term. I will review several projects which Calit2 is carrying out with our UCSD and UCI faculty in energy efficient data centers, personal computers, smart buildings, and telepresence and show how university campuses can be urban testbeds of the greener future.

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ICT Could be a Key Factor in Reducing the Rate of Climate Change

Applications of ICT
could enable emissions reductions
of 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.





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www.smart2020.org

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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"

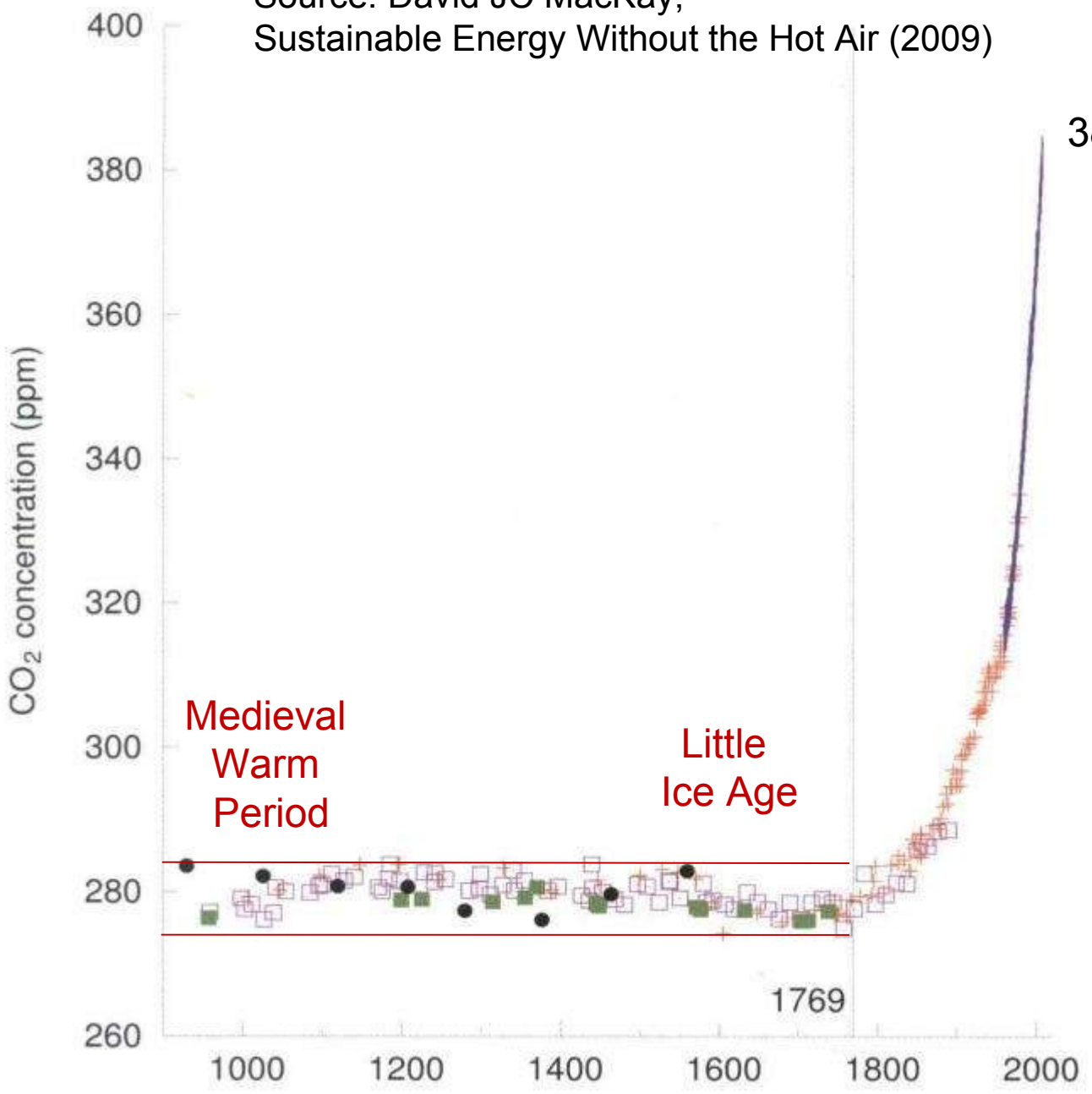


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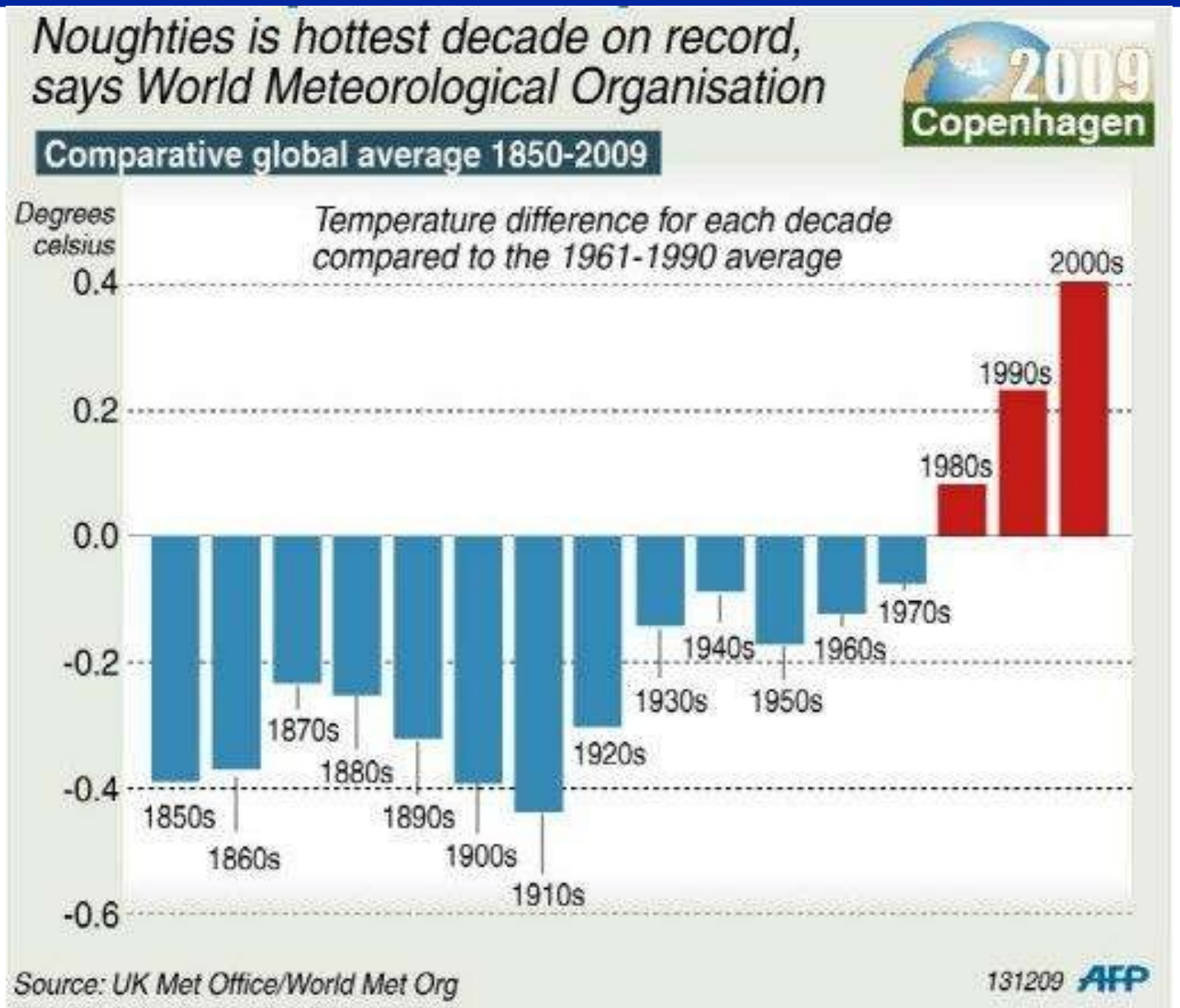
Rapid Increase in the Greenhouse Gas CO_2 Since Industrial Era Began

Source: David JC MacKay,
Sustainable Energy Without the Hot Air (2009)



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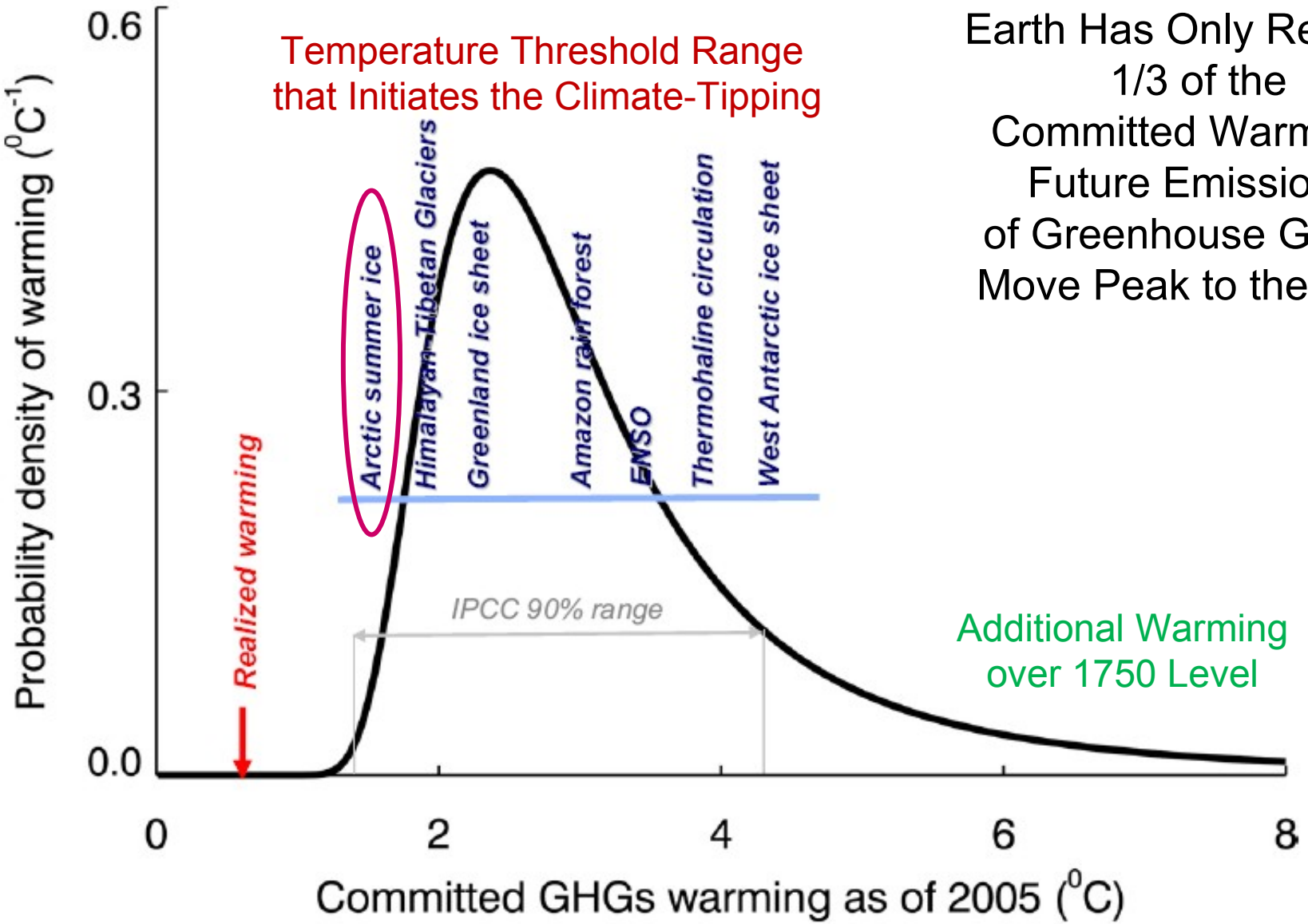
Global Average Temperature Per Decade Over the Last 160 Years



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The Planet is Already Committed to a Dangerous Level of Warming



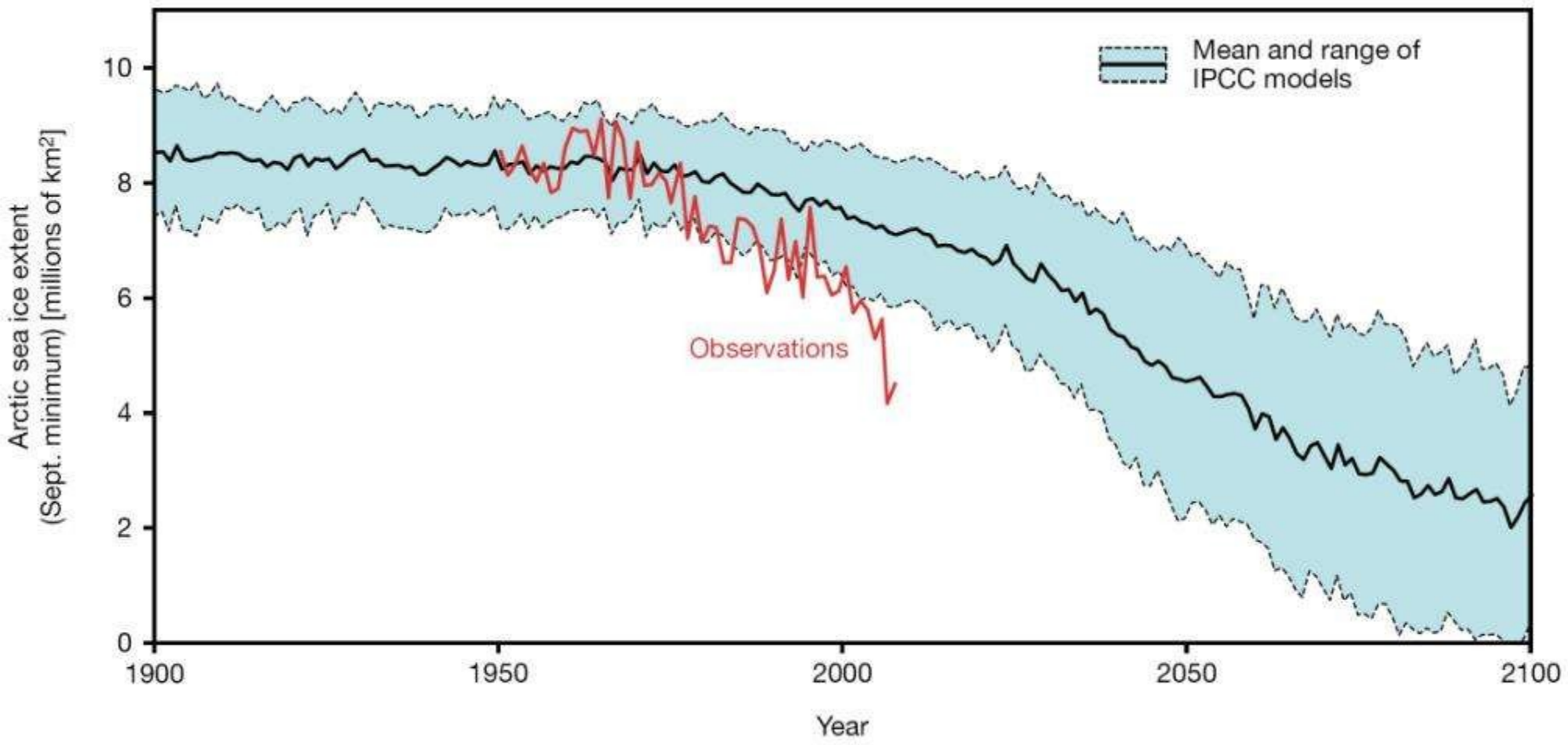
Earth Has Only Realized 1/3 of the Committed Warming - Future Emissions of Greenhouse Gases Move Peak to the Right

Additional Warming over 1750 Level

V. Ramanathan and Y. Feng, Scripps Institution of Oceanography, UCSD
September 23, 2008
www.pnas.orgcgidoi10.1073pnas.0803838105

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Arctic Summer Ice Melting Accelerating Relative to IPCC 2007 Predictions



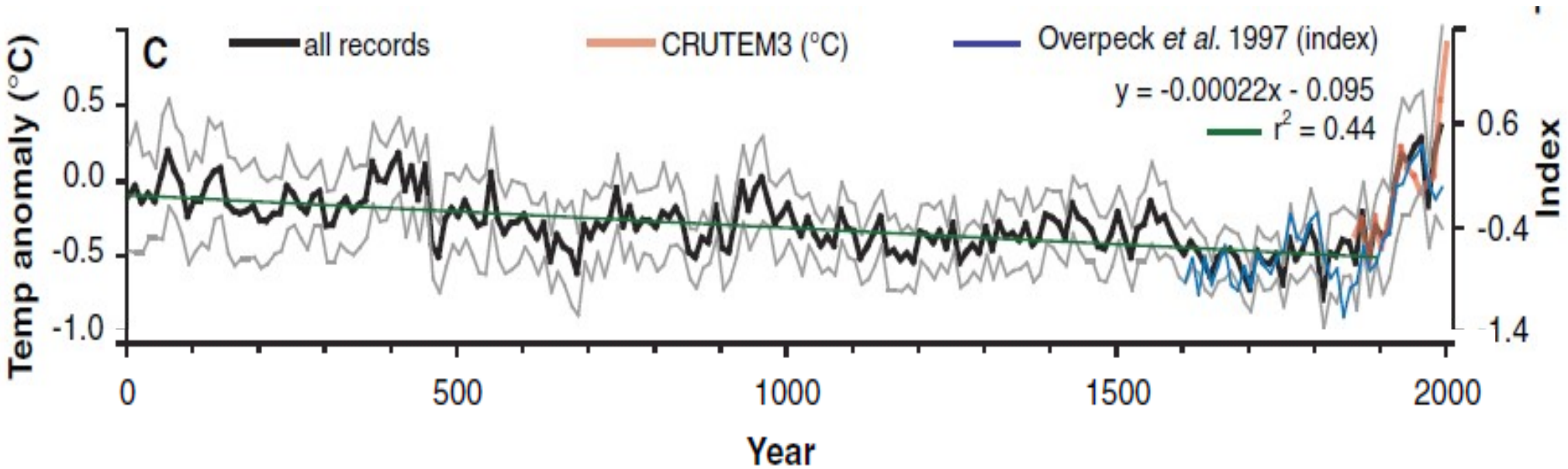
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Source: www.copenhagendiagnosis.org

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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

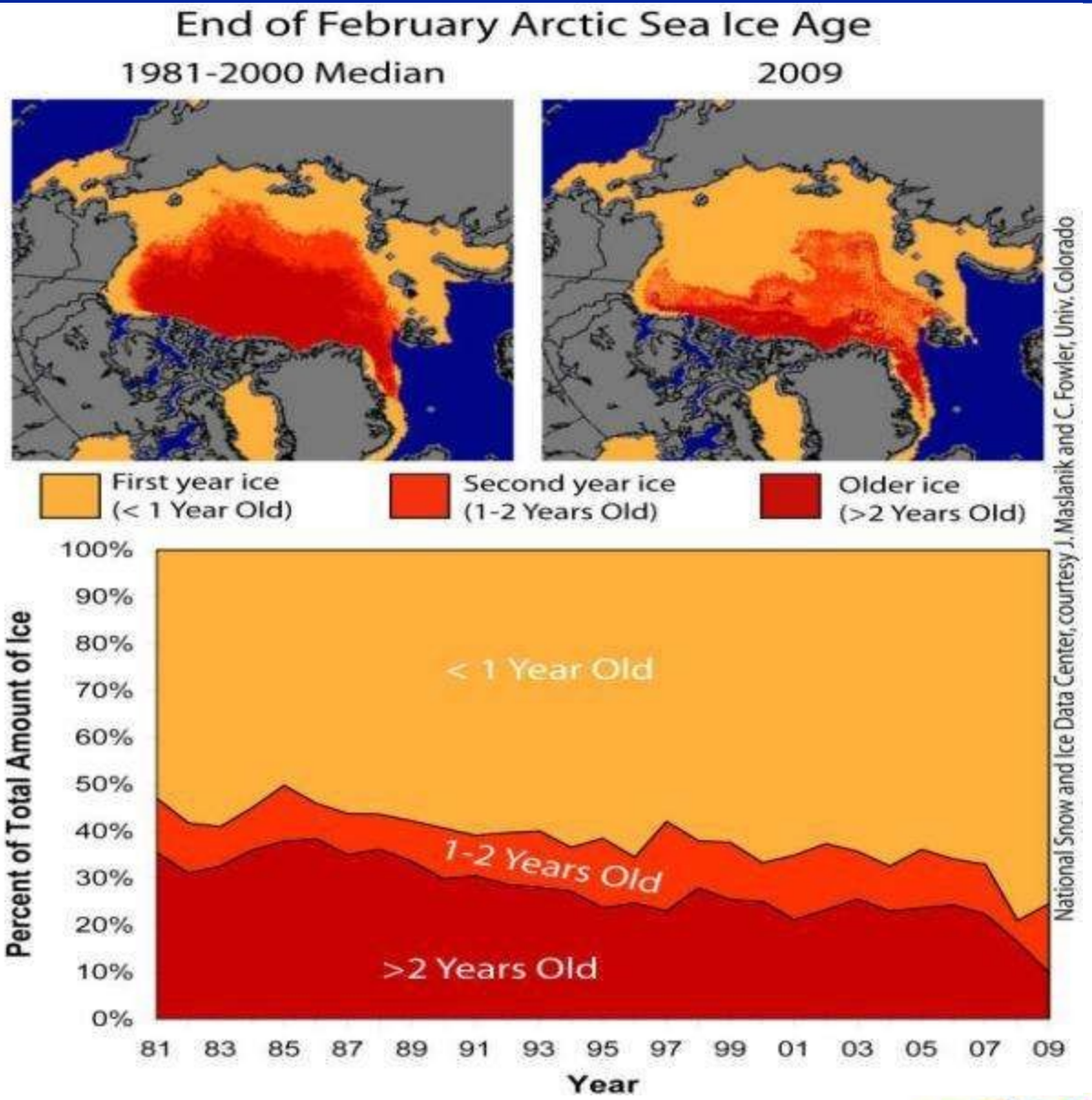
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Science v. 325 pp 1236 (September 4, 2009)

Global Climatic Disruption Early Signs: Area of 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

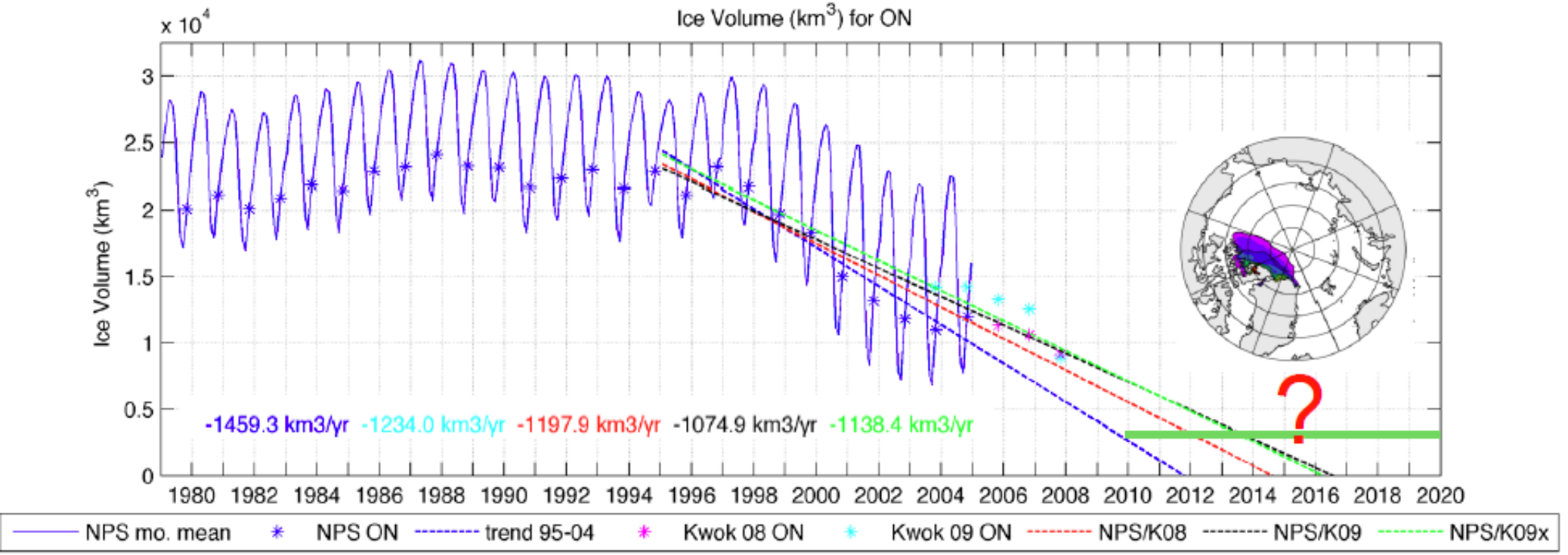
http://news.yahoo.com/s/nm/20091029/sc_nm/us_climate_canada_arctic_1



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

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Summer Arctic Sea Ice Volume Shows Even More Extreme Melting—Ice Free by 2015?



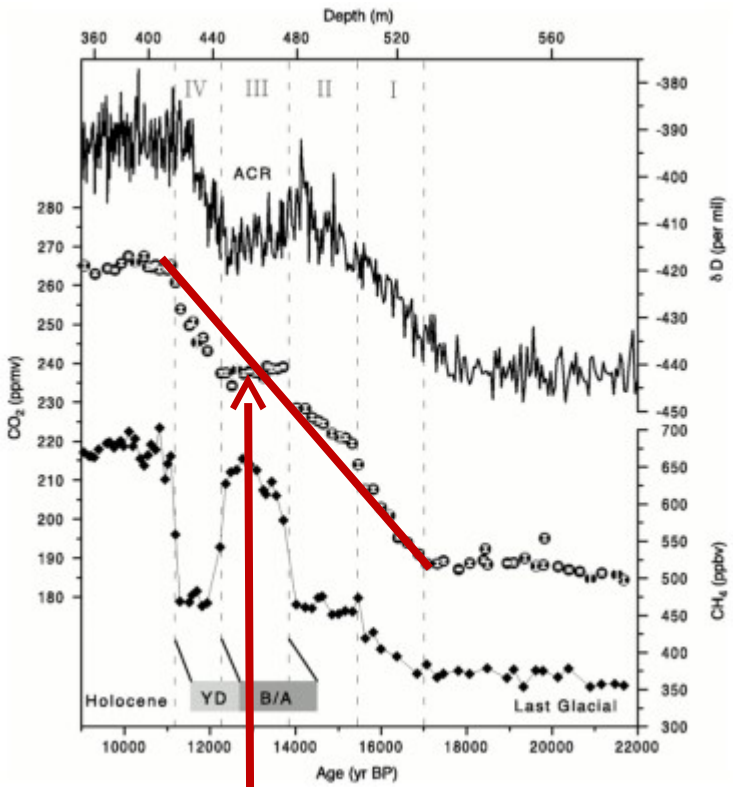
Source: Wieslaw Maslowski
Naval Postgraduate School,
AAAS Talk 2010

Observational estimates (cyan / purple stars):

- Obs Fall (ON) '07 volume <9000 km^3 , ~20% uncertainty,
- Negative volume trends: 1197 - 1234 km^3/yr
- Combined (95-07) model / data linear volume trend projects ice-free fall by 2016
  - Same trend with extended K09 (assuming the constant ON volume for 07 - 09)
- Some (?) sea ice will remain beyond due to increased ridging of thinner ice
- Uncertainty (95-07) is ±3yrs and not all volume must disappear

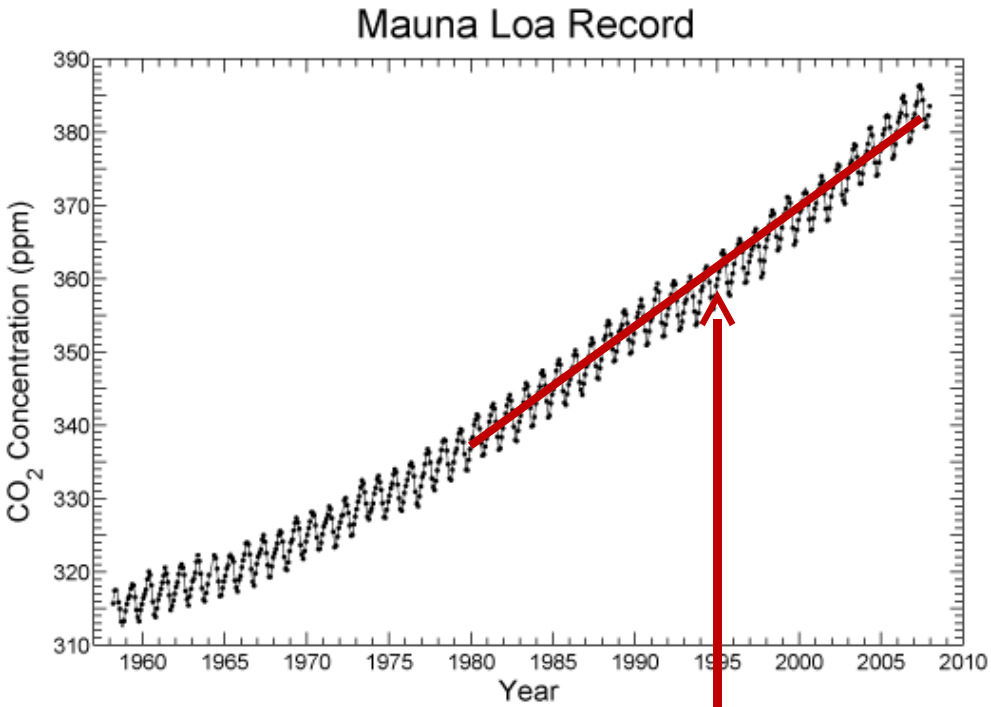
Kwok et al., JGR 2009, Kwok & Cunnigham, JGR 2008

The Earth is Warming Over 100 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

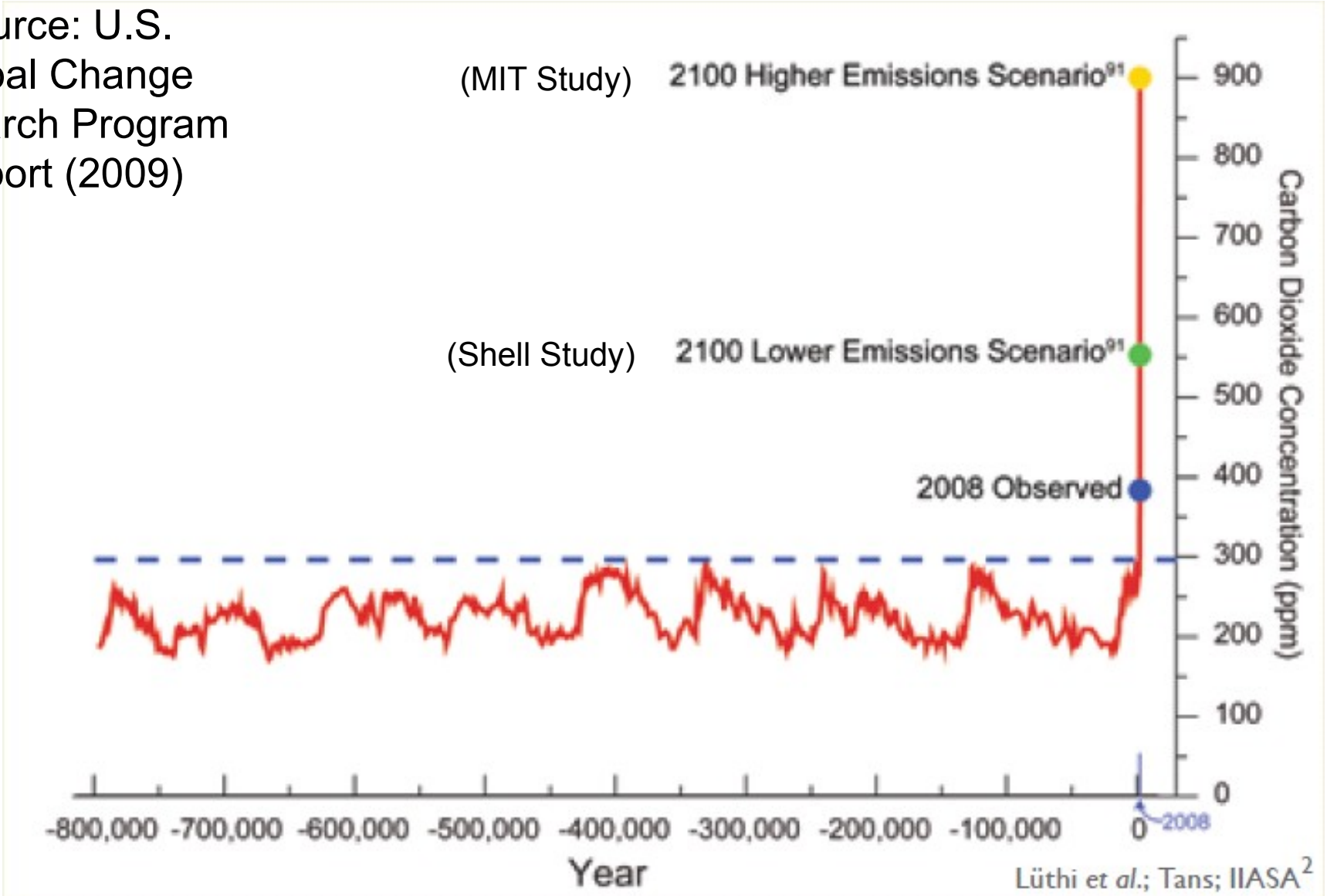


CO_2 Has Risen From
335 to 385ppm (50ppm)
in 30 years or
1.6 ppm per Year

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Atmospheric CO_2 Levels for 800,000 Years and Projections for the 21st Century

Source: U.S. Global Change Research Program Report (2009)

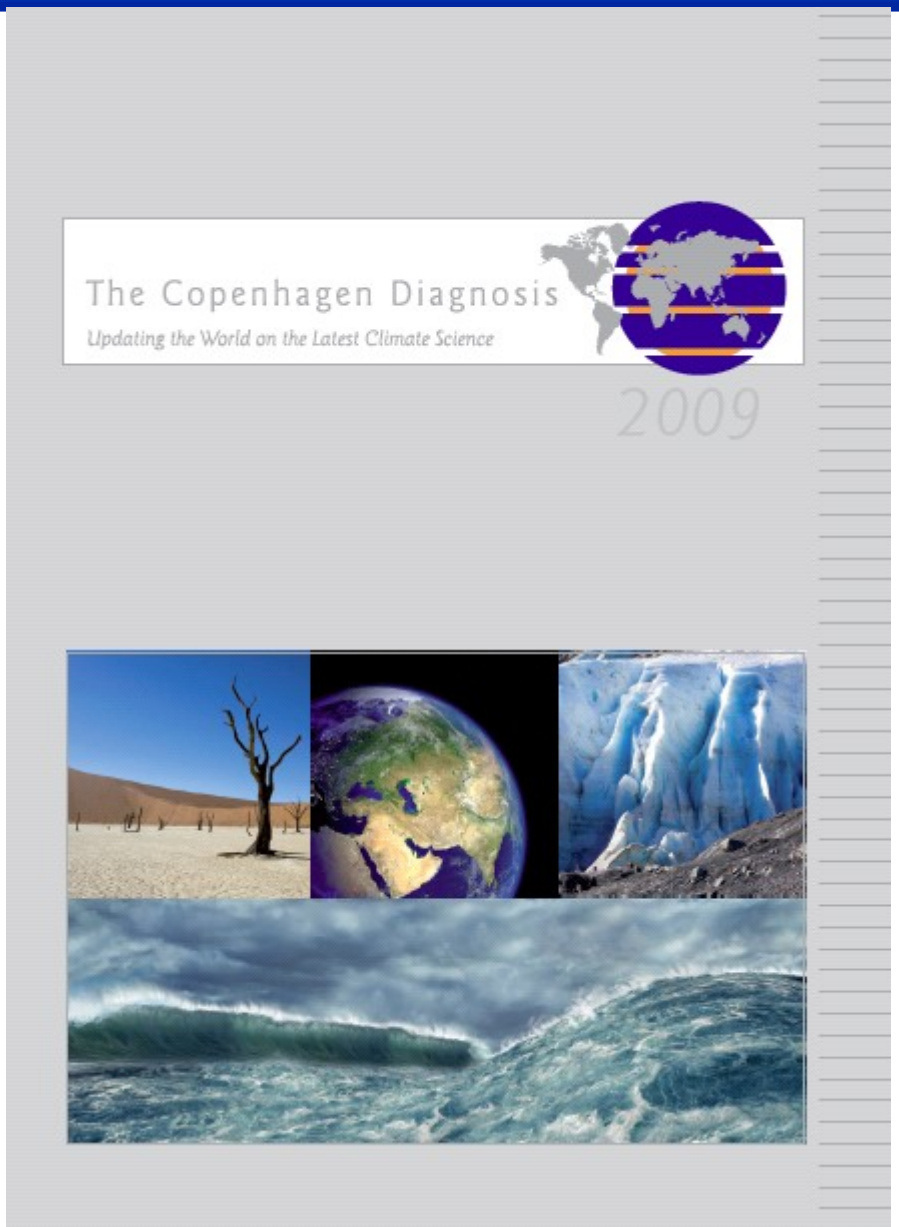


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www.globalchange.gov/publications/reports/scientific-assessments/us-impacts/download-the-report

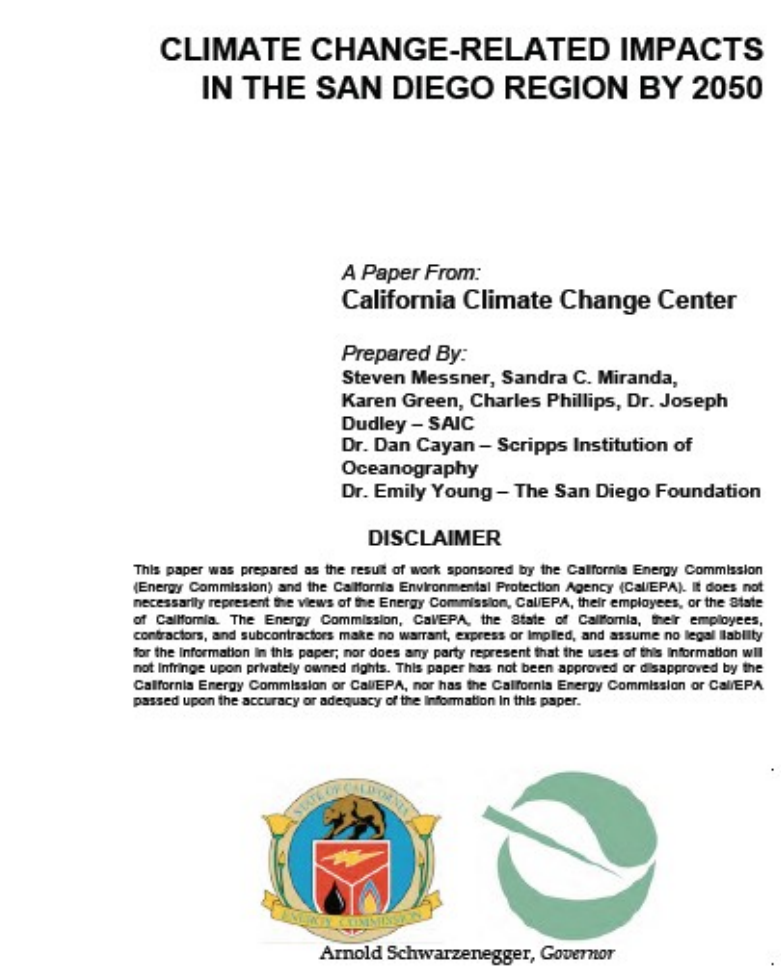
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The Latest Science on Global Climatic Disruption
An Update to the 2007 IPCC Report



www.copenhagendiagnosis.org

Climate Change Will Pose Major Challenges to California in Water and Wildfires



CLIMATE CHANGE-RELATED IMPACTS
IN THE SAN DIEGO REGION BY 2050

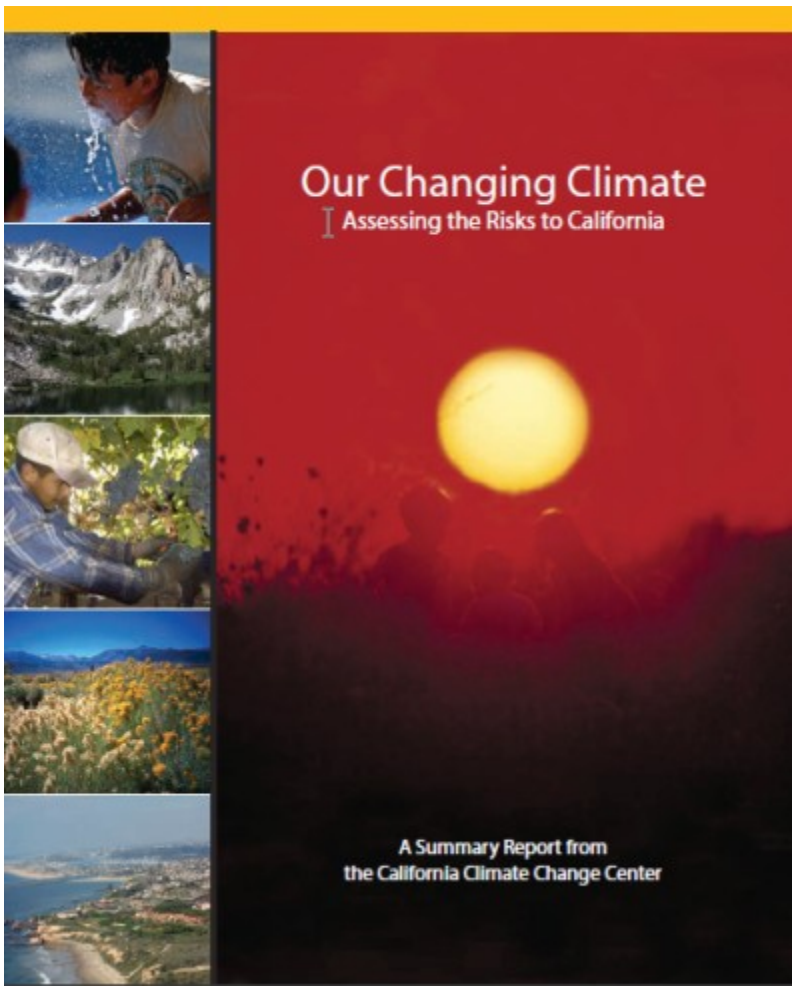
A Paper From:
California Climate Change Center

Prepared By:
Steven Messner, Sandra C. Miranda, Karen Green, Charles Phillips, Dr. Joseph Dudley – SAIC
Dr. Dan Cayan – Scripps Institution of Oceanography
Dr. Emily Young – The San Diego Foundation

DISCLAIMER

This paper was prepared as the result of work sponsored by the California Energy Commission (Energy Commission) and the California Environmental Protection Agency (Cal/EPA). It does not necessarily represent the views of the Energy Commission, Cal/EPA, their employees, or the State of California. The Energy Commission, Cal/EPA, the State of California, their employees, contractors, and subcontractors make no warrant, express or implied, and assume no legal liability for the information in this paper; nor does any party represent that the uses of this information will not infringe upon privately owned rights. This paper has not been approved or disapproved by the California Energy Commission or Cal/EPA, nor has the California Energy Commission or Cal/EPA passed upon the accuracy or adequacy of the information in this paper.

Arnold Schwarzenegger, *Governor*



"It is likely that the changes in climate that San Diego is experiencing due to the warming of the region will increase the frequency and intensity of fires even more, making the region more vulnerable to devastating fires like the ones seen in 2003 and 2007."

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California Applications Program (CAP) & The California Climate Change Center (CCCC)
CAP/CCCC is directed from the Climate Research Division, Scripps Institution of Oceanography

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How Can Information and Communications Technologies (ICT) Help Reduce Carbon Emissions?

- The Big Picture—Smart2020 Report
- Reduce Wasted Energy for Laptops, Printers, & PCs
- Make Cellular Infrastructure More Energy Efficient
- Campus Consolidation of Computing and Storage
- Make Data Centers More Energy Efficient
- Apply ICT to Other Sectors

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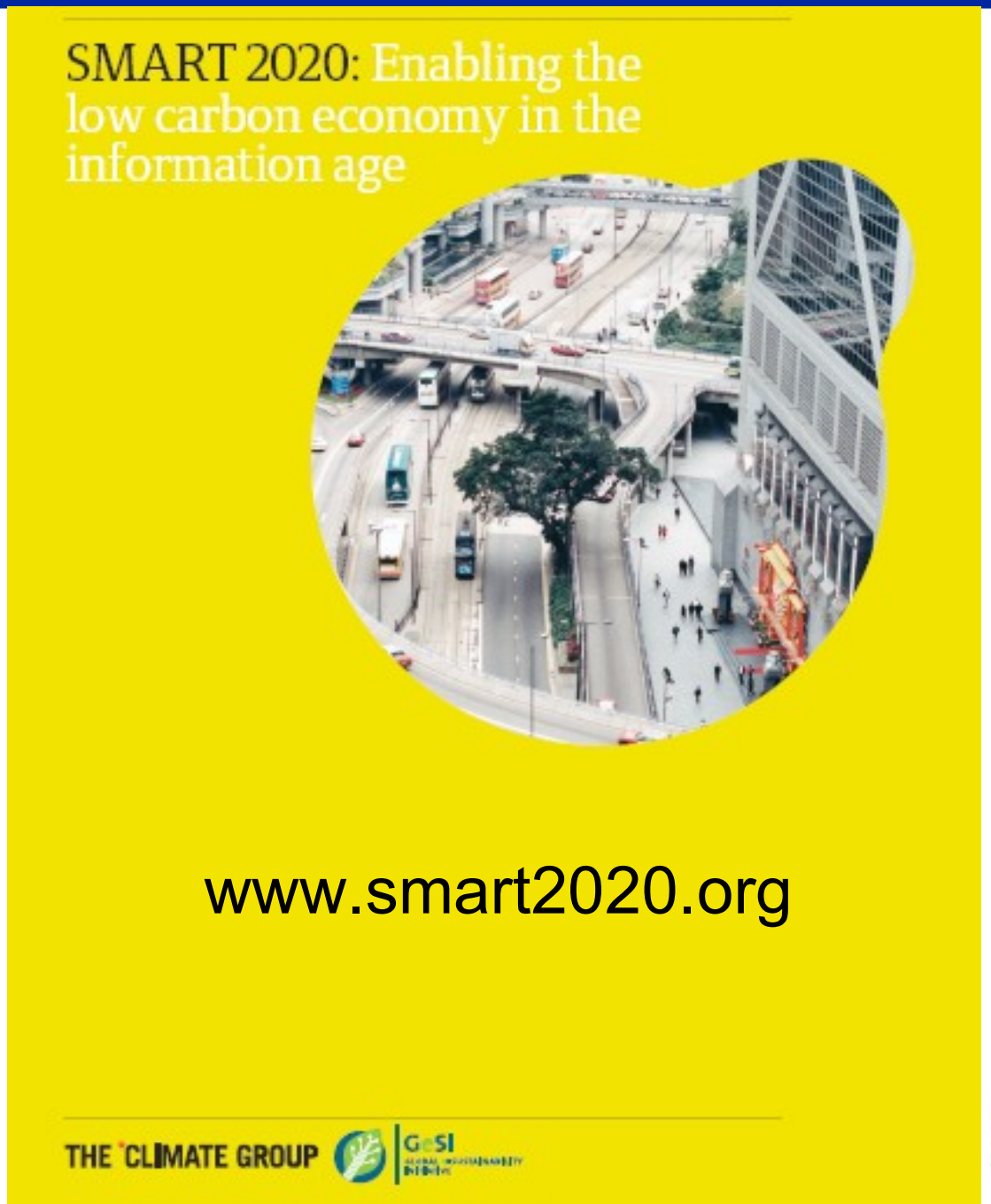
ICT is a Critical Element in Achieving Countries Greenhouse Gas Emission Reduction Targets

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:

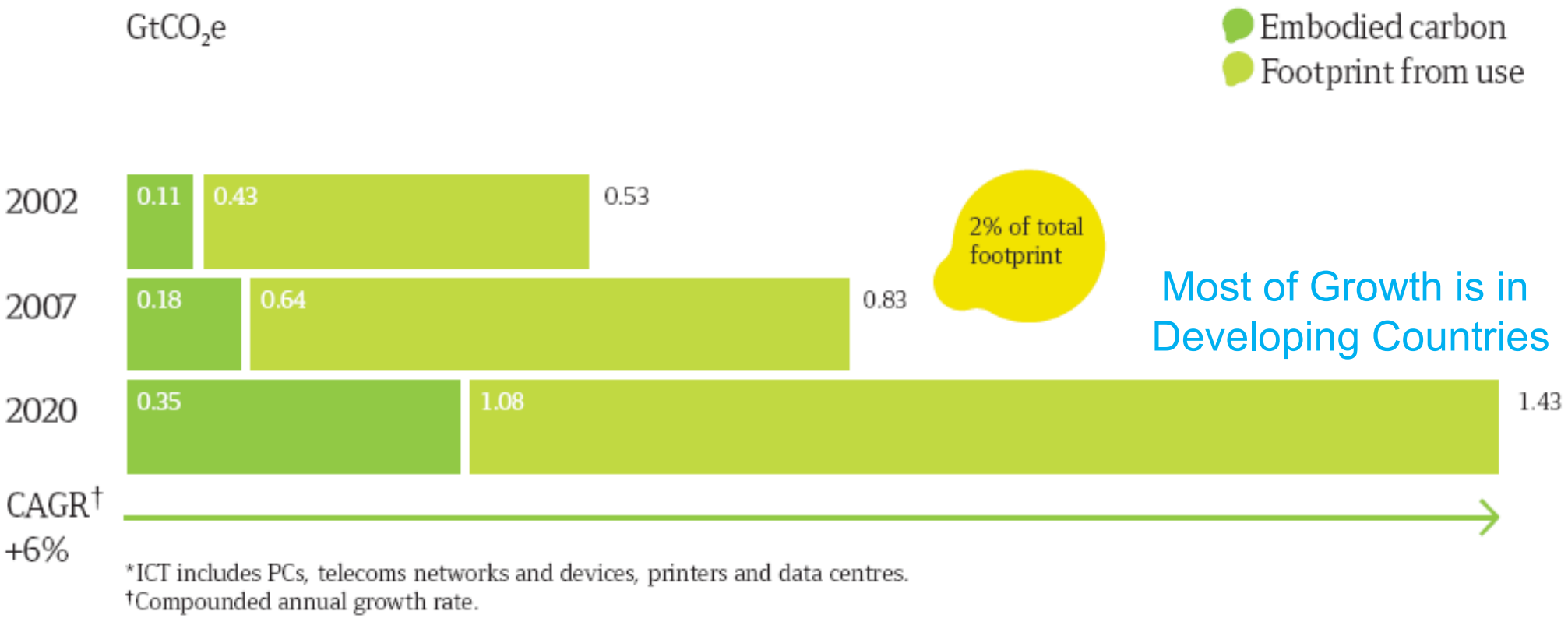
- Dell, LG.



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The Global ICT Carbon Footprint is Significant and 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

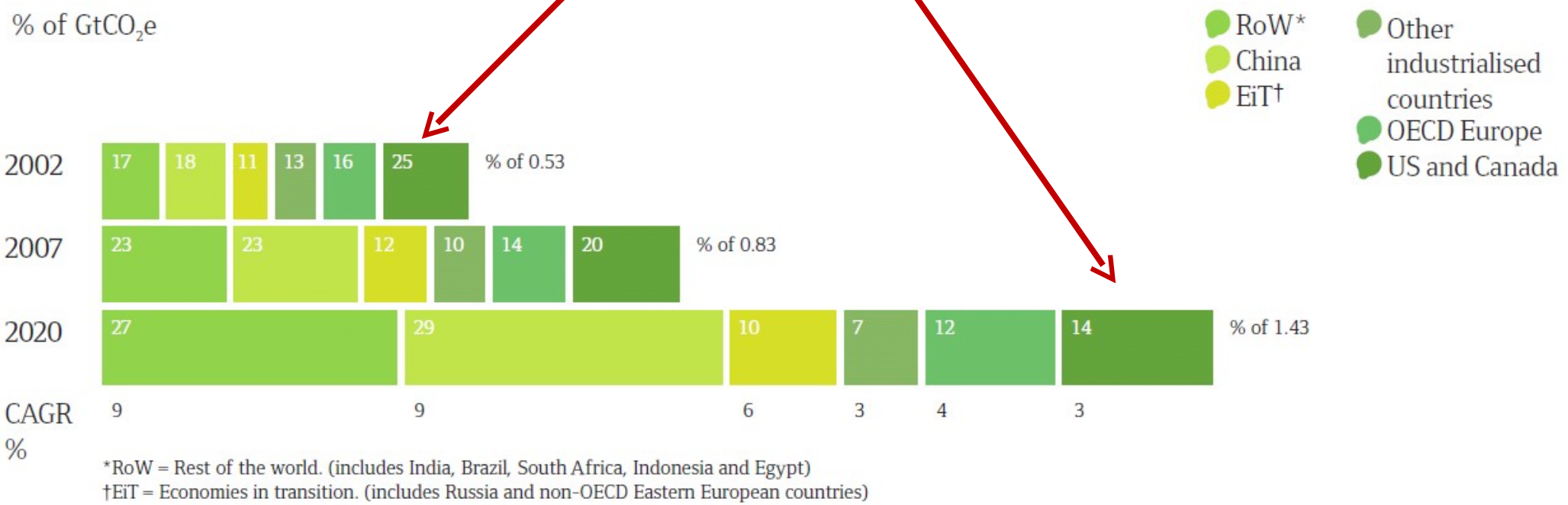
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Reduction of ICT Emissions is a Global Challenge – U.S. and Canada are Small Sources

U.S. plus Canada Percentage Falls From
25% to 14% of Global ICT Emissions by 2020

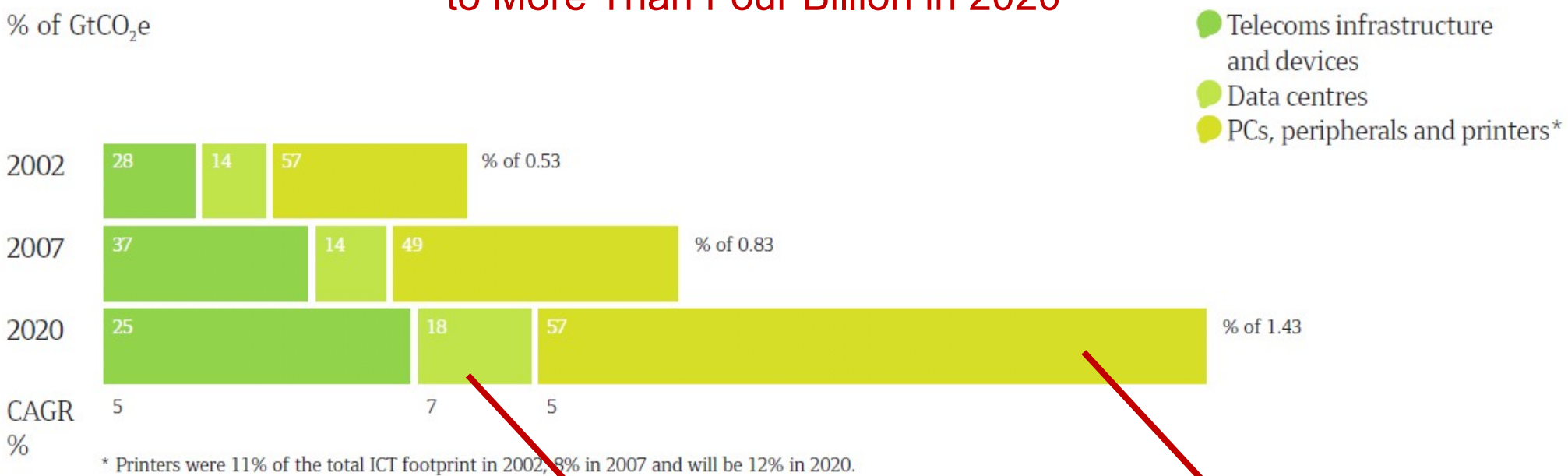


*RoW = Rest of the world. (includes India, Brazil, South Africa, Indonesia and Egypt)
†EiT = Economies in transition. (includes Russia and non-OECD Eastern European countries)

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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

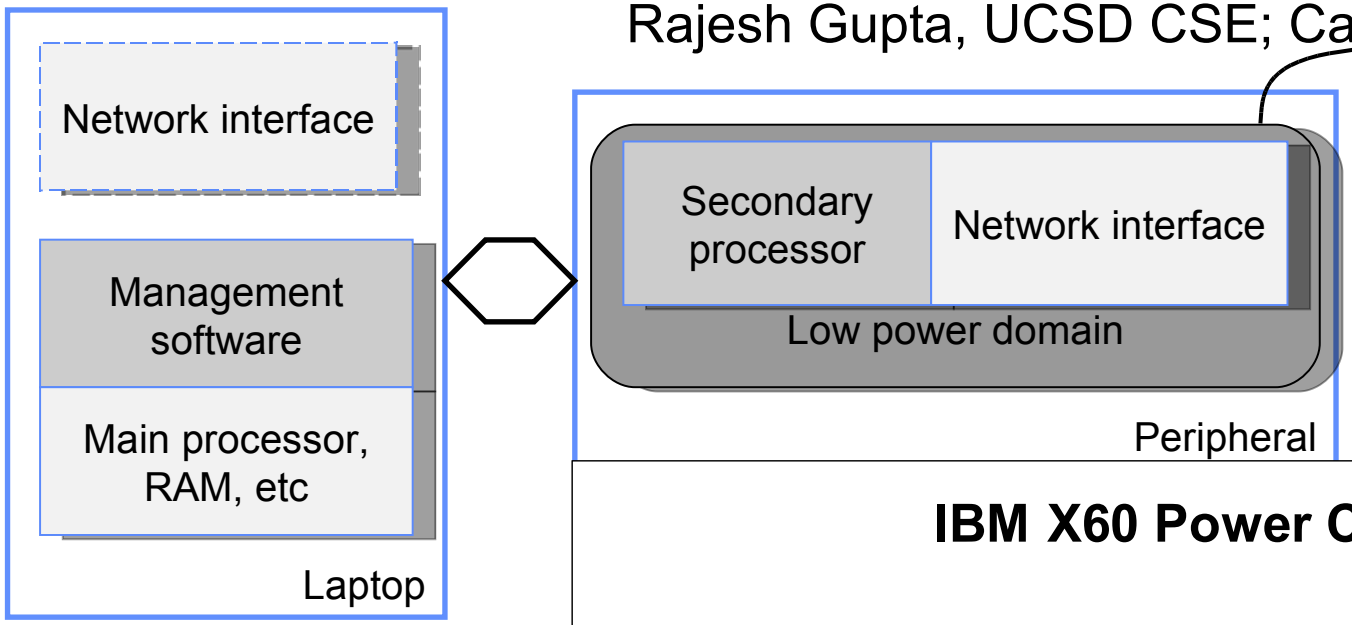
PCs Are Biggest Problem

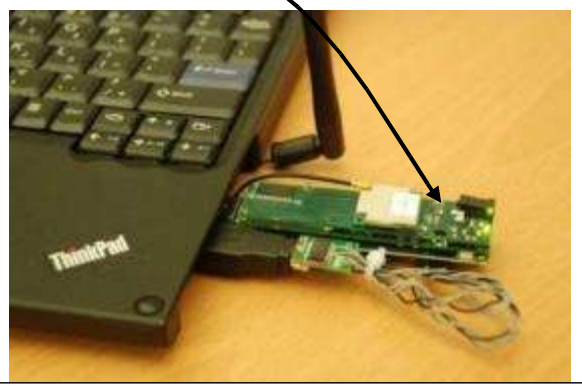
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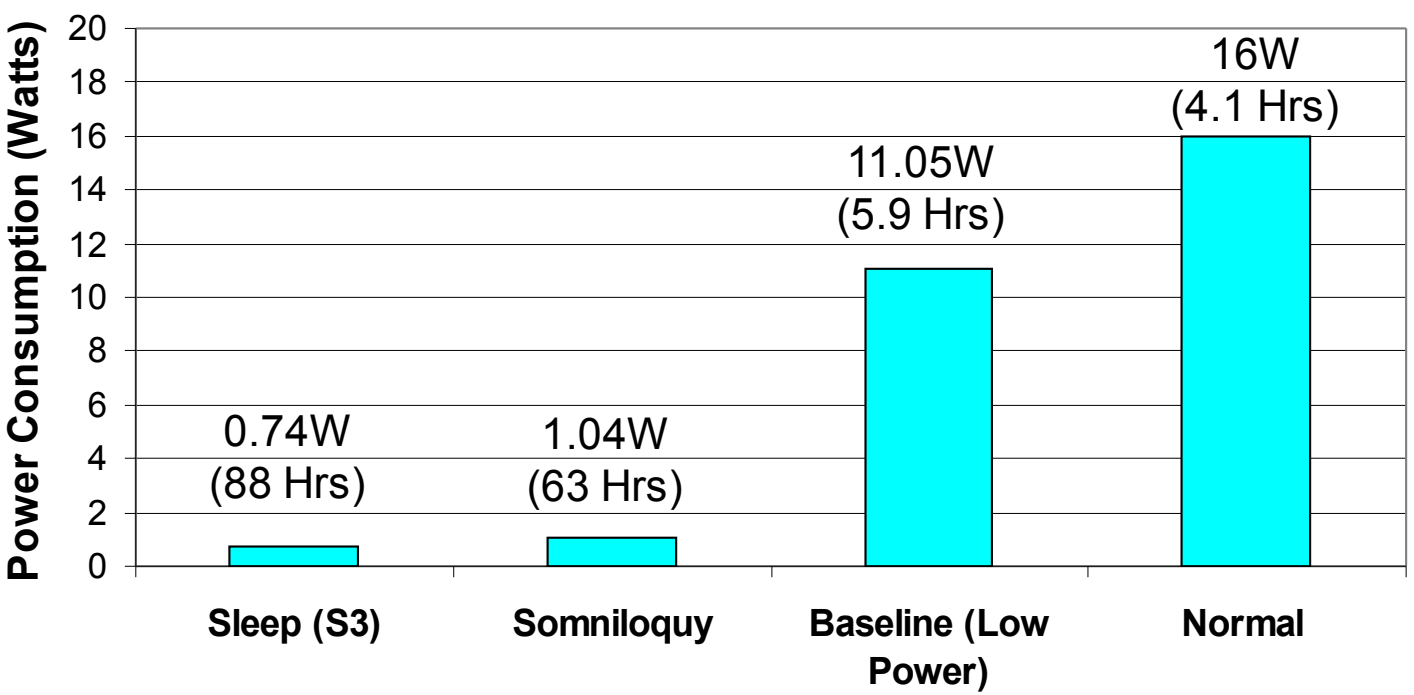
Increasing Laptop Energy Efficiency: Putting Machines To Sleep Transparently

Rajesh Gupta, UCSD CSE; Calit2





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



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Desktops: Power Savings with *SleepServer:* A Networked Server-Based Energy Saving System

State	Power
Normal Idle State	102.1W
Lowest CPU Frequency	97.4W
Disable Multiple Cores	93.1W
"Base Power"	93.1W
Sleep state (ACPI State S3) Using SleepServers	2.3W

Dell OptiPlex 745 Desktop PC

- **Power Drops from 102W to < 2.5W**
- **Assuming a 45 Hour Work Week**
  - **620kWh Saved per Year, for Each PC (~ $60 Savings/Year)**
- **Additional Application Latency: 3s - 10s Across Applications**
  - **Not Significant as a Percentage of Resulting Session**

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Source: Rajesh Gupta, UCSD CSE, Calit2

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PC: 68% Energy Saving Since SSR Deployment

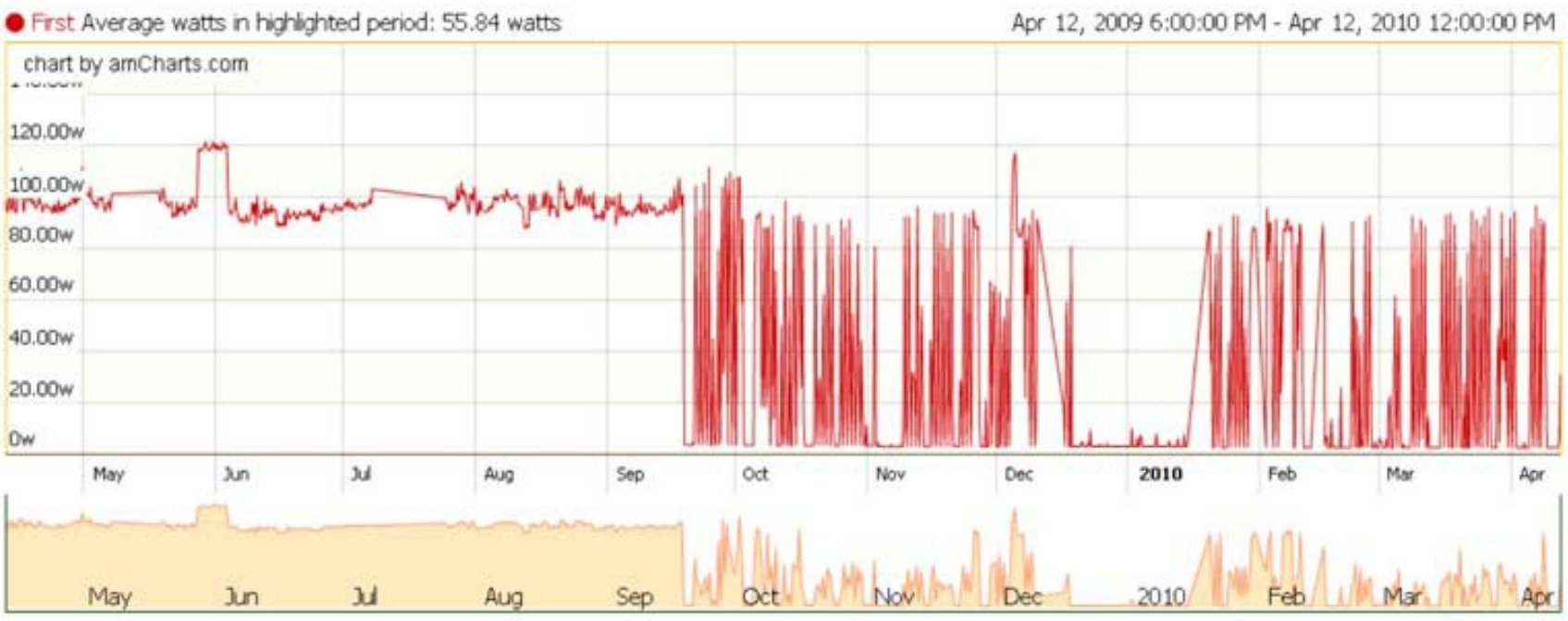


energy.ucsd.edu

kW-Hours:488.77 kW-H Averge Watts:55.80 W
Energy costs:$63.54
Estimated Energy Savings with Sleep Server: 32.62%
Estimated Cost Savings with Sleep Server: $28.4

Past year Power consumption for device #3091420330

From: Apr, 12, 2009 12:28:50 PM **Resolution:** Every six hours (averaged)
To: Apr, 12, 2010 12:28:50 PM **Timespan:** 1 year



Zoom in this graph (for better data resolution, generate a new graph with a smaller time duration): 10D 1M 3M 1Y YTD MAX

Power Management in the Cellular Infrastructure: Calit2 Team 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

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Power Transistor Tradeoffs:

Si-LDMOS, GaN, & GaAs

Price & Performance

Eudyna

Power Amplifier Tradeoffs:

WiMAX & 3.9GPP LTE

Efficiency & Linearity

STMicroelectronics

Digital Signal Processing Tradeoffs:

Pre-Distortion, Memory Effects
& Power Control

MIPS & Memory

NOKIA

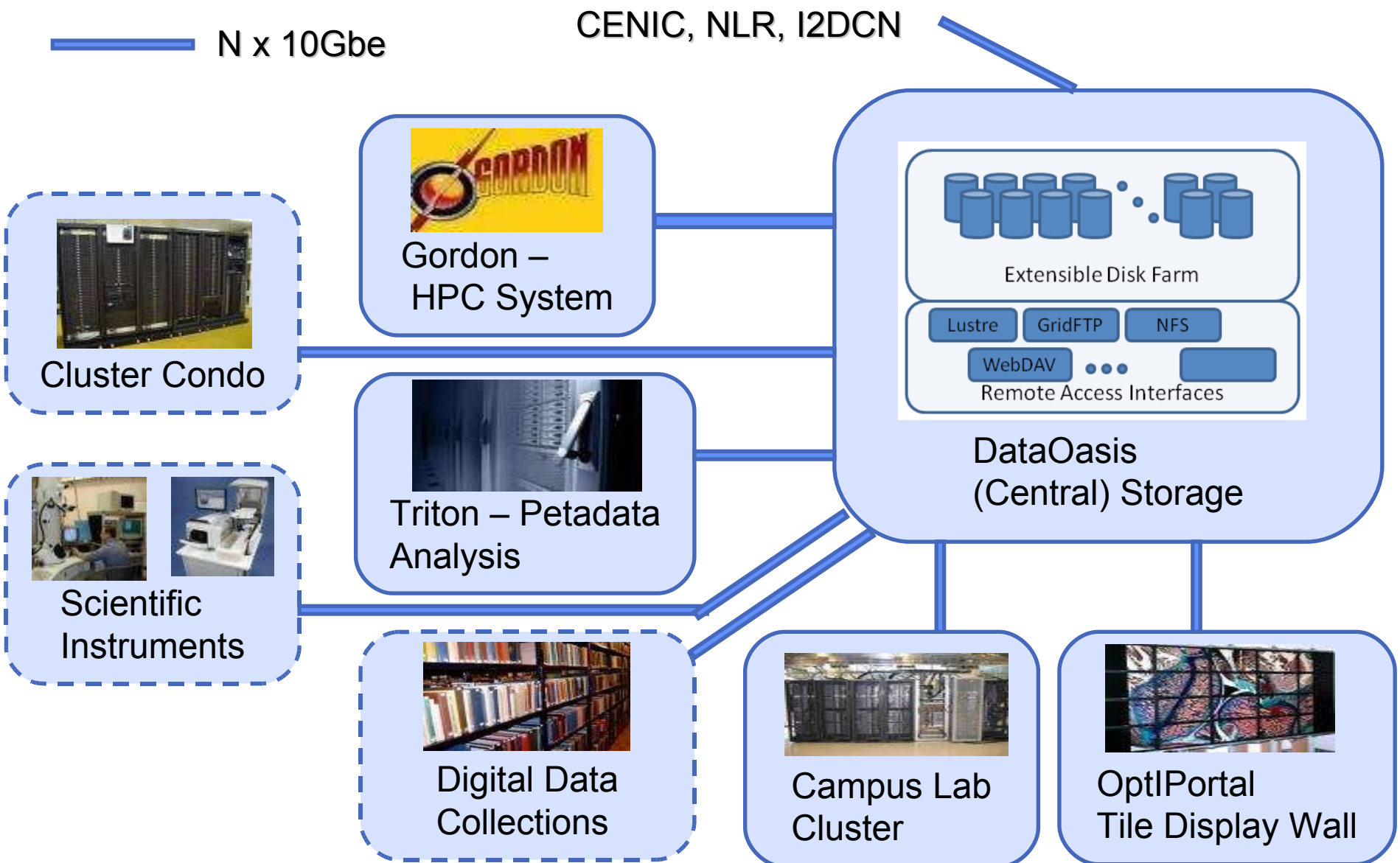
QUALCOMM

www.universityofcalifornia.edu/news/article/19058

Source: Don Kimball, Calit2; Peter Asbeck and Larry Larson, ECE

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UCSD Campus Investment in Fiber and Networks Enables Consolidation of Computing and Storage



Source: Philip Papadopoulos, SDSC, UCSD

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**





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Source: Tom DeFanti, Calit2; GreenLight PI

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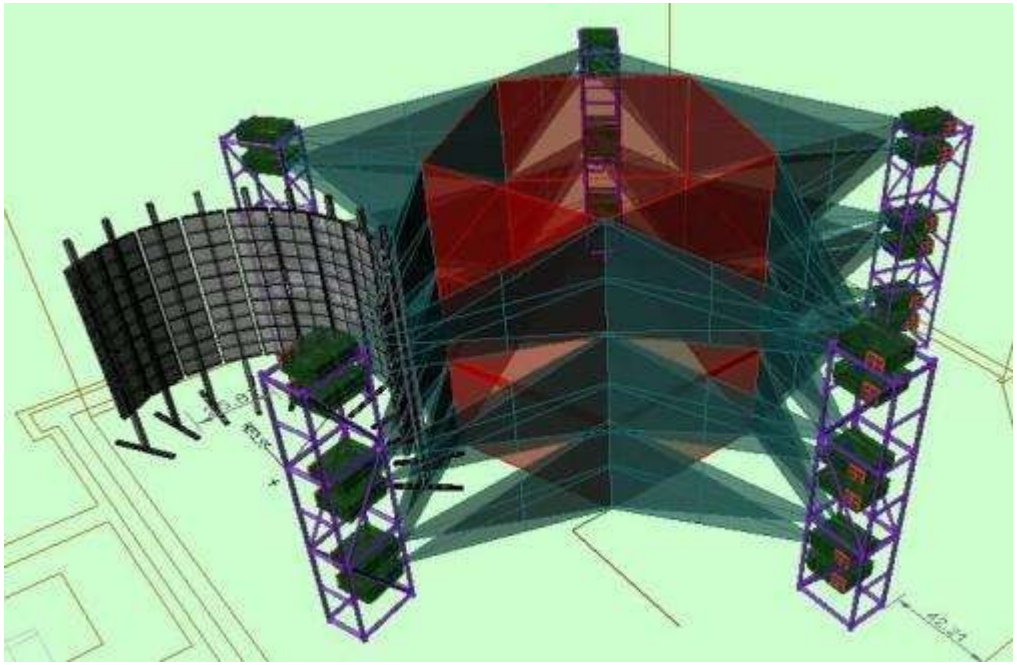
GreenLight's Data is Available Remotely: Virtual Version in Calit2 StarCAVE







30 HD Projectors!



Connected at 50 Gb/s to Quartzite

Source: Tom DeFanti, Greg Dawe, Jurgen Schulze, Calit2

Research Needed on How to Deploy a Green CI



- **Computer Architecture**
  - Rajesh Gupta/CSE
- **Software Architecture, Clouds**
  - 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

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http://greenlight.calit2.net

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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

QUALCOMM hp invent Texas Instruments Inc. YAHOO! DARPA NSF Los Alamos NATIONAL LABORATORY EST. 1943 U.S. DEPARTMENT OF ENERGY Sun microsystems CISCO National Institutes of Health The Nation's Medical Research Agency SRC Semiconductor Research Corporation

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

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Berkeley University of California

CALTECH

Columbia University in the City of New York

NSU Norfolk State University

STANFORD

Tuskegee University

UCLA

USC

CIAN Center for Integrated Access Networks

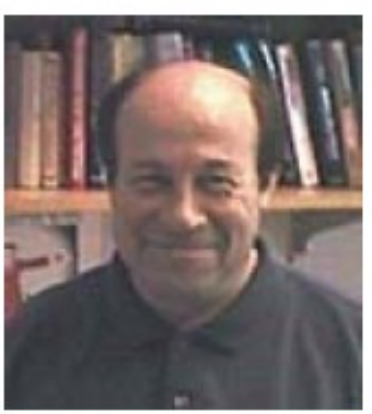


Director:
N. Peyghambarian

The University of Arizona
Tucson Arizona

Deputy Director:
S. Fainman

University of California San Diego

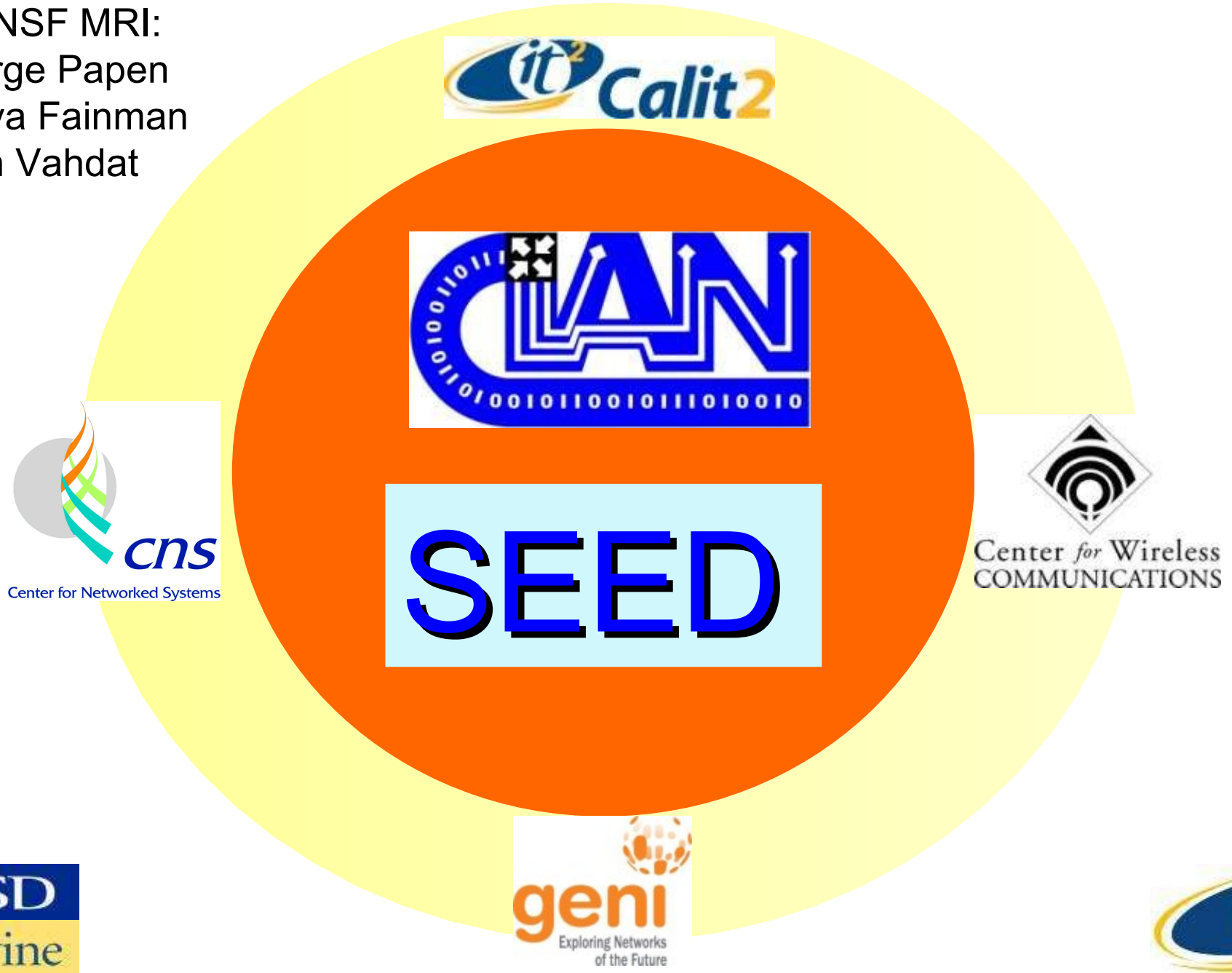


An NSF Gen-III Engineering Research Center
www.cian-erc.org

UCSD Scalable Energy Efficient Datacenter Project (SEED)

PIs of NSF MRI:

- George Papen
- Shaya Fainman
- Amin Vahdat



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Challenge: How Can Commercial Modular Data Centers Be Made More Energy Efficient?

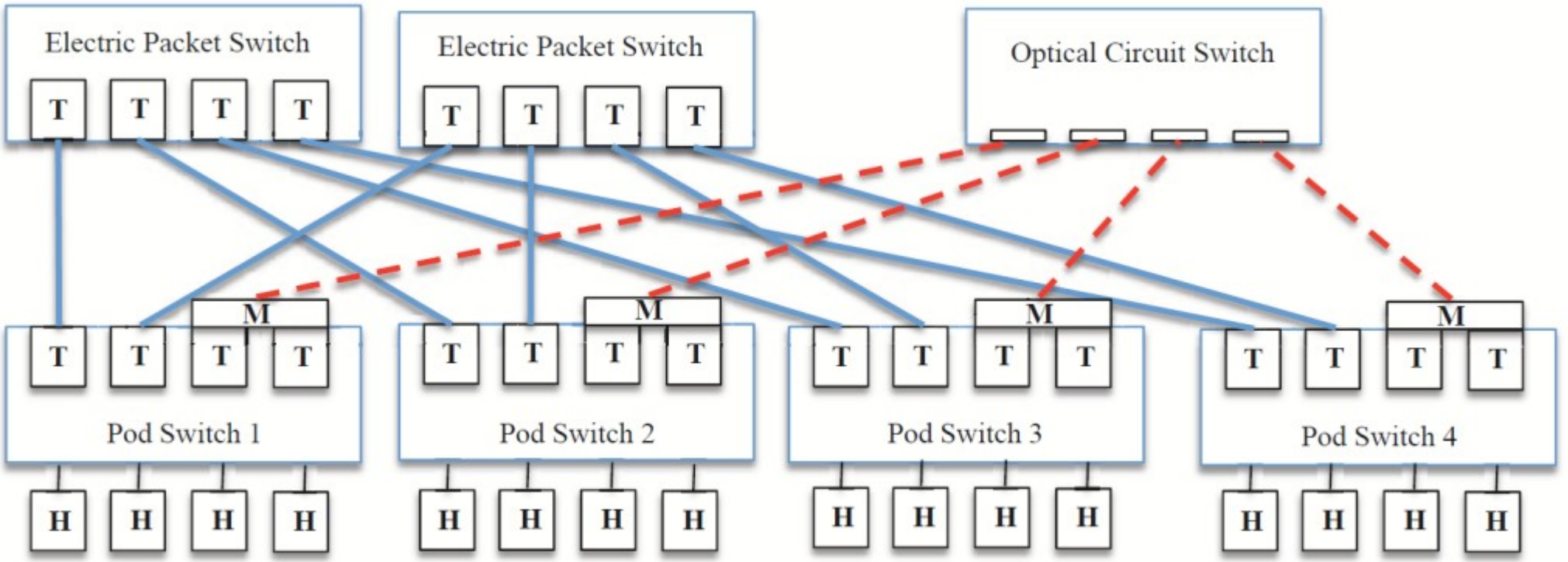


Source: Michael Manos

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Energy-Efficient Networking: Hybrid Electrical-Optical Switch



- **Build a Balanced System to Reduce Energy Consumption**
  - **Dynamic Energy Management**
  - **Use Optics for 90% of Total Data Which is Carried in 10% of the Flows**
- **SEED Testbed in Calit2 Machine Room and Sunlight Optical Switch**
  - **Hybrid Approach Can Realize 3x Cost Reduction; 6x Reduction in Cabling; and 9x Reduction in Power**

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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

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

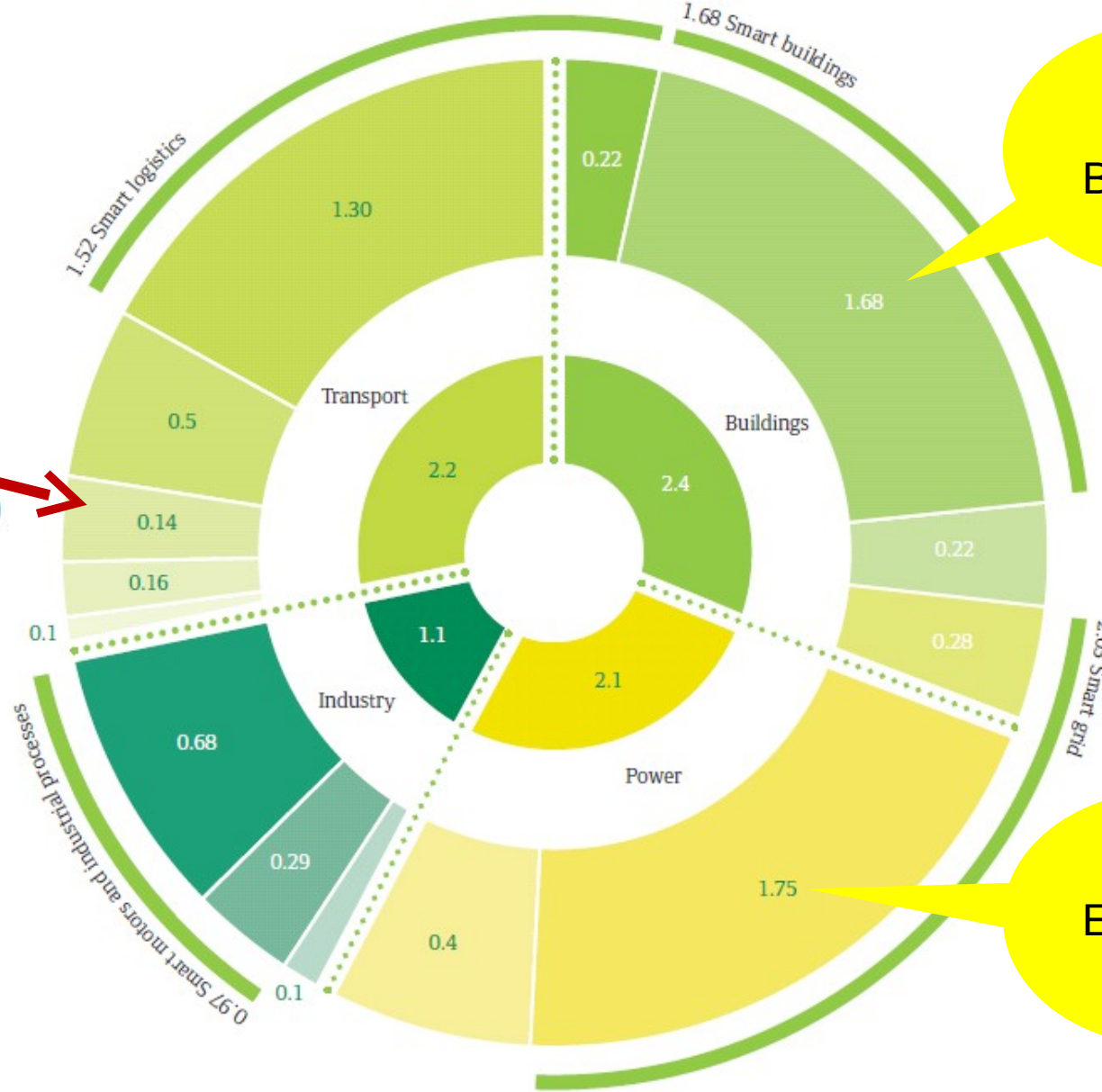
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Industry
- Smart motors
- Industrial process automation
- Dematerialisation* (reduce production of DVDs, paper)

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

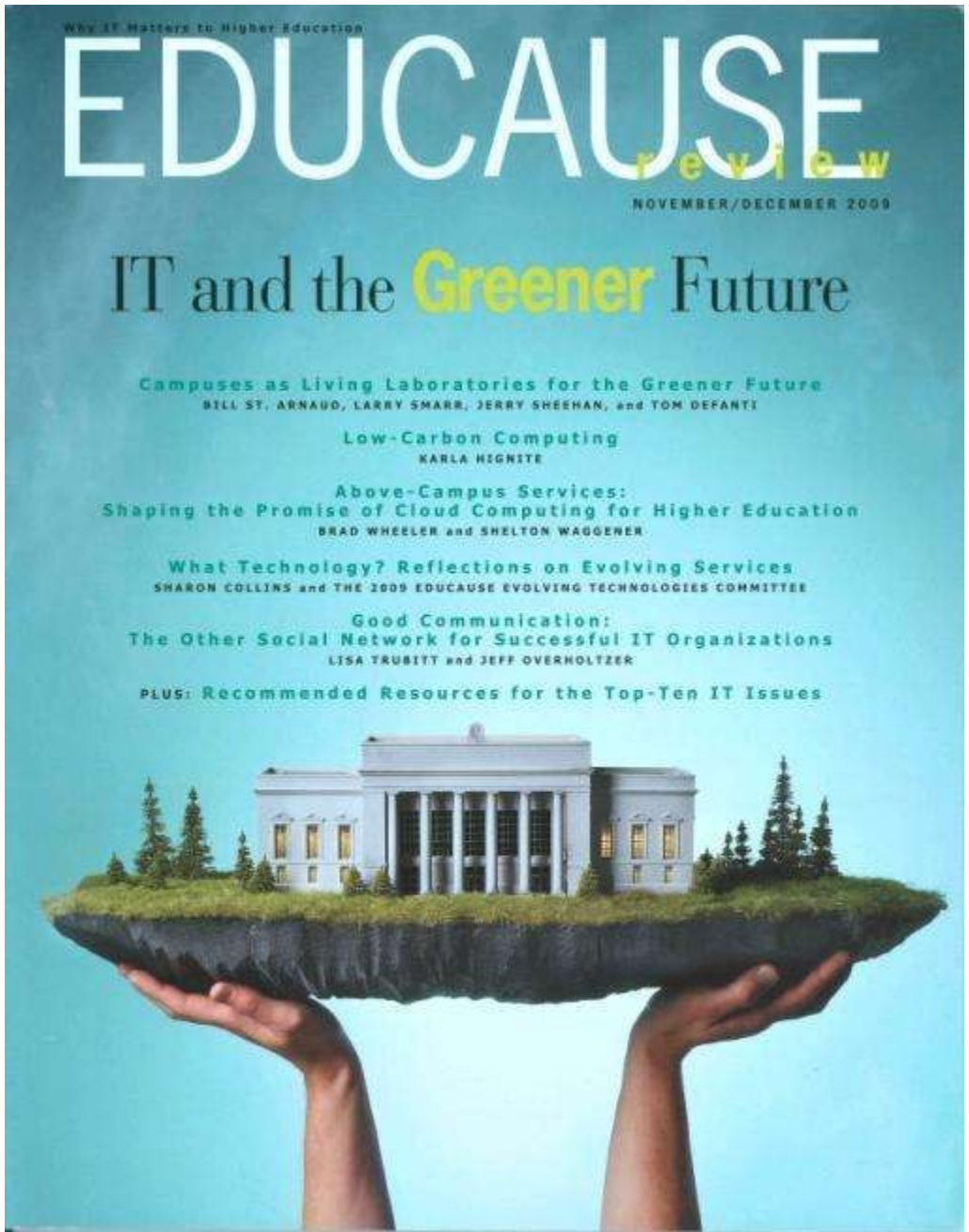
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UCI Named 'Best Overall' in Flex Your Power Awards
www.today.uci.edu/news/release_detail.asp?key=1859

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Making University Campuses Living Laboratories for the Greener Future

www.educause.edu/EDUCAUSE+Review/EDUCAUSEReviewMagazineVolume44/CampusesasLivingLaboratoriesfo/185217



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Using High Definition to Link the Calit2 Buildings: Living Greener



une 2, 2008

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HD Talk to Australia's Monash University from Calit2: Reducing International Travel



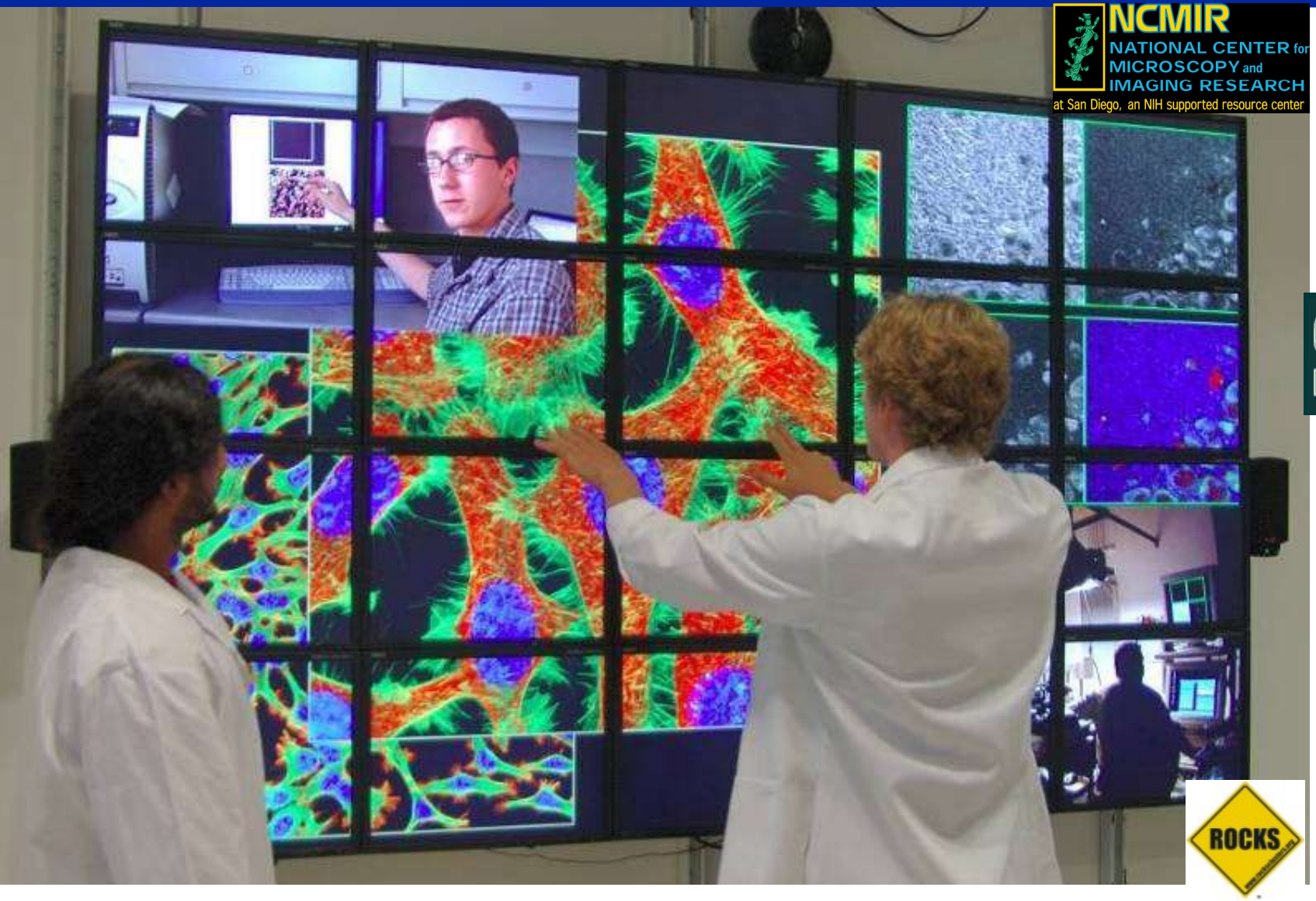
Qvidium Compressed HD ~140 mbps

Source: David Abramson, Monash Univ

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The OptIPuter Project: Creating High Resolution Portals Over Dedicated Optical Channels to Global Science Data



NCMIR
NATIONAL CENTER for MICROSCOPY and IMAGING RESEARCH
at San Diego, an NIH supported resource center

Scalable Adaptive Graphics Environment (SAGE)

SAGE

evl electronic visualization laboratory

NSF

ROCKS

Picture Source: Mark Ellisman, David Lee, Jason Leigh

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Calit2 (UCSD, UCI), SDSC, and UIC Leads—Larry Smarr PI
Univ. Partners: NCSA, USC, SDSU, NW, TA&M, UvA, SARA, KISTI, AIST
Industry: IBM, Sun, Telcordia, Chiaro, Calient, Glimmerglass, Lucent

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



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Photo by Erik Jepsen, UC San Diego

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



NASA Interest in Supporting Virtual Institutes

CGLX

LifeSize HD

NASA Ames
Lunar Science Institute
Mountain View, CA

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

First Tri-Continental Premier of a Streamed 4K Feature Film With Global HD Discussion



CRCA

CISCO
C-wave
CineGrid

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4K Transmission Over 10Gbps--
4 HD Projections from One 4K Projector

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



Import/Production | Meter Reads | Vista

UCSD MAP | HOUSING

Real Time Cost Per Hour $ 2,570

Real Time kW Usage 30,238 kW

	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

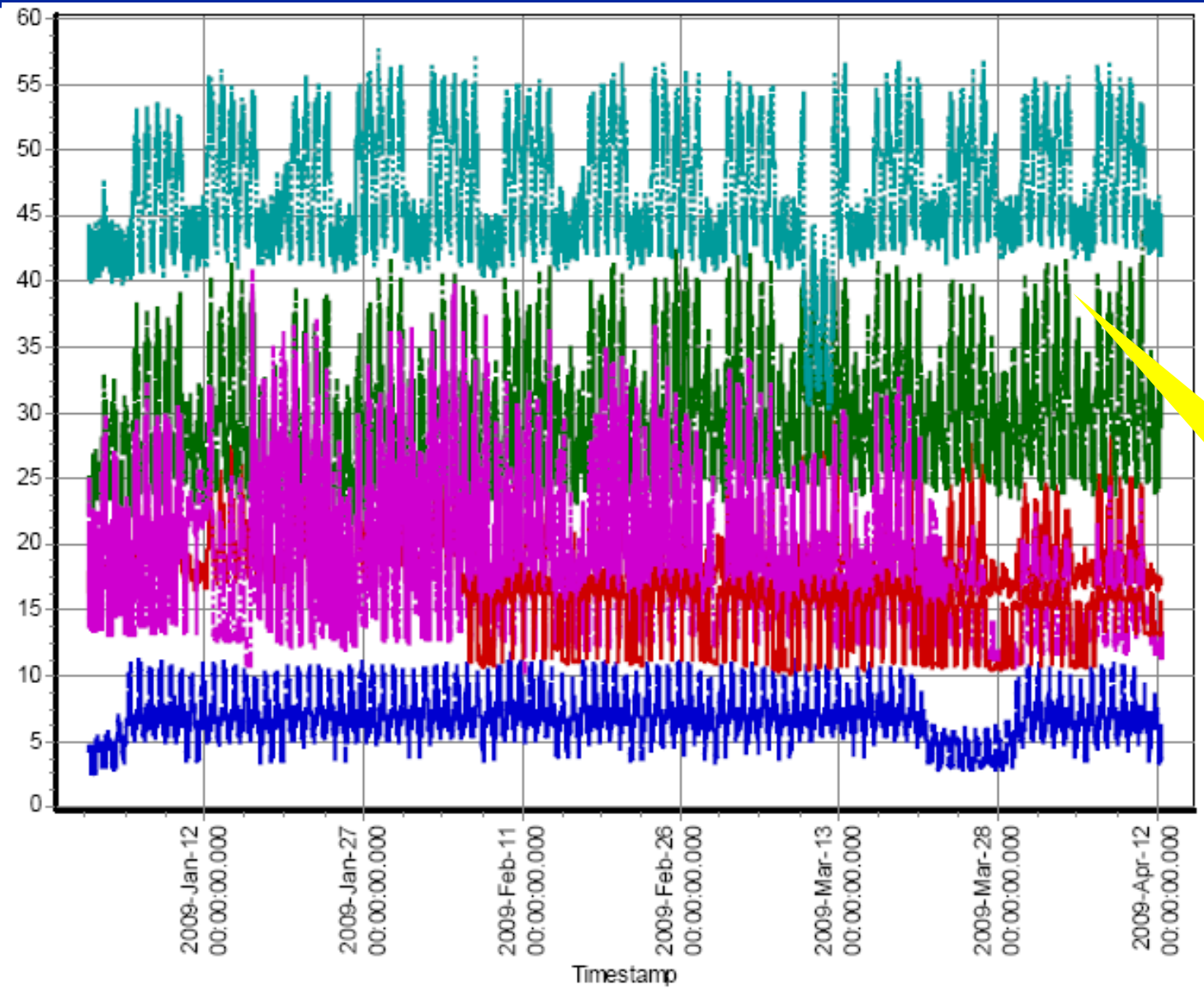
	SOM	North Campus	Revelle Campus	Central Plant	UCSD Total
Current Month:					
Monthly Cost ($)	19,075	30,163	236,794	93,913	734,148
kWh del	224,414 kWh	354,860 kWh	2,785,807 kWh	1,104,854 kWh	8,637,030 kWh
Previous Month:					
Monthly Cost ($)	45,133	67,085	557,638	184,830	1,673,499
kWh del	530,982 kWh	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

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

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Comparision Between UCSD Buildings: kW/sqFt Year Since 1/1/09



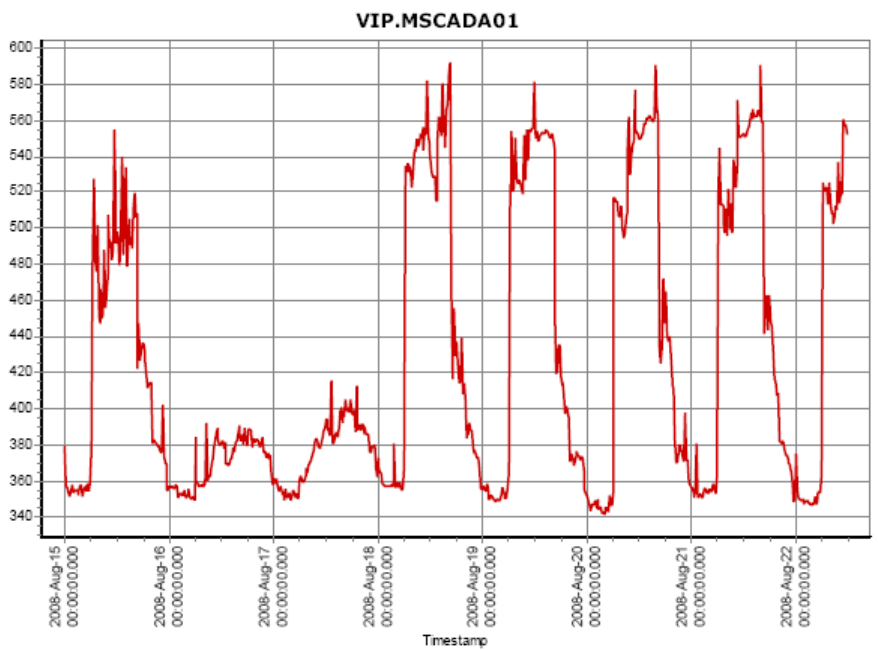
Calit2 and CSE are Very Energy Intensive Buildings

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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!



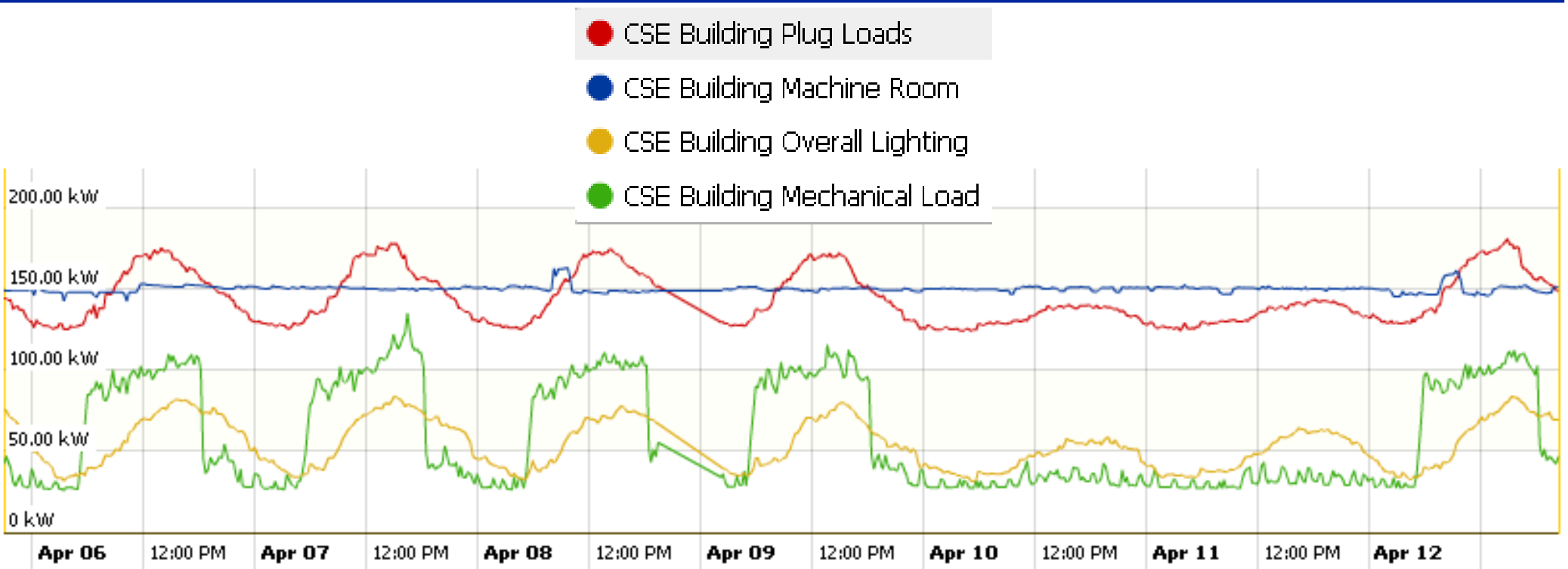


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Source: Rajesh Gupta, CSE, Calit2

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Contributors to the CSE Base Load



- **IT loads account for 50% (peak) to 80% (off-peak)!**
  - **Includes machine room + plug loads**
- **IT equipment, even when idle, not put to sleep**
- **Duty-Cycling IT loads essential to reduce baseline**

Source: Rajesh Gupta, UCSD CSE, Calit2

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

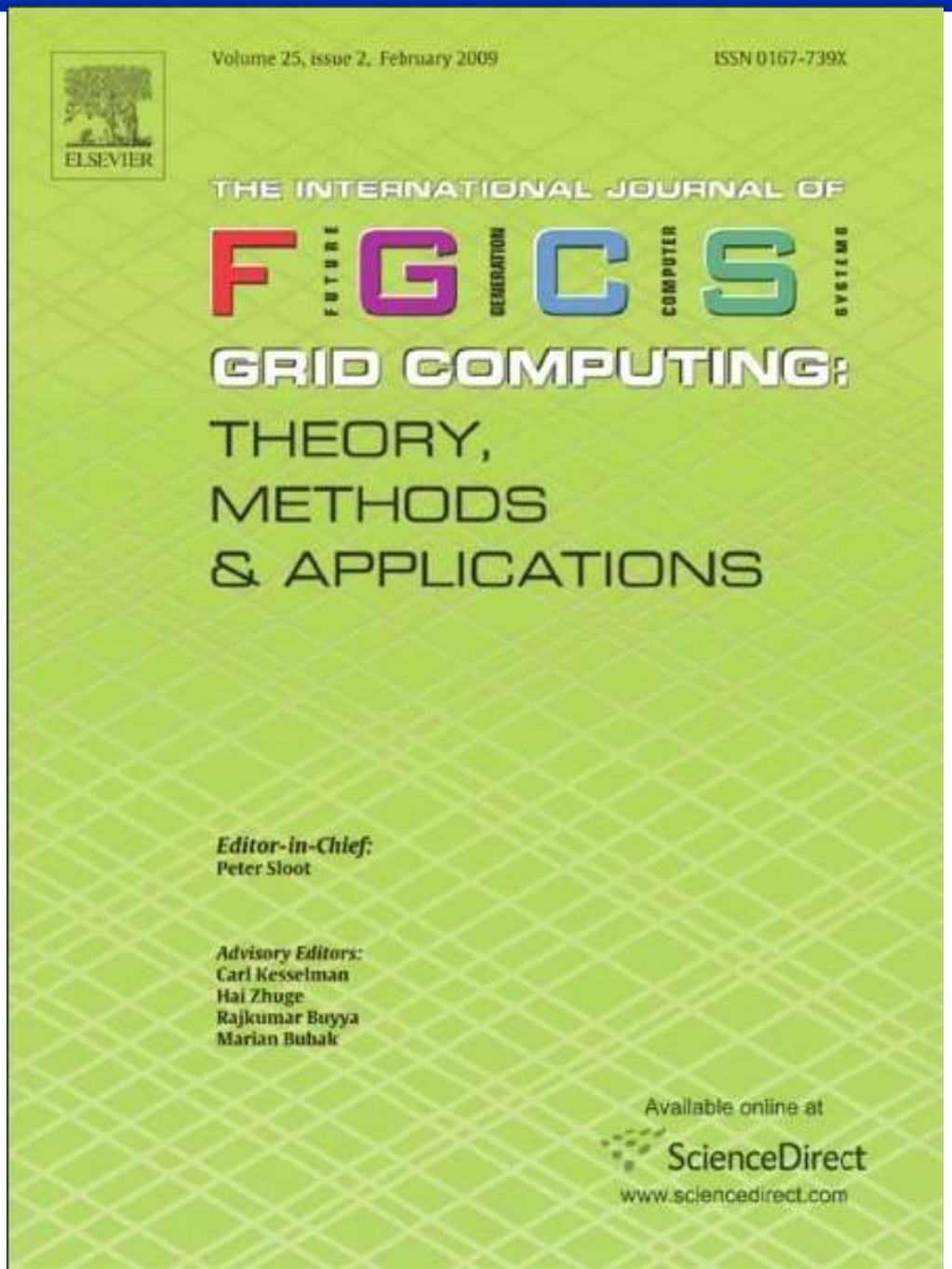
Co-Hosted By Calit2 & CPUC

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January 22-23, 2009



For Technical Details
On OptIPuter Project and OptIPortals



"OptIPlanet: The OptIPuter Global Collaboratory" –

Special Section of Future Generations Computer Systems,

Volume 25, Issue 2, February 2009

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- T. Pering, Y. Agarwal, R.h Gupta, R. Want, “CoolSpots: Reducing the power consumption of wireless mobile devices with multiple radio interfaces,” in Proc. of ACM Mobile Systems, Apps and Services (MobiSys ’06), June 2006.
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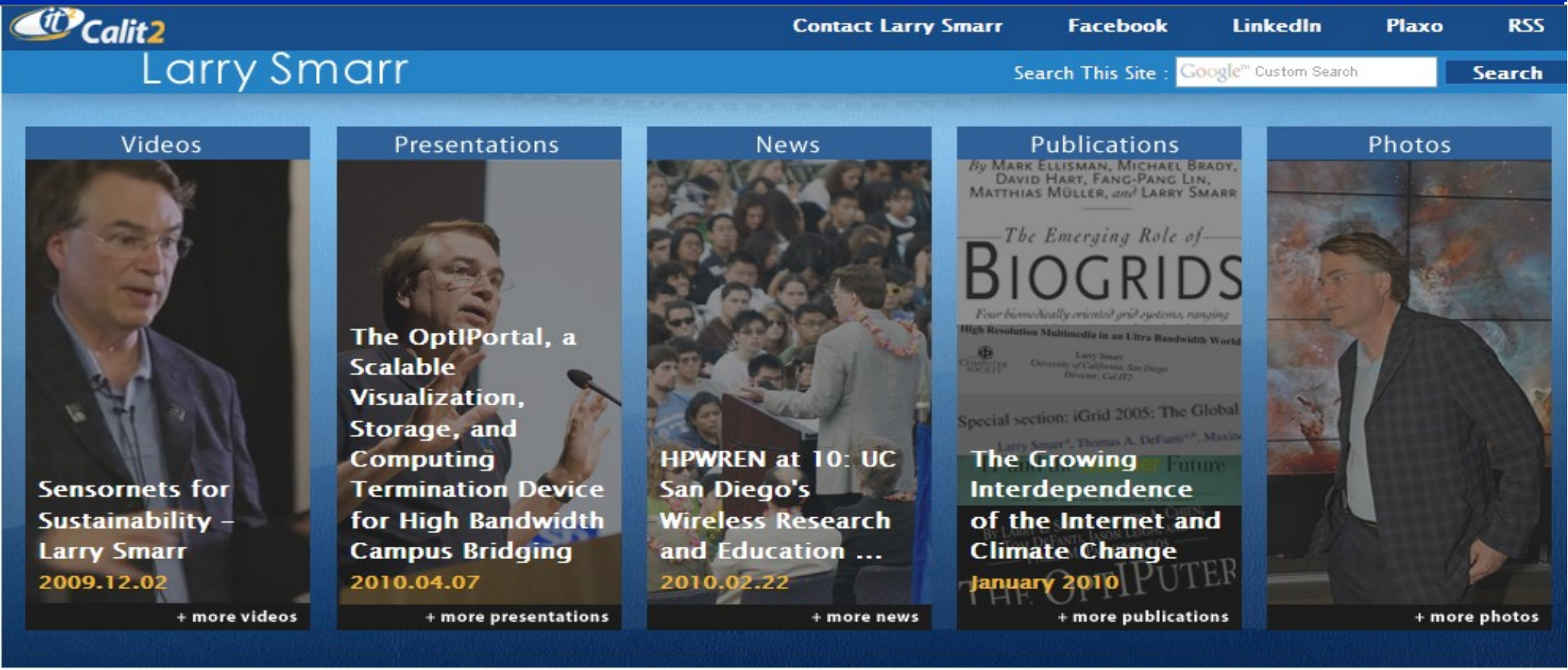
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You Can Download This Presentation at lsmarr.calit2.net



ABOUT LARRY SMARR

Larry Smarr is the founding Director of the California Institute for Telecommunications and Information Technology (Calit2), a UC San Diego/UC Irvine partnership, and holds the Harry E. Gruber professorship in Computer Science and Engineering (CSE) at UCSD's Jacobs School. At Calit2, Smarr has continued to drive major developments in information

WHAT I'M READING

Complete List of Larry's Recommendations

American College and University Presidents' Climate Commitment

A Doctor's Vision of the Future of Medicine

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Ismarr: Had dinner with John Bowers, Director, UCSB Institute for Energy Efficiency, & Fred Chong, Director, Center for Energy-Efficient Computing

Wed, 14 Apr