Digital Infrastructure in a Carbon Constrained World

Invited Presentation to the
West Coast Leadership Dialogue
Stanford University
January 15, 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

I thank my colleagues for their input to this talk:

Tom DeFanti, Jerry Sheehan
California Institute for Telecommunications and Information Technology (Calit2),

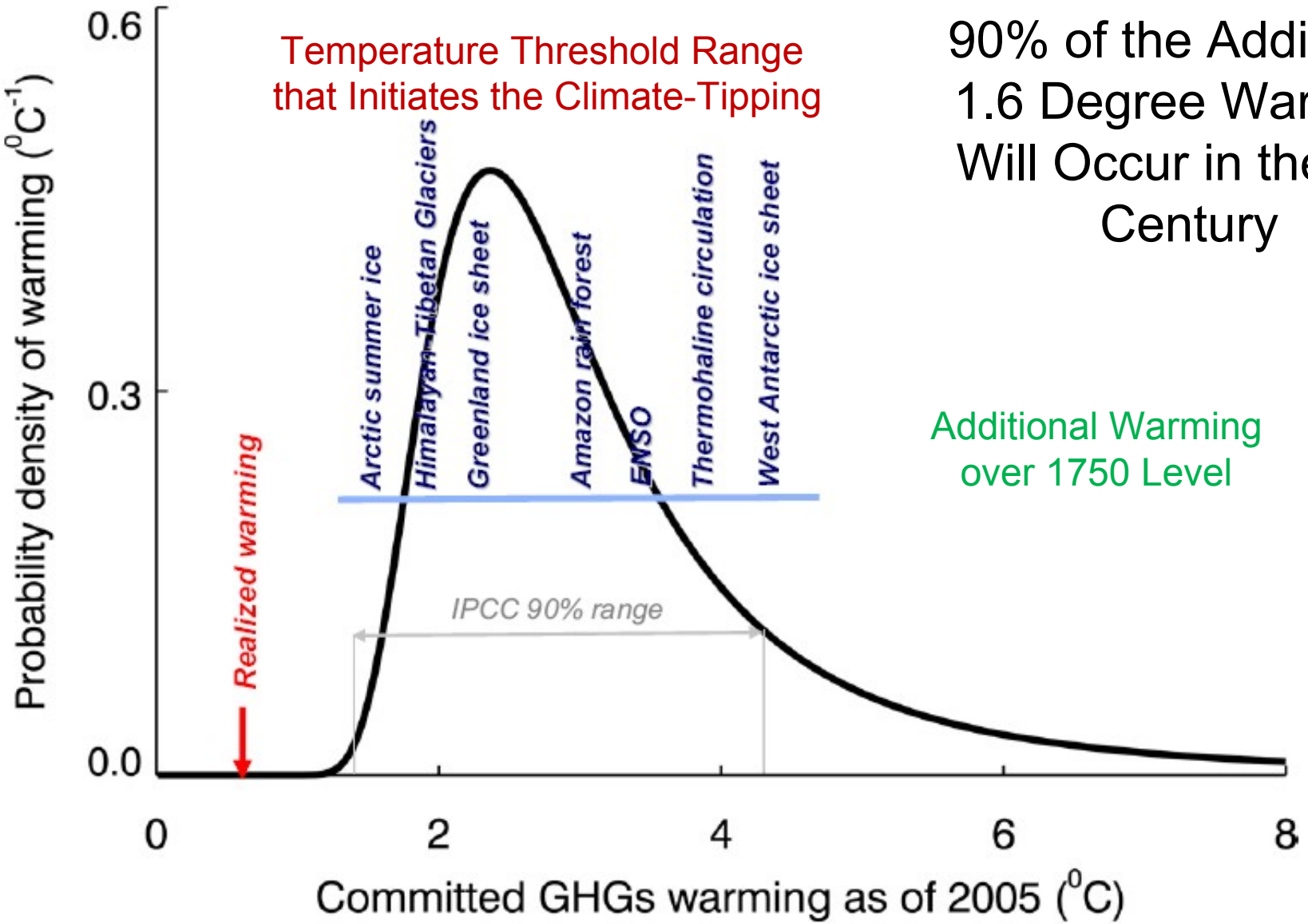
Rod Tucker
Australian Research Council Centre for Ultra-Broadband Information Networks (CUBIN),

Bill St Arnaud,
Canada's Advanced Network CANARIE,





The Planet is Already Committed to a Dangerous Level of Warming

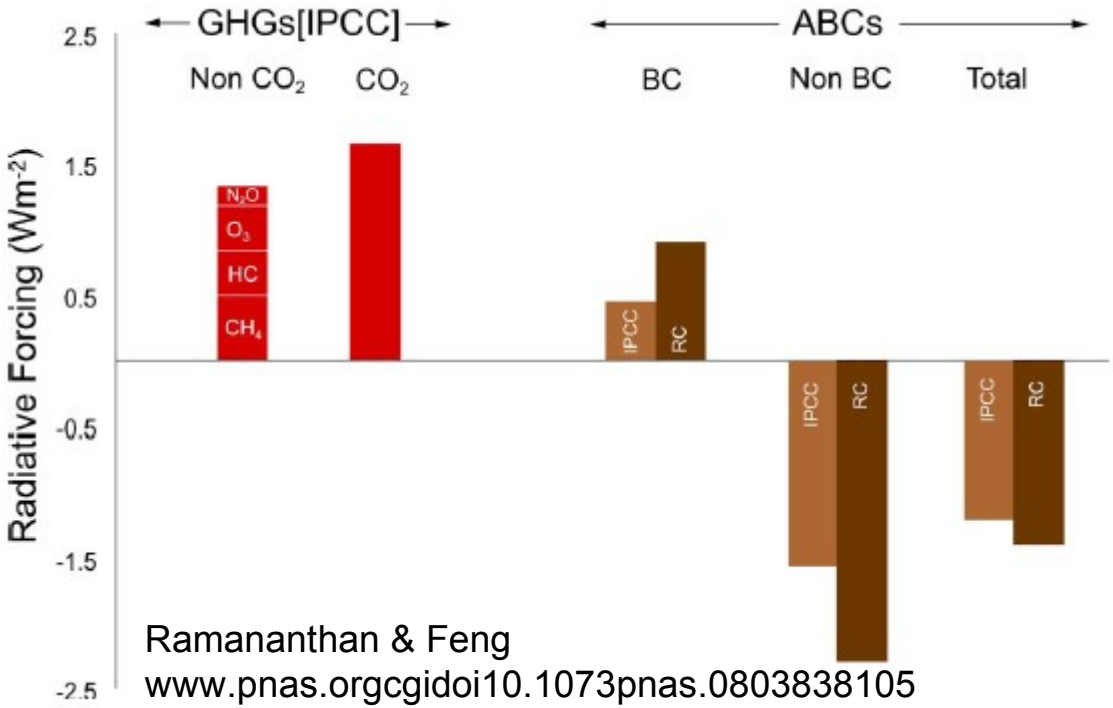


90% of the Additional 1.6 Degree Warming Will Occur in the 21st Century

Additional Warming over 1750 Level

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

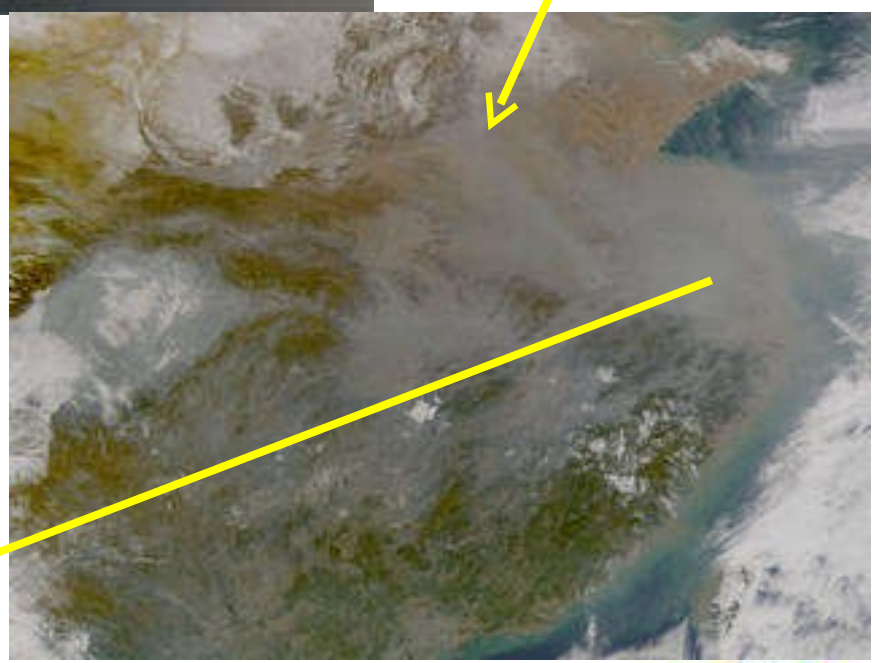
Atmospheric Aerosols Cool Climate—Cleaning Air Pollution will Accelerate Warming!



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





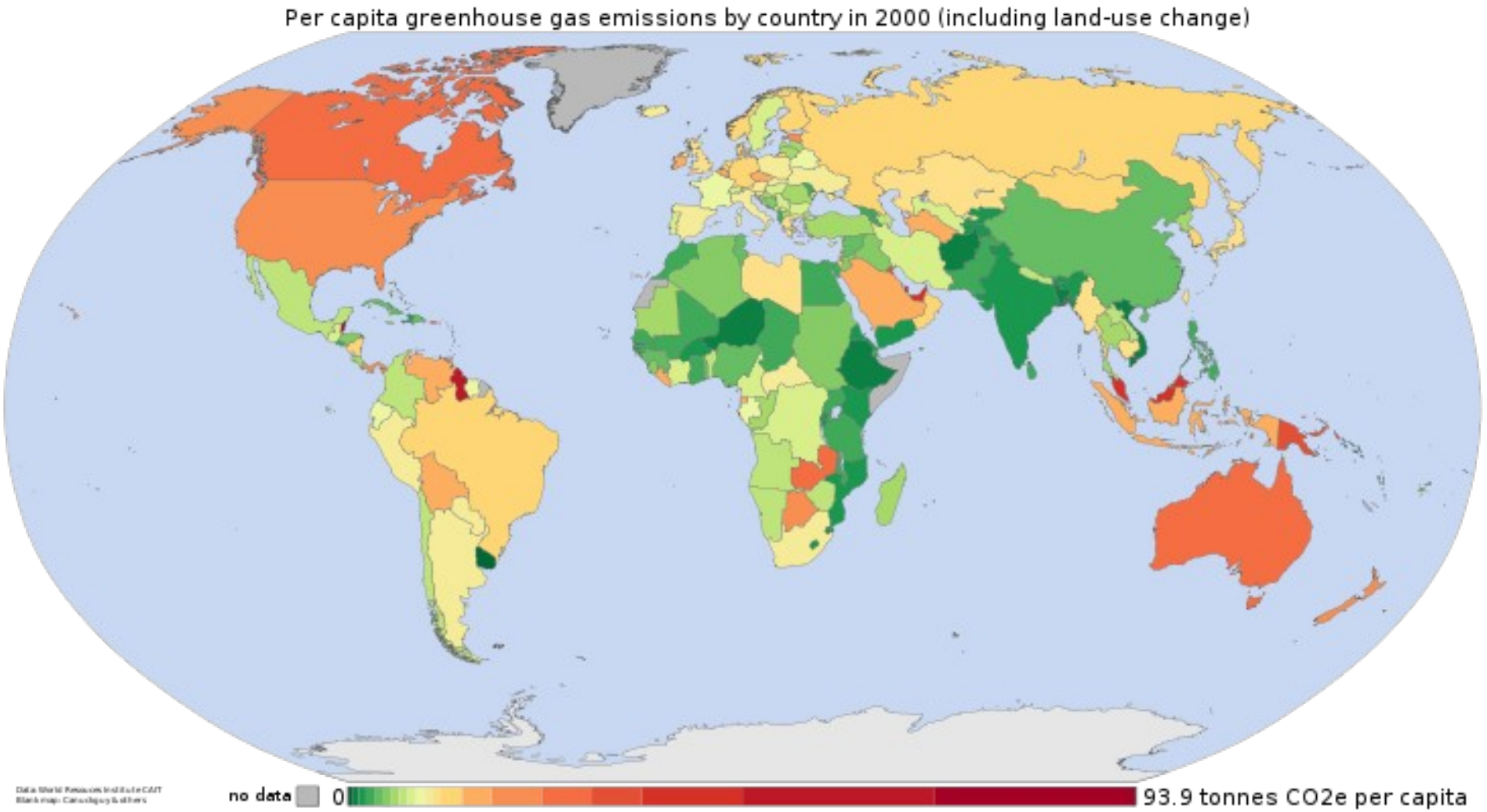


NASA satellite image

Outside Beijing 11/9/2008



Australia, the U.S., and Canada Share a Problem: Top 3 Developed Countries For Per Capita GHG Emission



"Australia's Total Emissions Exceed Those of France and Italy"
--Australia Institute

http://en.wikipedia.org/wiki/File:GHG_per_capita_2000.svg

Countries and States are Setting Aggressive Greenhouse Gas Reduction Goals

"Australia is today the biggest carbon polluter
in the developed world on a per capita basis,
yet we are the developed country
with the most to lose from climate change.
Without action on climate change,
Australia faces a future of parched farms,
bleached reefs, and empty reservoirs."
--Australian Prime Minister Kevin Rudd

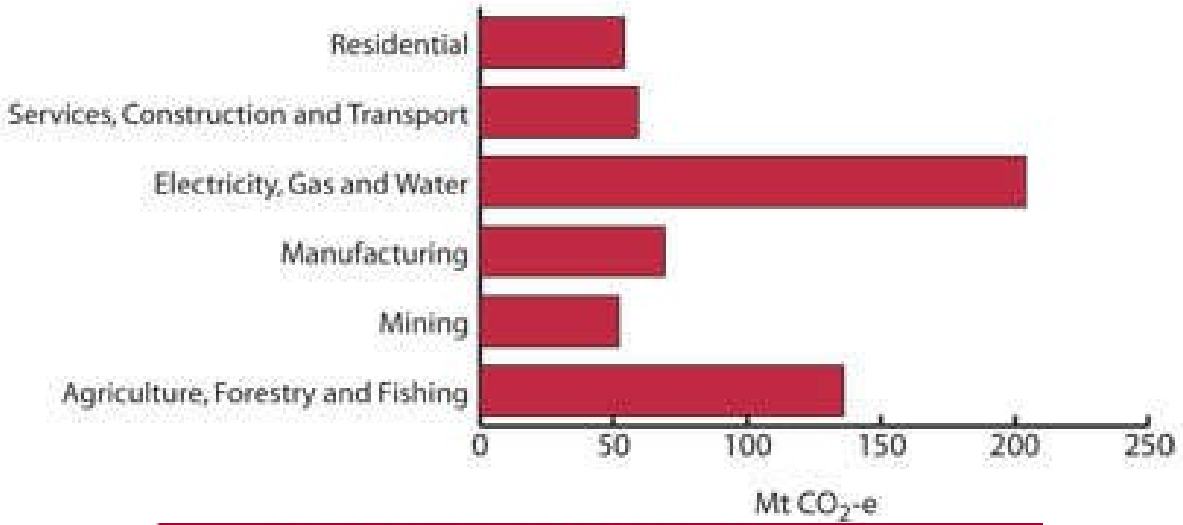
www.guardian.co.uk/environment/2008/dec/15/climate-change-australia

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

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

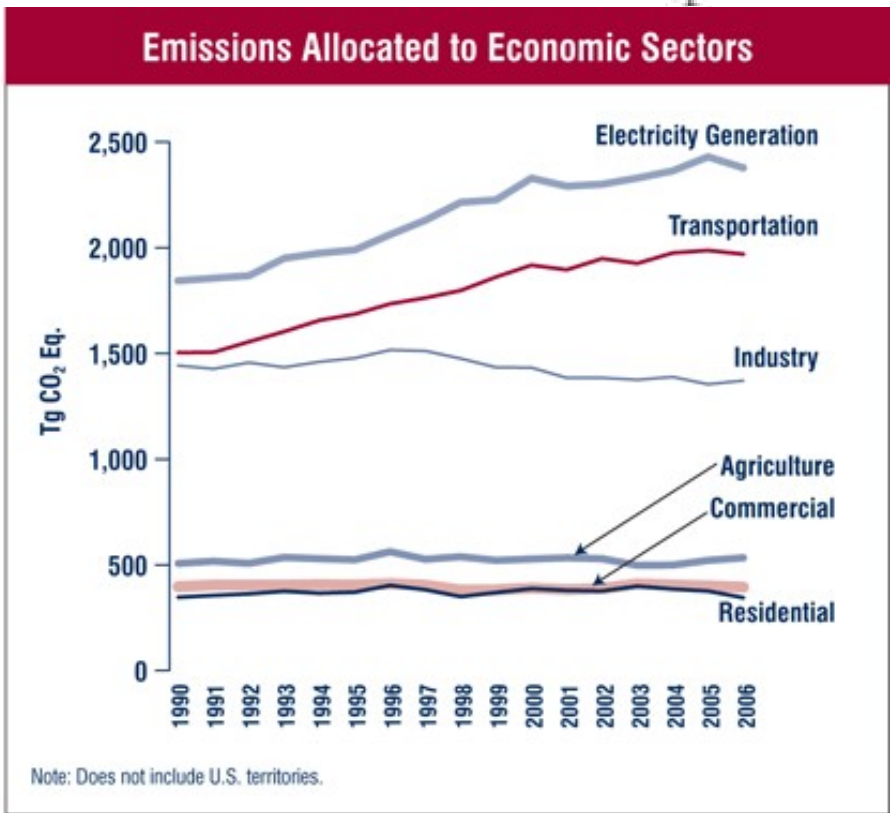
Australian and U.S. Greenhouse Gas Emissions by Economic Sector

Australian Total:
576 Mt CO_2 eq.



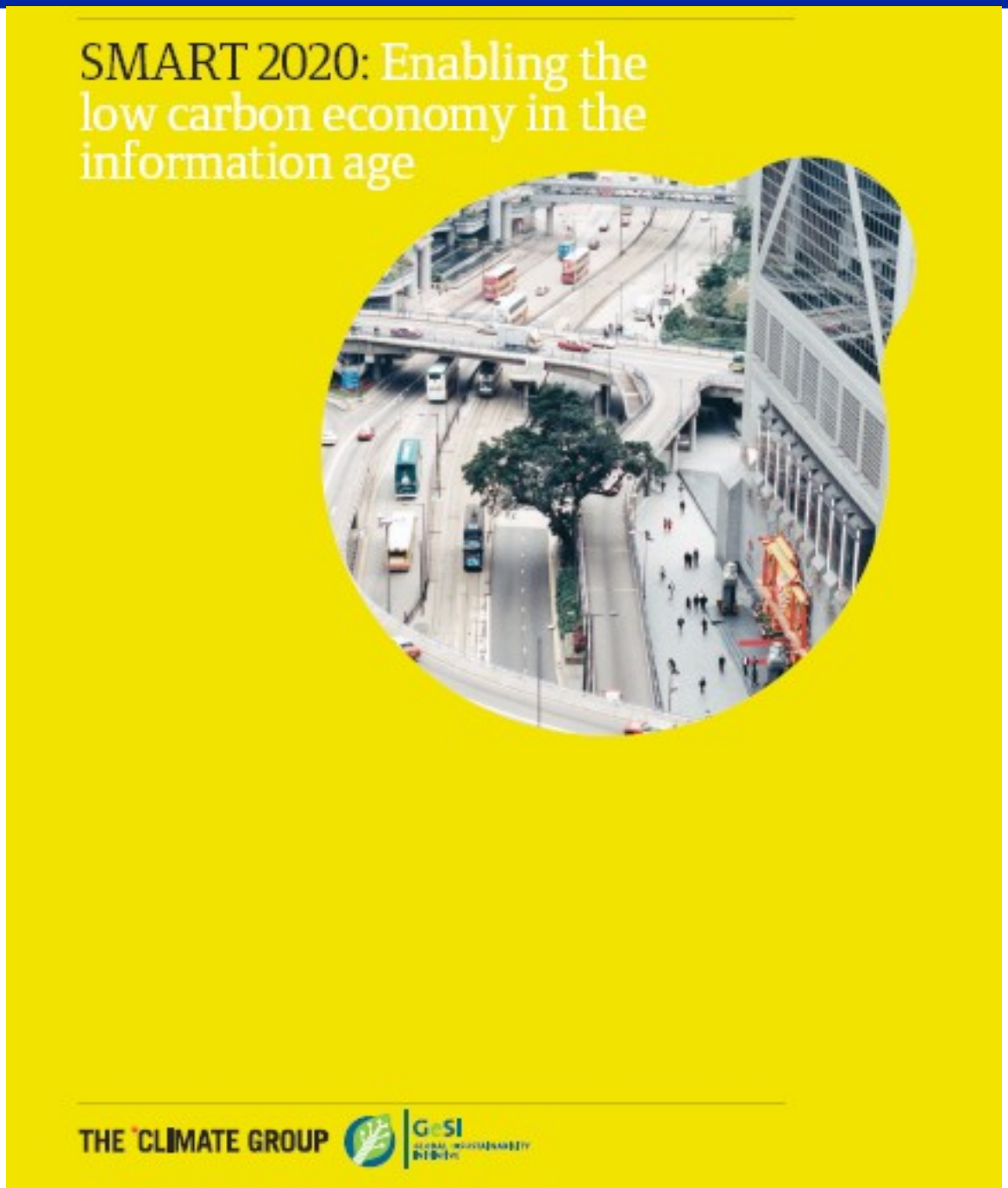
Australia's Direct Greenhouse Gas Emissions by economic sector 1990, 2006

U.S. Total:
6170 Mt CO_2 eq.



Reference: Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2006, USEPA #430-R-08-005

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

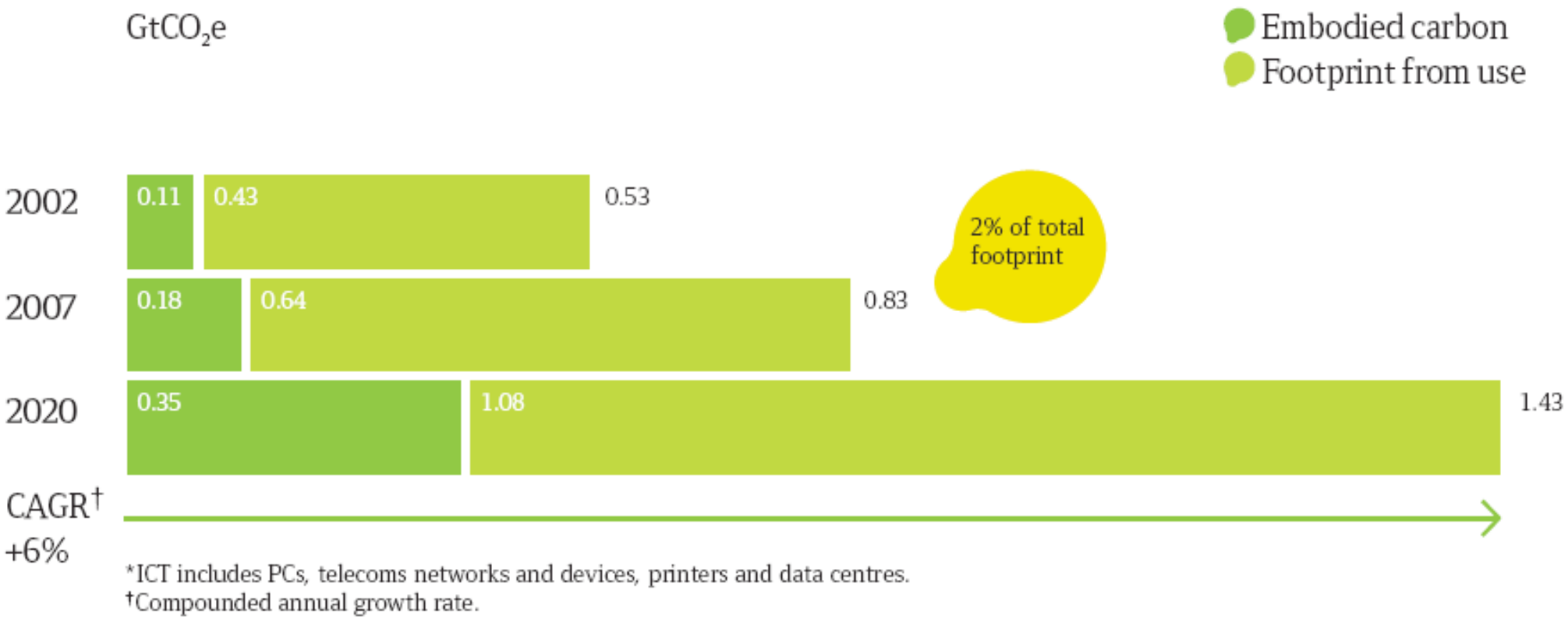


ICT is a Key Sector in the Fight Against Climate Change

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



Global ICT GHG Emissions
Roughly Same as Australia's

www.smart2020.org

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



Why is Energy Important?

- OPEX
- Greenhouse Impact
- Energy-limited capacity bottlenecks ("hot spots")
- Enabling energy efficiencies in other sectors

Source: Rod Tucker, U Melbourne

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.



Buying Green

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

Google pushes 'green' power initiative

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

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

How Microsoft is going green

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

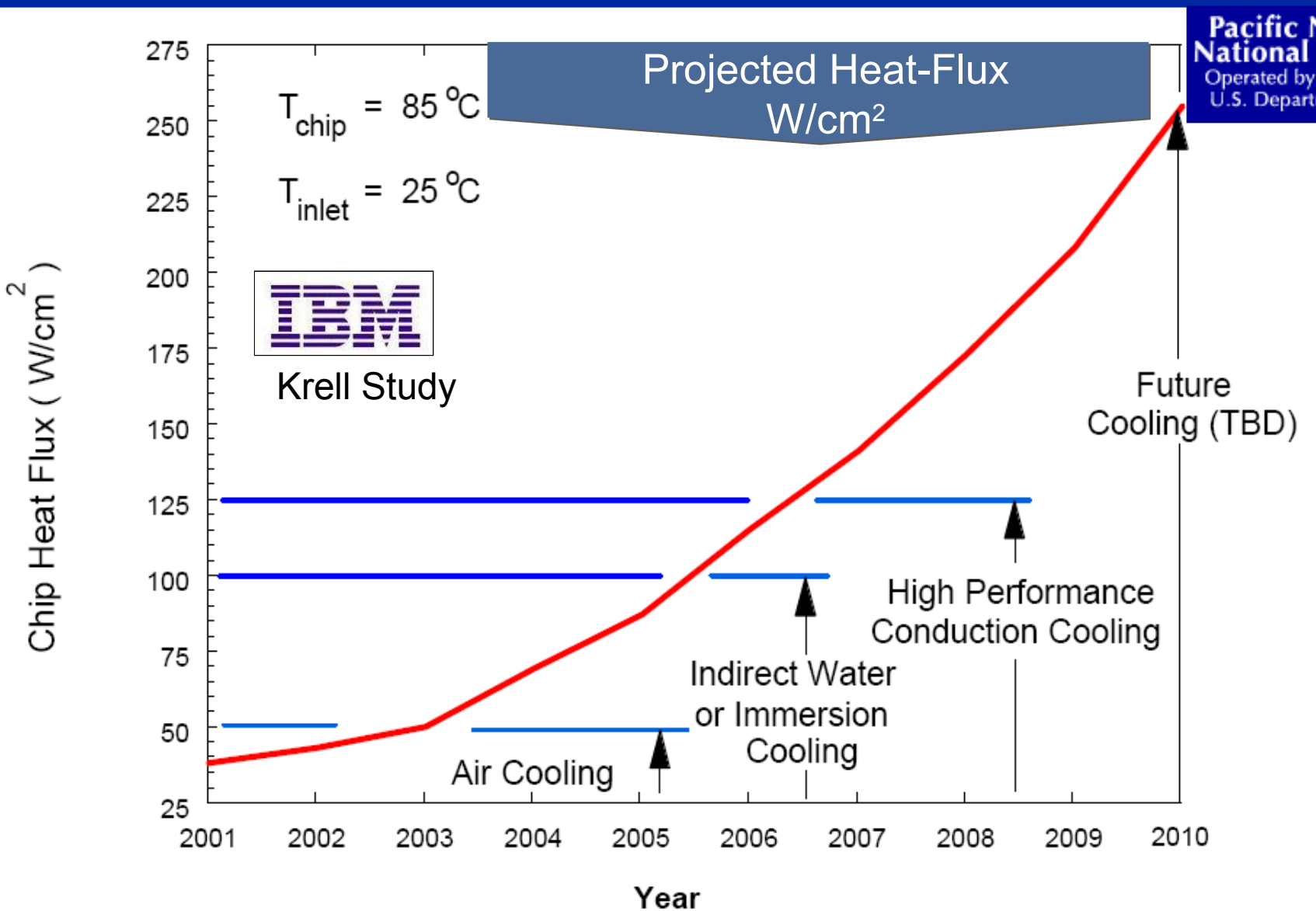
By John Fontana , Network World , 01/09/2008

IBM Project Big Green

Big Green Banner

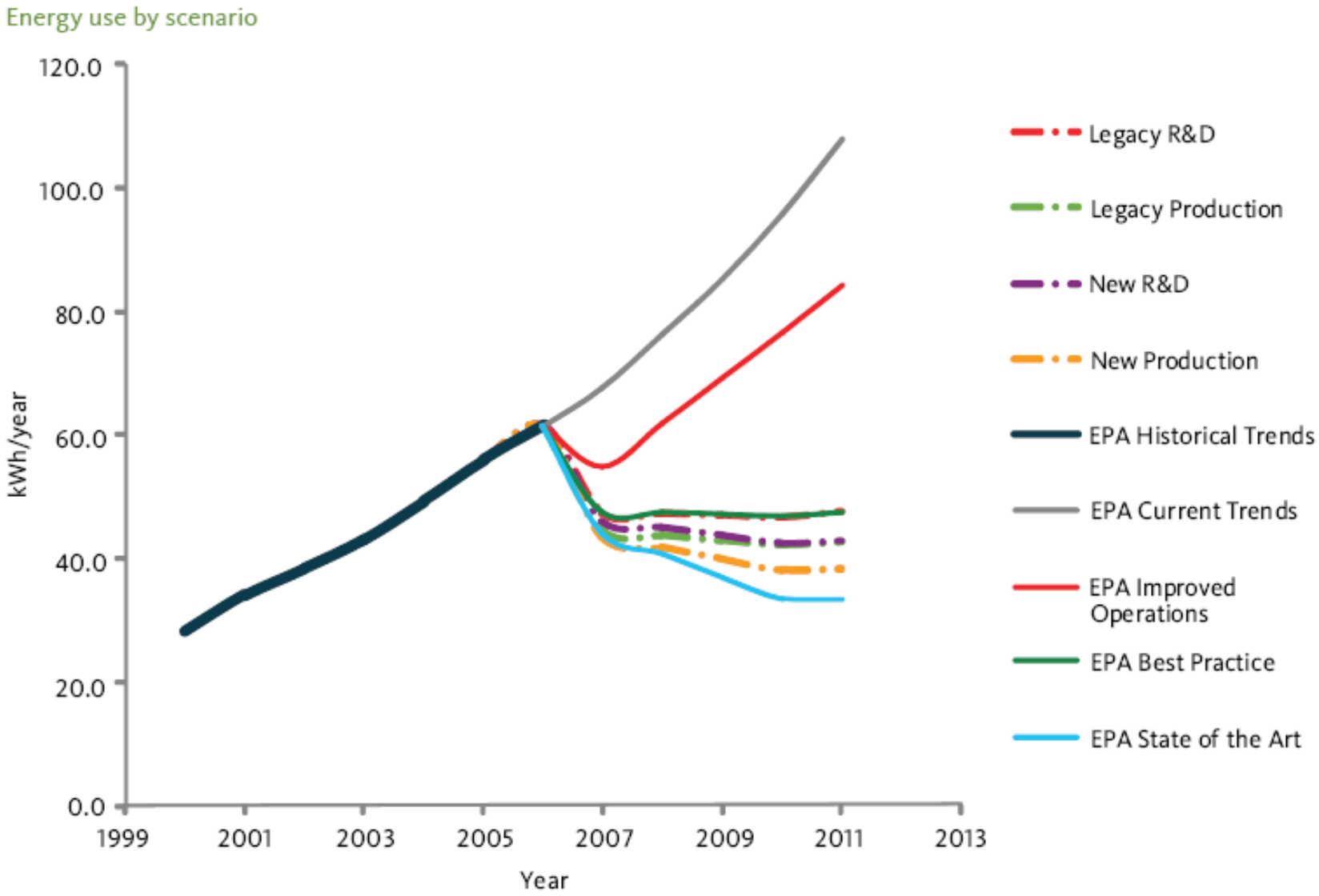
Project Big Green is a $1 billion investment to dramatically increase the efficiency of IBM products. New IBM products and services,

Data Centers Will Require Advanced Cooling Environments



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

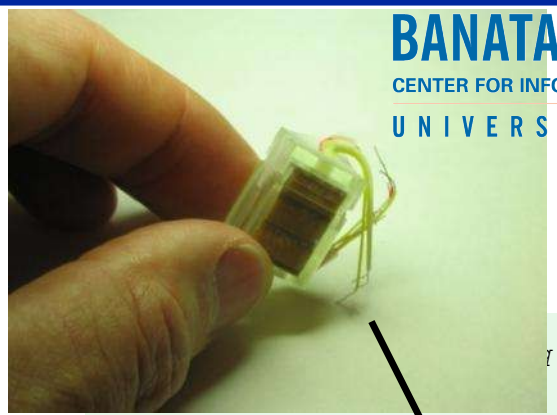
Electricity Usage by U.S. Data Centers: Emission Reductions are Underway



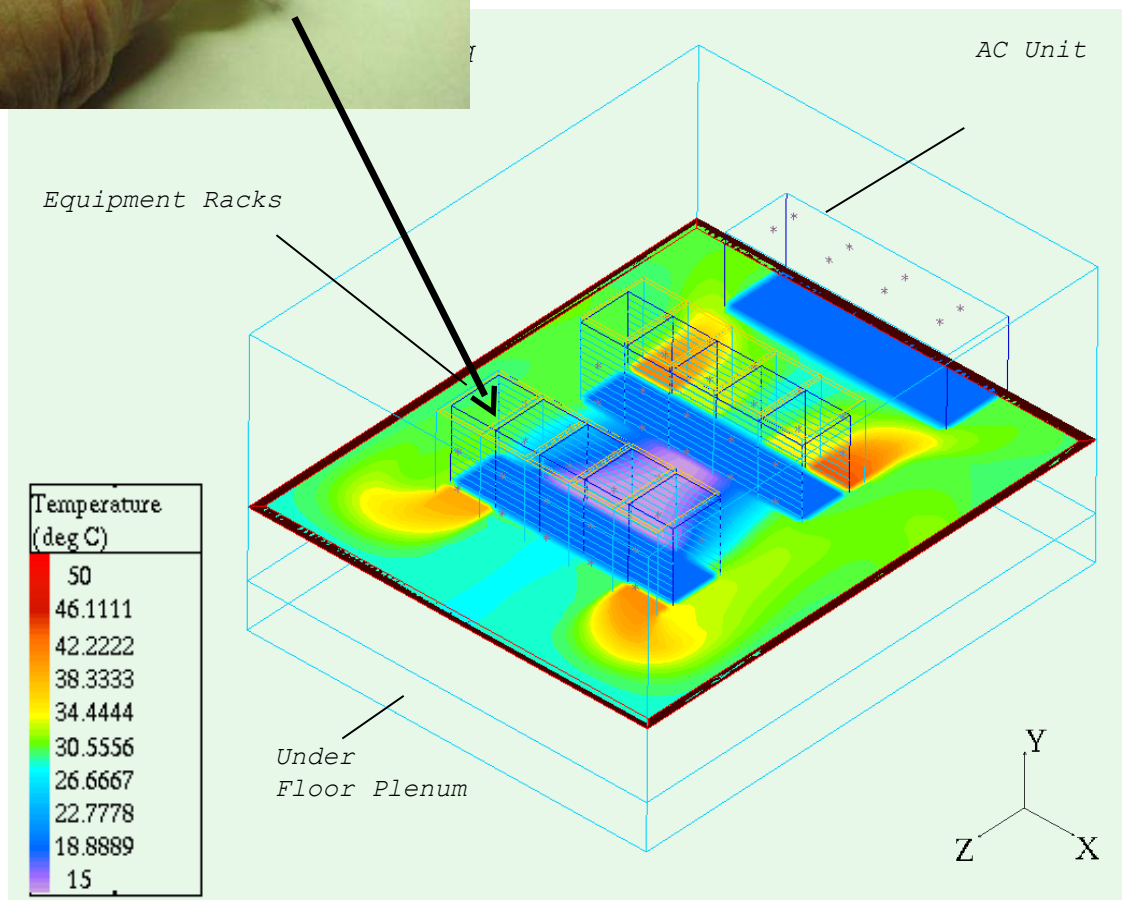
Source: Silicon Valley Leadership Group Report July 29, 2008
https://microsite.accenture.com/svlgreport/Documents/pdf/SVLG_Report.pdf

CITRIS and HP: Energy Aware Design and Control

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



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



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

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

Strategy

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

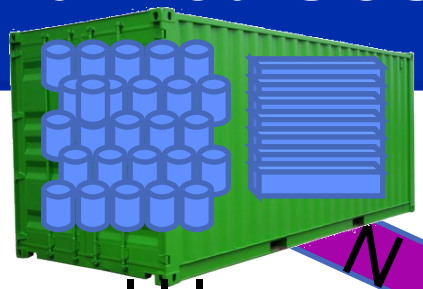
Objectives

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

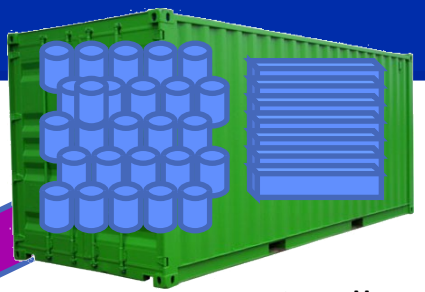
Pacific Northwest National Laboratory
Operated by Battelle for the U.S. Department of Energy

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

Planned UCSD Energy Instrumented Cyberinfrastructure



Active Data Replication



N x 10 Gbit

N x 10 Gbit

Eco-Friendly Storage and Compute

"Network in a box"
- > 200 Connections
- DWDM or Gray Optics

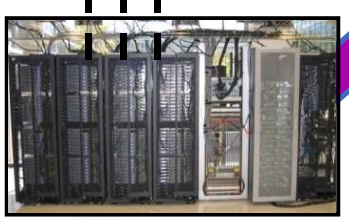


10 Gigabit L2/L3 Switch

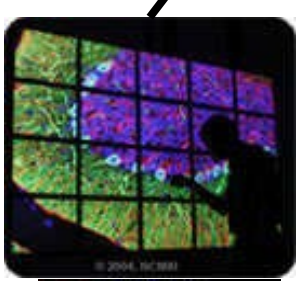
Wide-Area 10G
- Cenic/HPR
- NLR Cavewave
- Cinegrid
- …

On-Demand Physical Connections

OptIPuter



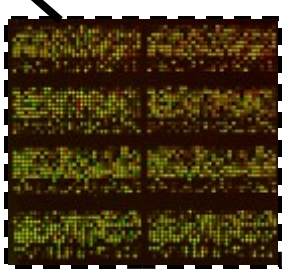
camera
Marine Microbial Ecology



NCMIR
NATIONAL CENTER for MICROSCOPY and IMAGING RESEARCH



NBCR



Microarray

Your Lab Here

ROCKS

Source:Phil Papadopoulos, SDSC/Calit2

California's Universities are Engines for Green Innovation—Partnering with Industry

UCSD Structural Engineering Dept. Conducted 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 Spots in 8 Racks**
  - **Power Utilization in Each of the 8 Racks**
  - **Chilled Water Cooling Systems**



$2M NSF-Funded GreenLight Project

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

Calit2 GreenLight Project Enables Green IT Computer Science Research

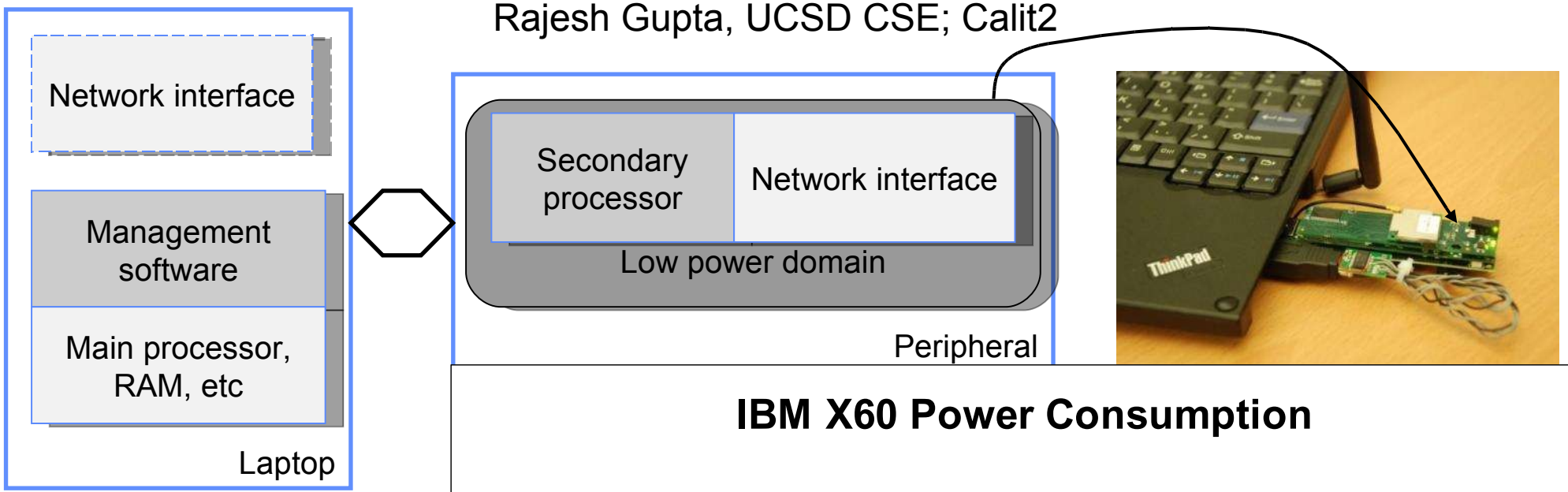


- **Computer Architecture**
  - Rajesh Gupta/CSE
- **Software Architecture**
  - Amin Vahdat & Ingolf Kruger/ CSE
- **CineGrid Exchange**
  - Tom DeFanti/Calit2
- **Visualization**
  - Falko Kuster/Structural Engineering
- **Power and Thermal Management**
  - Tajana Rosing/CSE
- **Analyzing Power Consumption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

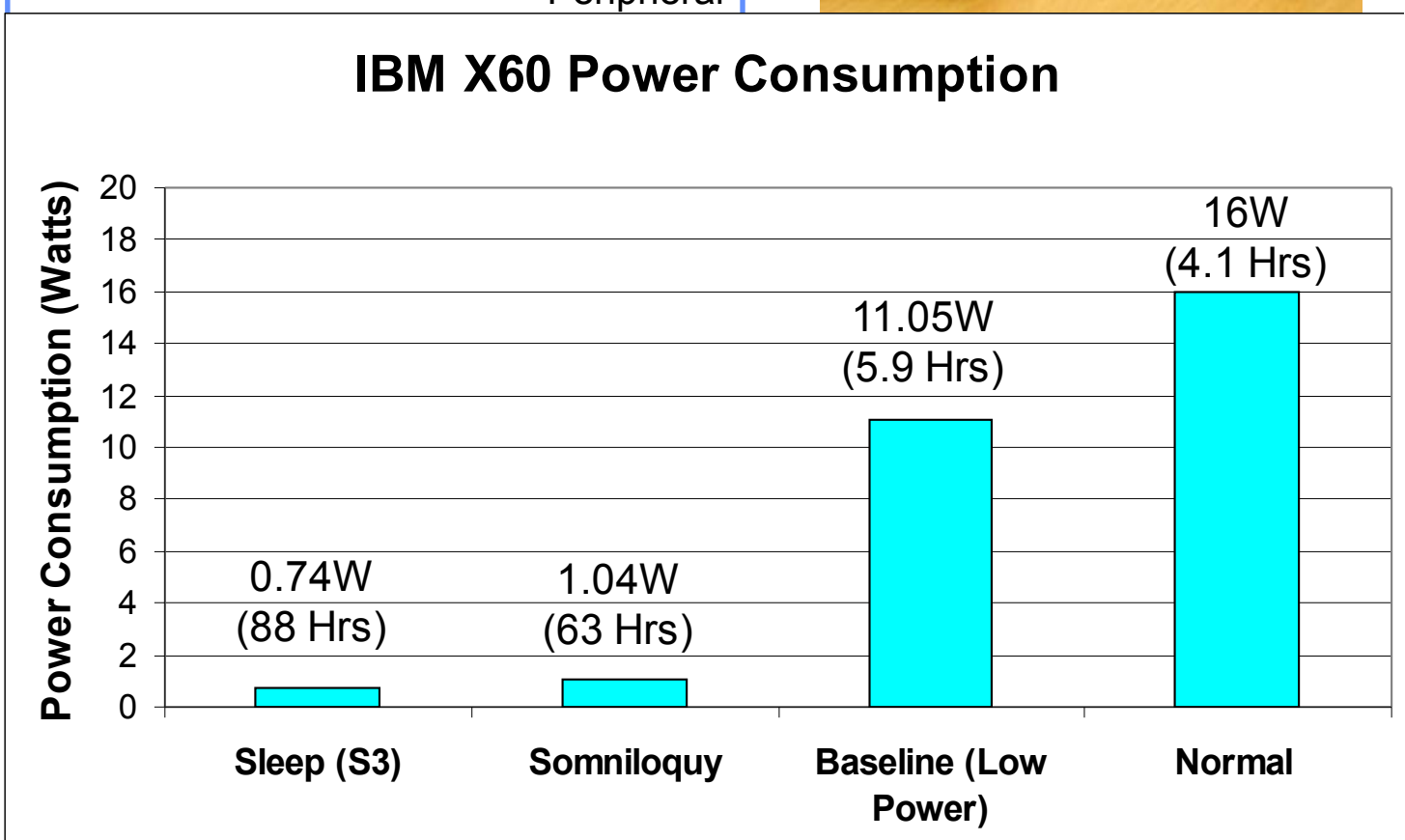
http://greenlight.calit2.net

GreenLight Project: Putting Machines To Sleep Transparently

Rajesh Gupta, UCSD CSE; Calit2

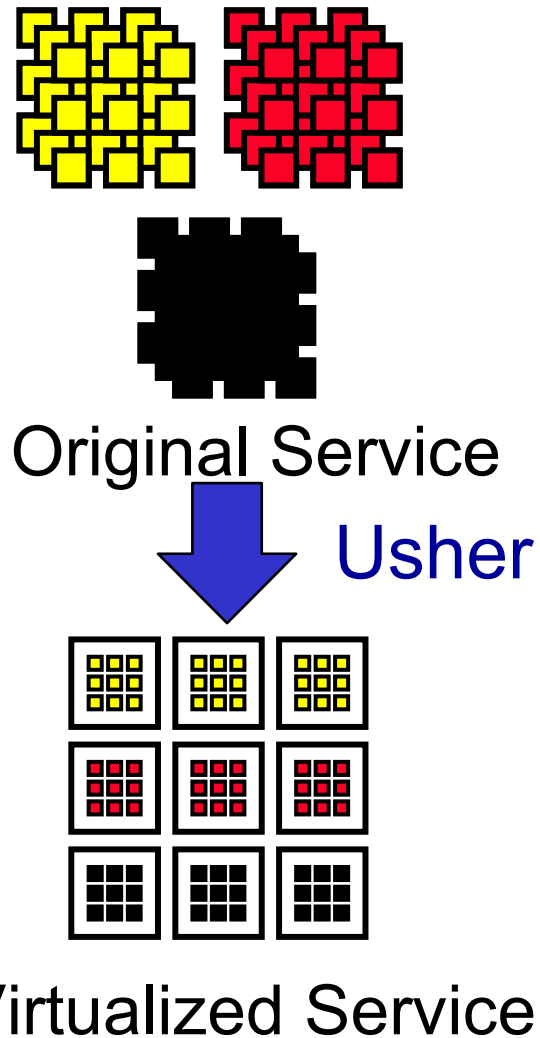


Somniloquy Enables Servers to Enter and Exit Sleep While Maintaining Their Network and Application Level Presence



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**

UCSDCSE Computer Science and Engineering

cns center for networked systems

it²

The GreenLight Project Focuses on Minimizing Energy for Key User Communities



- Microbial Metagenomics
- Ocean Observing
- Microscopy
- Bioinformatics
- Digital Media—CineGrid Project
  - Calit2 will Host TB of Media Assets in GreenLight CineGrid Exchange to Measure and Propose Reductions in the "Carbon Footprint" Generated by:
    - File Transfers and
    - Computational Tasks
  - Required for Digital Cinema and Other High Quality Digital Media Applications

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 Expected to Grow Dramatically**
- **ICT Facilities Don't Need To Be Located In Cities**
  - **Cooling Also a Major Problem 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**
- **ICT is Only Industry Ideally Suited to Relocate to Renewable Energy Sites**

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

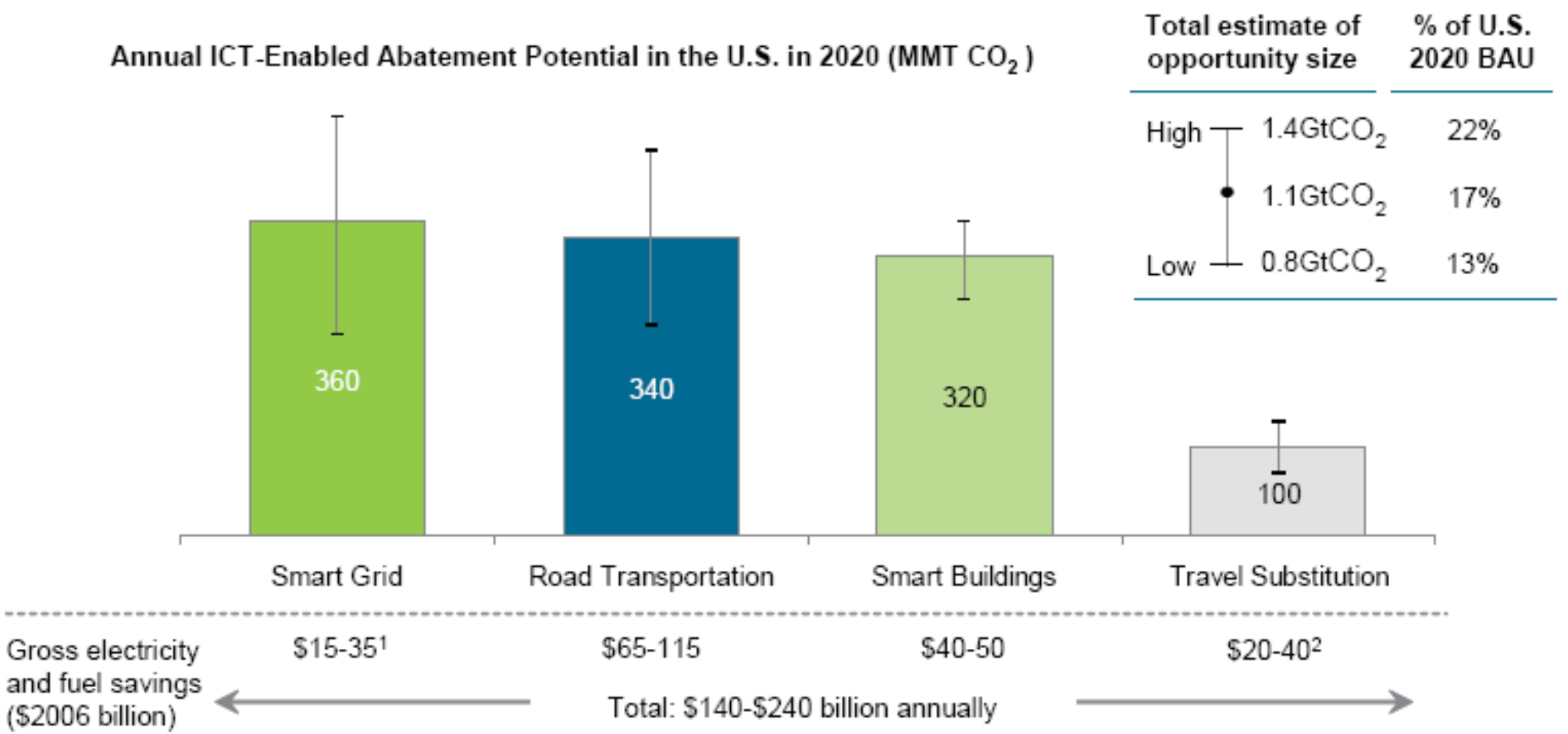
Major Opportunities for the United States*

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

*** Smart 2020 United States Report Addendum**

www.smart2020.org

How to Get 15% Reduction of 2020 Emissions By Applying ICT to Applications



Source: Smart 2020 United States Report Addendum
www.smart2020.org

Smart Electrical Grids

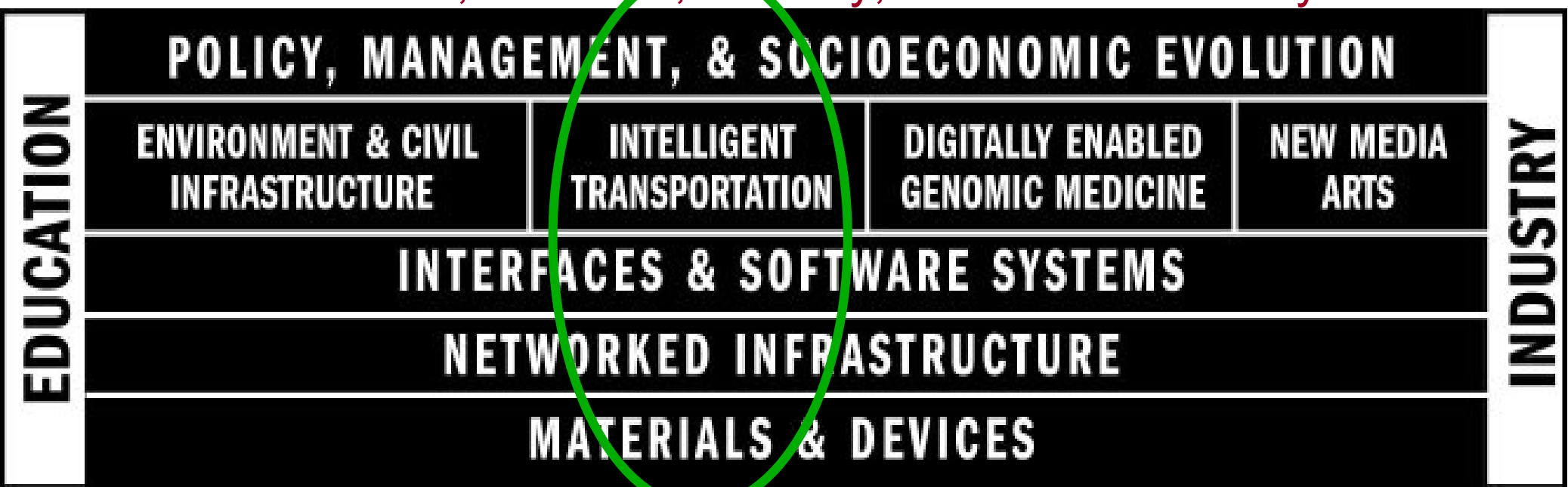
"That means updating the way we get our electricity
by starting to build a new smart grid that will save us money; protect our power sources from blackout or attack; and deliver clean, alternative forms of energy to every corner of our nation."
---President-Elect Obama

Smart energy grids would allow real-time monitoring of a customer's energy use through Internet technology. Proponents of a national smart grid say it would likely result in decreased electricity use, allow energy companies to more efficiently distribute electricity, and encourage homeowners to install alternative energy generators such as solar panels and sell their excess energy back to the grid.

Source: ComputerWorld Government 1/9/09

Calit2--A Systems Approach to the Future of the Internet and its Transformation of Our Society

Calit2 Has Assembled a Complex Social Network
of Over 350 UC San Diego & UC Irvine Faculty
From Two Dozen Departments
Working in Multidisciplinary Teams
With Staff, Students, Industry, and the Community



Integrating Technology Consumers and Producers
Into “Living Laboratories”

www.calit2.net

Making Cars Cleaner Requires Software Engineering-- Calit2 Established the Automotive Software Workshop

AUTOMOTIVE SOFTWARE WORKSHOP SAN DIEGO 2004



90 % of all Auto Innovations are Now Software-Driven

- Over 10 Million Lines of Code in Your Car!
- Sponsors: Calit2, NSF, EU, DFG
- 50:50 Participation Industry/Academia
- Next Instance Planned For 2009
- Industry Participants Include:

Ford
TOYOTA InfoTechnology Center, U.S.A., Inc.
DAIMLER
VALIDAS validated quality
BMW
TOYOTA
GM
BOSCH
AbsInt Angewandte Informatik
vector
it²

Source: Ingolf Krueger, Calit2

Launch of ZEVnet Fleet of Wireless Cars-- First Calit2 Testbed for Intelligent Transportation

TOY



April 18,
Irvine,
www.zevr

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









Natio
Universit

TORRANCE, Calif., Nov. 9, 2007 -- Toyota Motor Sales, U.S.A.,

TUDIES

Reducing Traffic Congestion: Calit2 California Peer-to -Peer Wireless Traffic Report

- **Citizen to Citizen Accident Reports**
- **Real-Time Freeway Speeds**
- **"Leave Now" Paging Services**

20,000+ Users
> 1000 Calls Per Day

San Diego
(866) 500 0977



LA & OC
(888) 9 CALIT2



Bay Area
(888) 4 CALIT2



http://traffic.calit2.net

Source: Ganz Chockalingam, Calit2

The Commercial Market for High Resolution Teleconference Systems in Rapidly Expanding

Changing the Way We Work, Live, Play and Learn

- 320 Cisco TelePresence

  major cities globally
- US/Canada: 101 CTS 3000, 79 CTS 1000, 3 CTS 3200, 13 CTS 500
- APAC: 24 CTS 3000, 20 CTS 1000, 3 CTS 500
- Japan: 5 CTS 3000, 2 CTS 1000, 1 CTS 500,1 CTS3200
- Europe: 30CTS 3000, 19 CTS 1000, 1 CTS3200, 5 CTS500
- Emerging: 13 CTS 3000, 1CTS1000

- 216K TelePresence meetings scheduled to date.
- 48% Average Utilization
- 279K hours (average meeting is 1.25 hrs)
- 22K+ meetings with customers to discuss Cisco Technology over TelePresence

- 31K+ meetings avoided travel
- Conservative estimate of cost savings:
  - ~$278M to date
- Cubic meters of emissions saved: 90 million
- Equal to >15,500+ cars off the road



Uses QoS Over Shared Internet ~ 15 mbps

Source: Cisco-Updated January 5, 2009

Using High Definition to Link the Calit2 Buildings: Living Greener



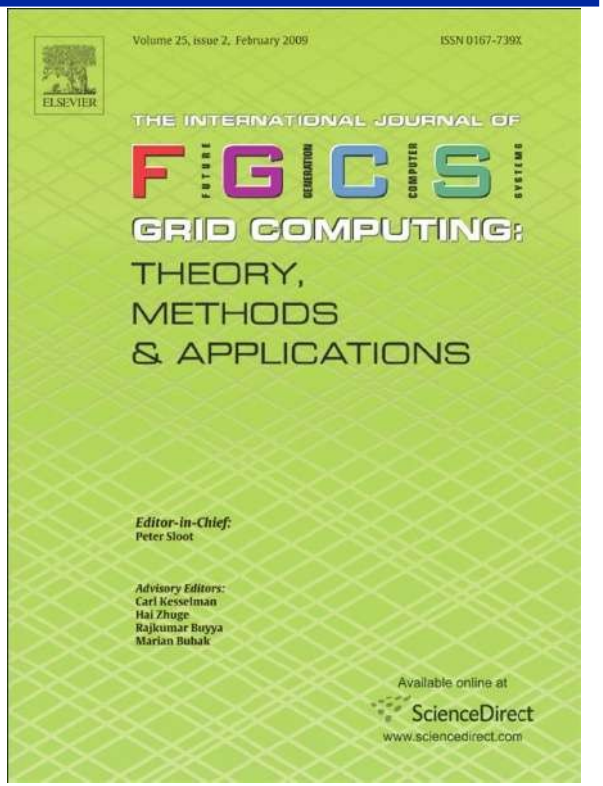
une 2, 2008

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



The OptIPuter Creates an OptIPlanet Collaboratory: Enabling Data-Intensive e-Research





"OptIPlanet: The OptIPuter Global Collaboratory" – Special Section of Future Generations Computer Systems, Volume 25, Issue 2, February 2009

evl electronic visualization laboratory

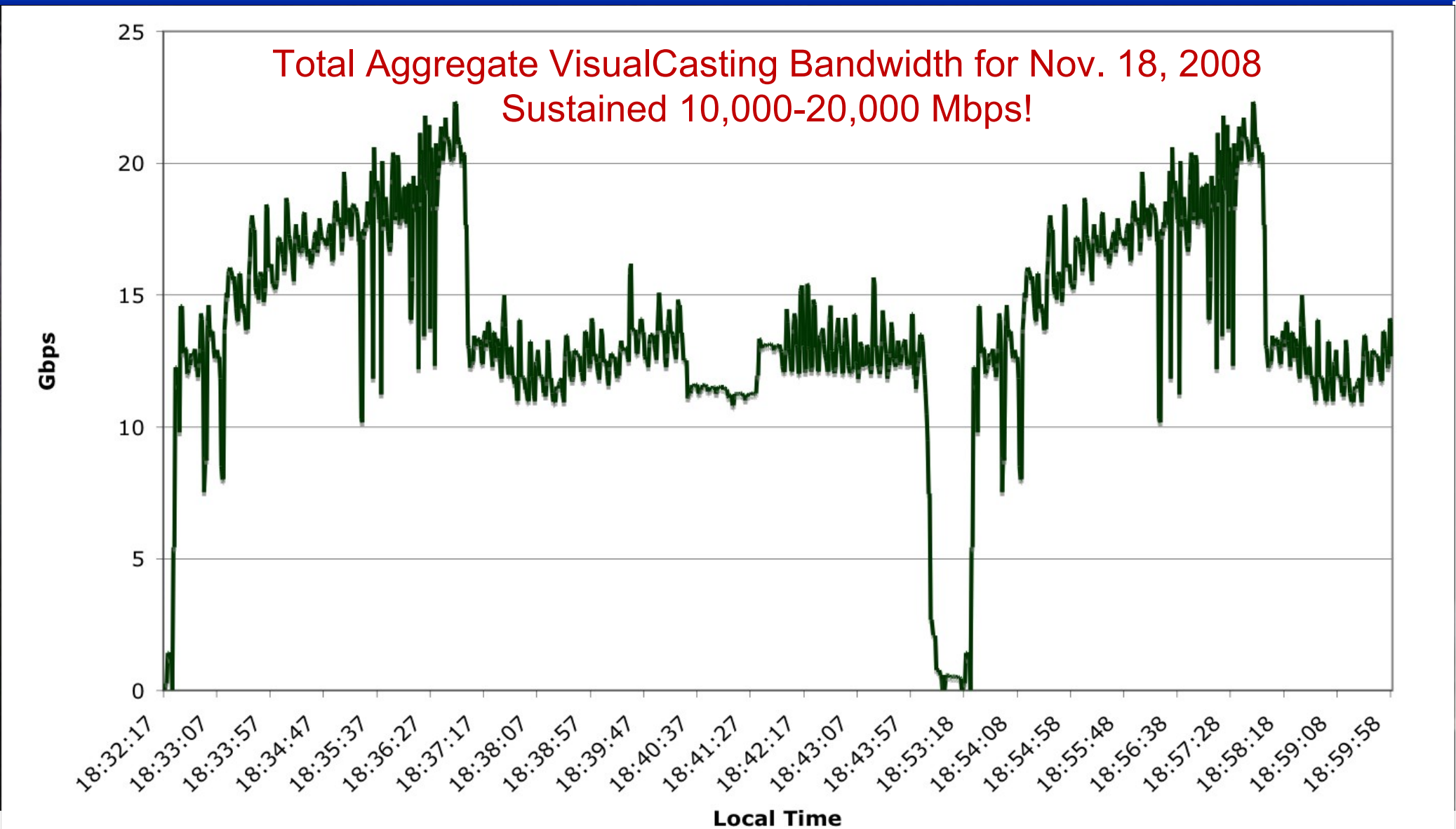
NSF

October 1, 2008
End of Six Year ITR

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

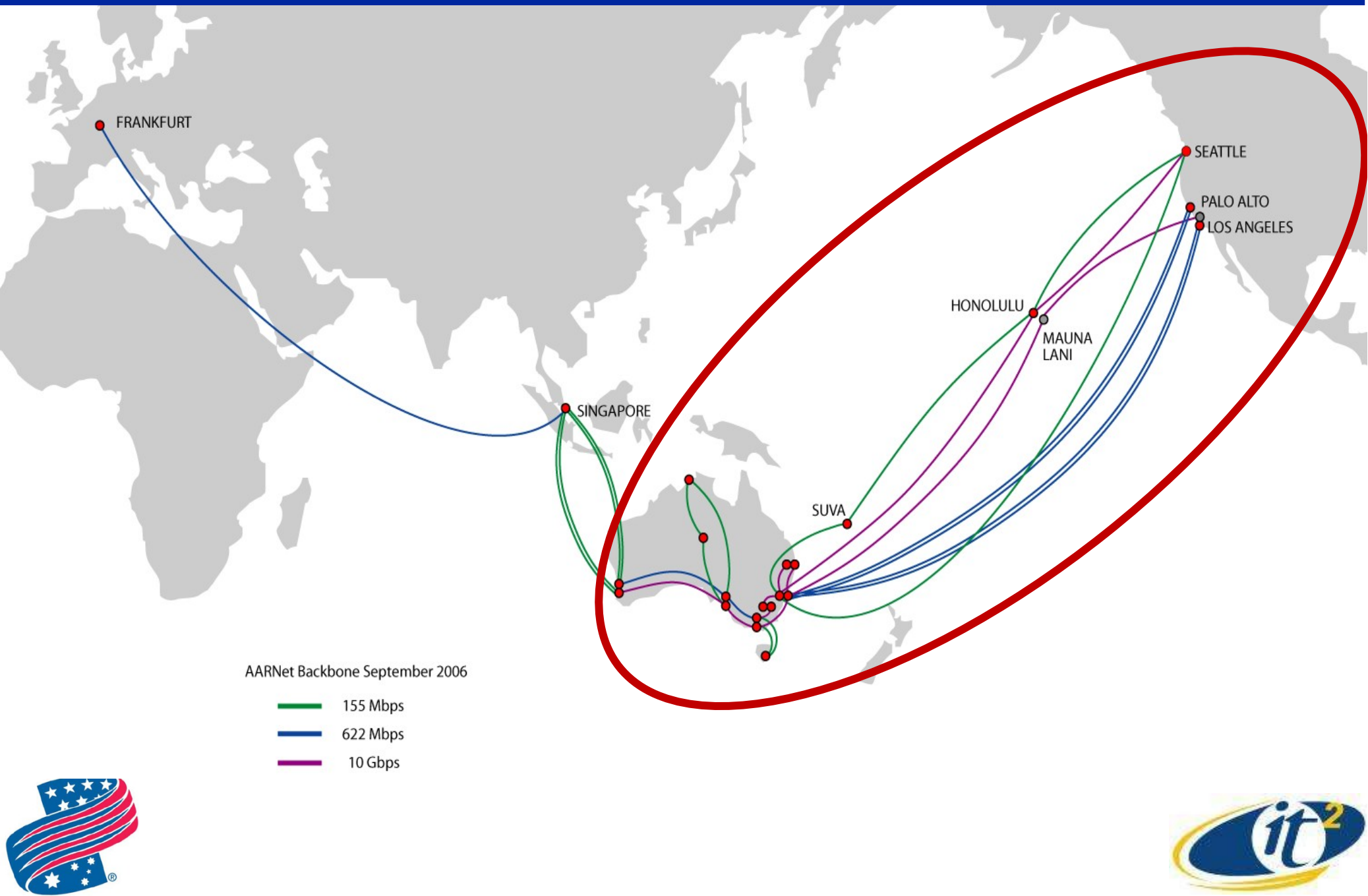
it2

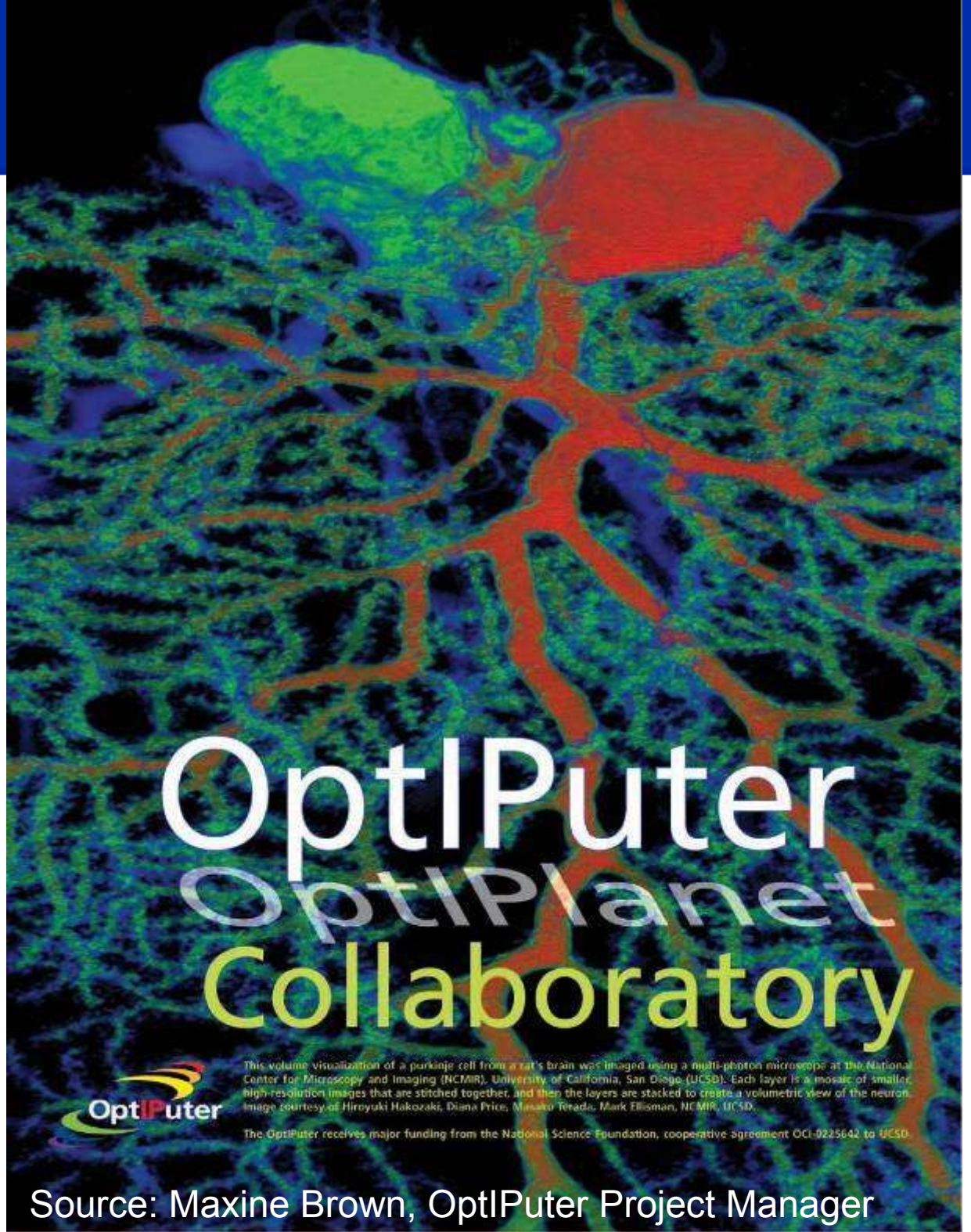
EVL's SAGE OptIPortal VisualCasting Multi-Site OptIPlanet Collaboratory



Source: Jason Leigh, Luc Renambot, EVL, UI Chicago

Coupling AARNet - CENIC/PW - CANARIE Optical Nets: An Australian-U.S.-Canada Green ICT Testbed





Source: Maxine Brown, OptIPuter Project Manager

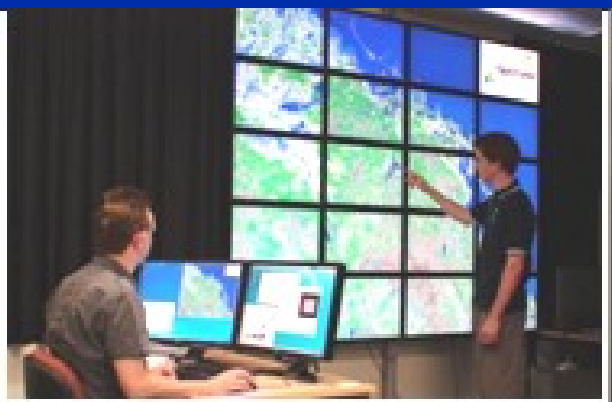
Green Initiative:

Can Optical Fiber Replace Airline Travel for Continuing Collaborations?

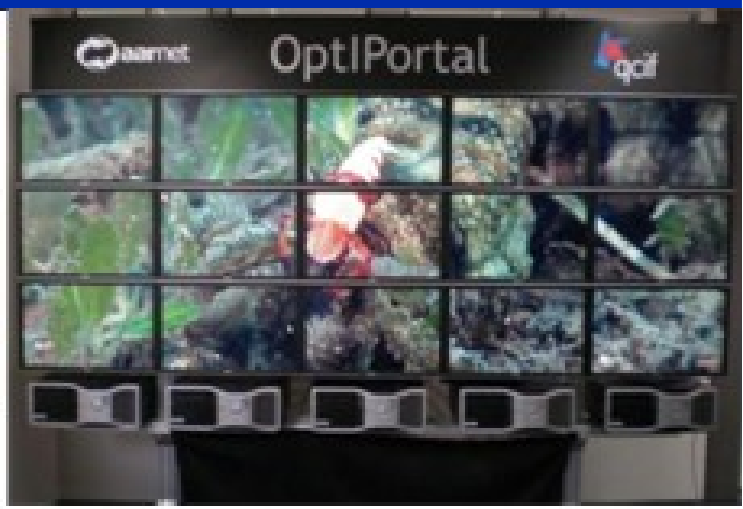
Launch of the 100 Megapixel OzIPortal Kicked Off a Rapid Build Out of Australian OptIPortals



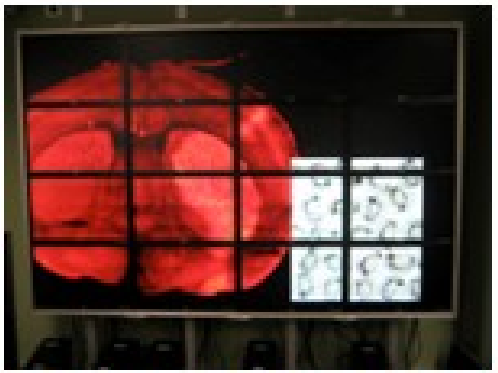
ANU



U Queensland



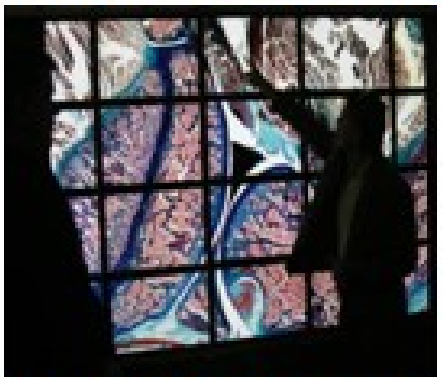
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