Sustainable Computing and Telecom Can Contribute to Limiting Global Climatic Disruption

Invited Seminar

AT&T Shannon Labs

Florham Park, NJ

July 28, 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

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Abstract

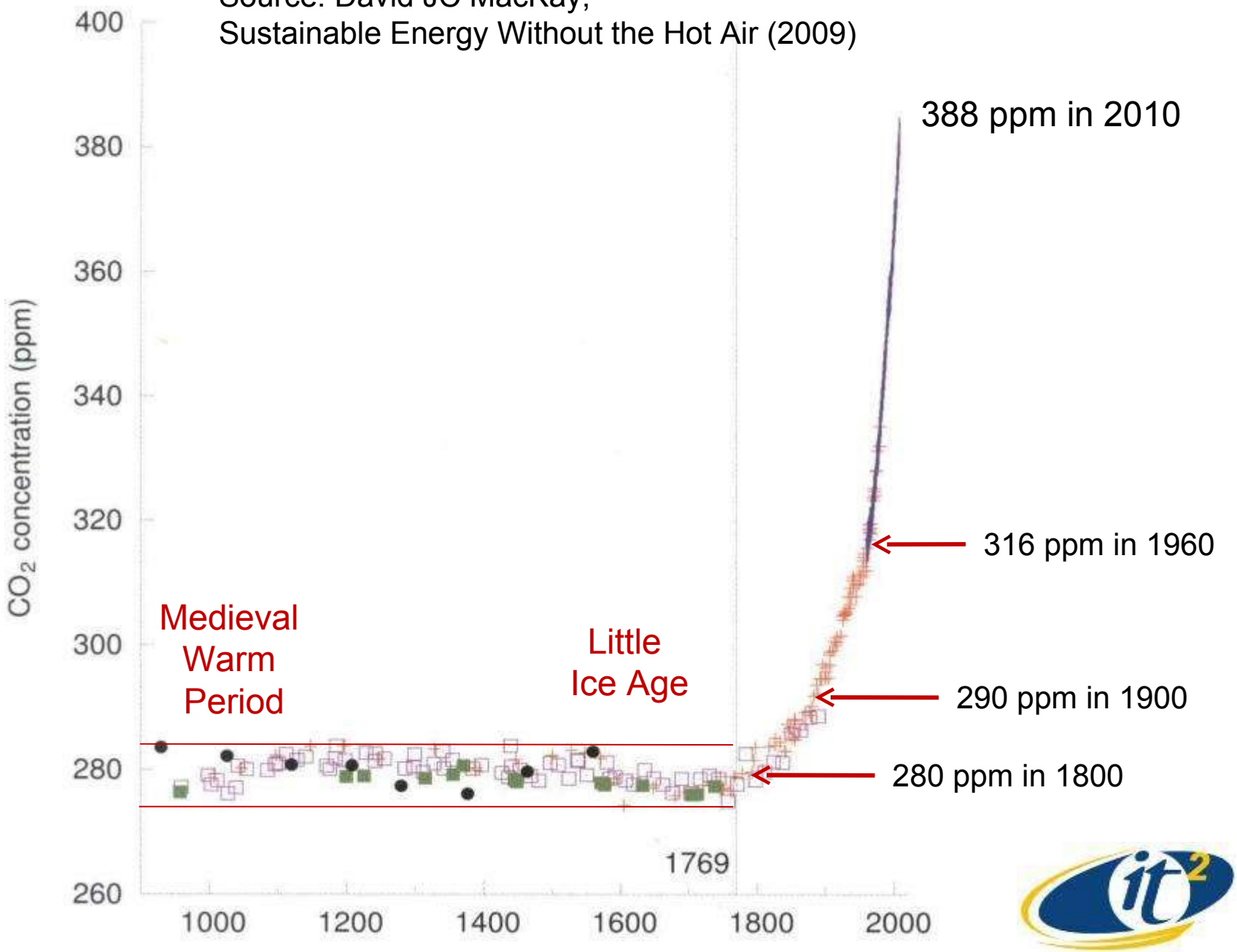
The Copenhagen Summit concluded that greenhouse gas emissions must be reduced in the coming decade if we are to limit global warming to 2 degrees C (The Earth has warmed ~0.8 degrees C since pre-industrial times). The International Energy Agency has shown what a radical challenge such a reduction will be for the global energy sector, but any solution requires increasing energy efficiency in electrical devices. The Information and Communication Technology (ICT) industry's Smart 2020 study reveals that the ICT industry produces ~2-3 percent of global greenhouse gas emissions. 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 applications of ICT to electricity grids, logistic chains, intelligent transportation and building infrastructure, and other social systems can reduce global greenhouse gas emissions by about 15 percent— five times ICT's own footprint! I will give results on several Calit2 affiliated projects aimed at increasing ICT energy efficiency, including for individual PCs, from the NSF-funded GreenLight Project (http://greenlight.calit2.net), deployed at UCSD, which creates an instrumented data center, to cellular base stations. At a higher level, we are using the two Calit2 university campuses (UC San Diego and UC Irvine) themselves as at-scale Green IT testbeds. Campuses are functionally small towns with their own power grids, commuter transportation systems, hospitals, and populations in the tens of thousands. Calit2 is working with campus administration, faculty and staff to instrument these campuses as Living Laboratories of the Greener Future.

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Accelerating Increase in the Greenhouse Gas CO_2 Since Industrial Era Began

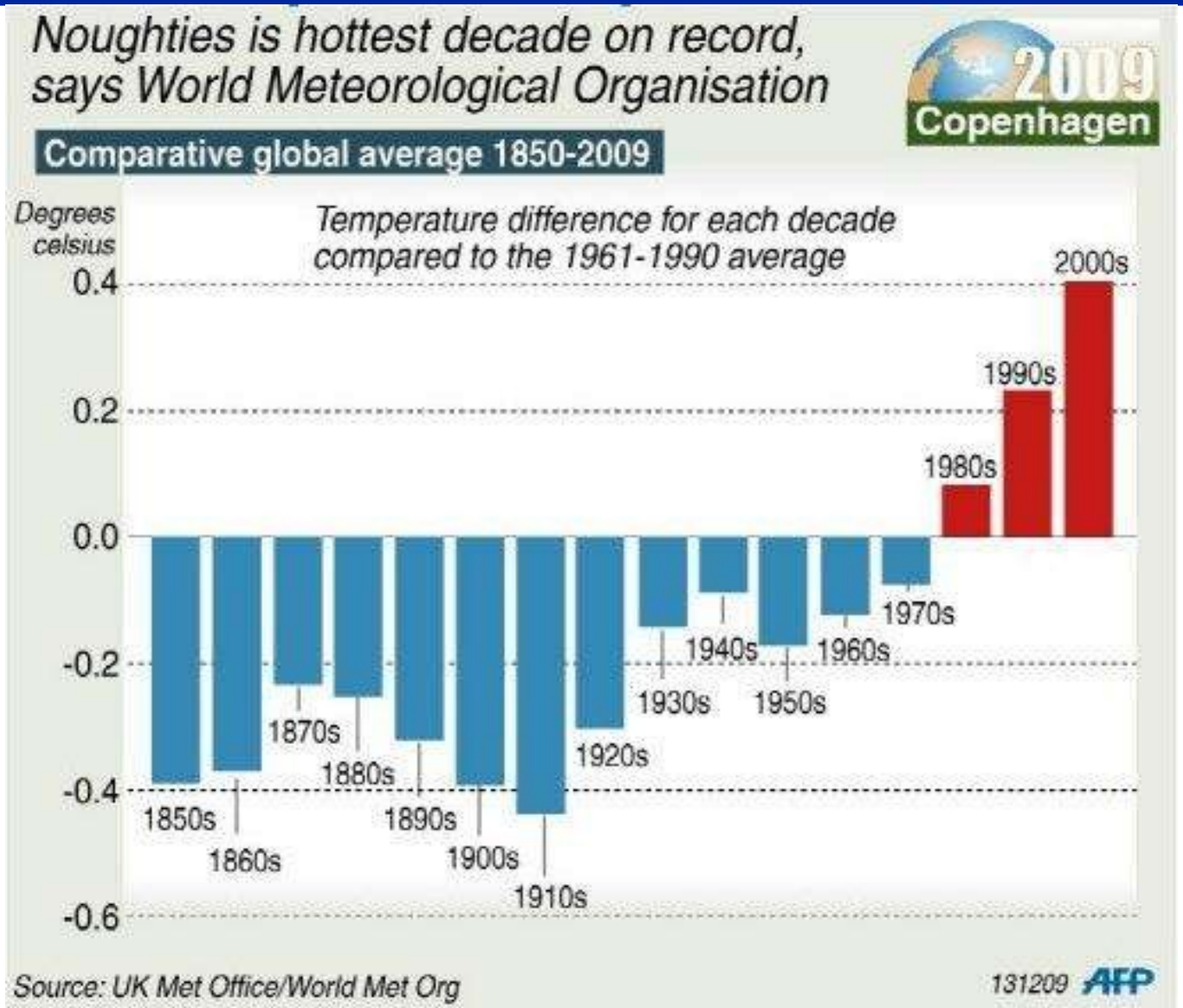
Source: David JC MacKay,
Sustainable Energy Without the Hot Air (2009)



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Global Average Temperature Per Decade Over the Last 160 Years



June 2010 Hottest Since Records Began in 1880
- National Oceanic and Atmospheric Administration
www.noaanews.noaa.gov/stories2010/20100715_globalstats.html

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Limit of 2° C Agreed to at the UN Climate Change Conference 2009 in Copenhagen

"To achieve the ultimate objective of the Convention to stabilize greenhouse gas concentration in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system, we shall, recognizing the scientific view that the increase in global temperature should be below 2 degrees Celsius, on the basis of equity and in the context of sustainable development, enhance our long-term cooperative action to combat climate change."

--*the Copenhagen Accord of 18 December 2009*

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However, Current Global Emission Reduction Commitments Imply ~4° C Temperature Rise

- **According to the MIT C-ROADS model:**
  - **Continuing business as usual would lead to an expected temperature increase of 4.8 °C (8.6 ° F) (CO_2 950ppm).**



John Sterman, Jay W. Forrester Professor in Computer Science Professor of System Dynamics Director, MIT System Dynamics Group

  - **But even if all the commitments for emissions reductions made by individual nations at the Copenhagen conference were fully implemented, the expected rise in temperatures is still 3.9 °C (7.0 °F) above preindustrial levels (CO_2 770ppm).**
  - **To stabilize atmospheric concentrations of greenhouse gases and limit these risks, Sterman says that global greenhouse gas emissions must peak before 2020 and then fall at least 80% below recent levels by 2050, continuing to drop by the end of this century until we have a carbon neutral economy. Doing so might limit the expected warming to the target of 2 °C (3.6 °F) (CO_2 450ppm).**

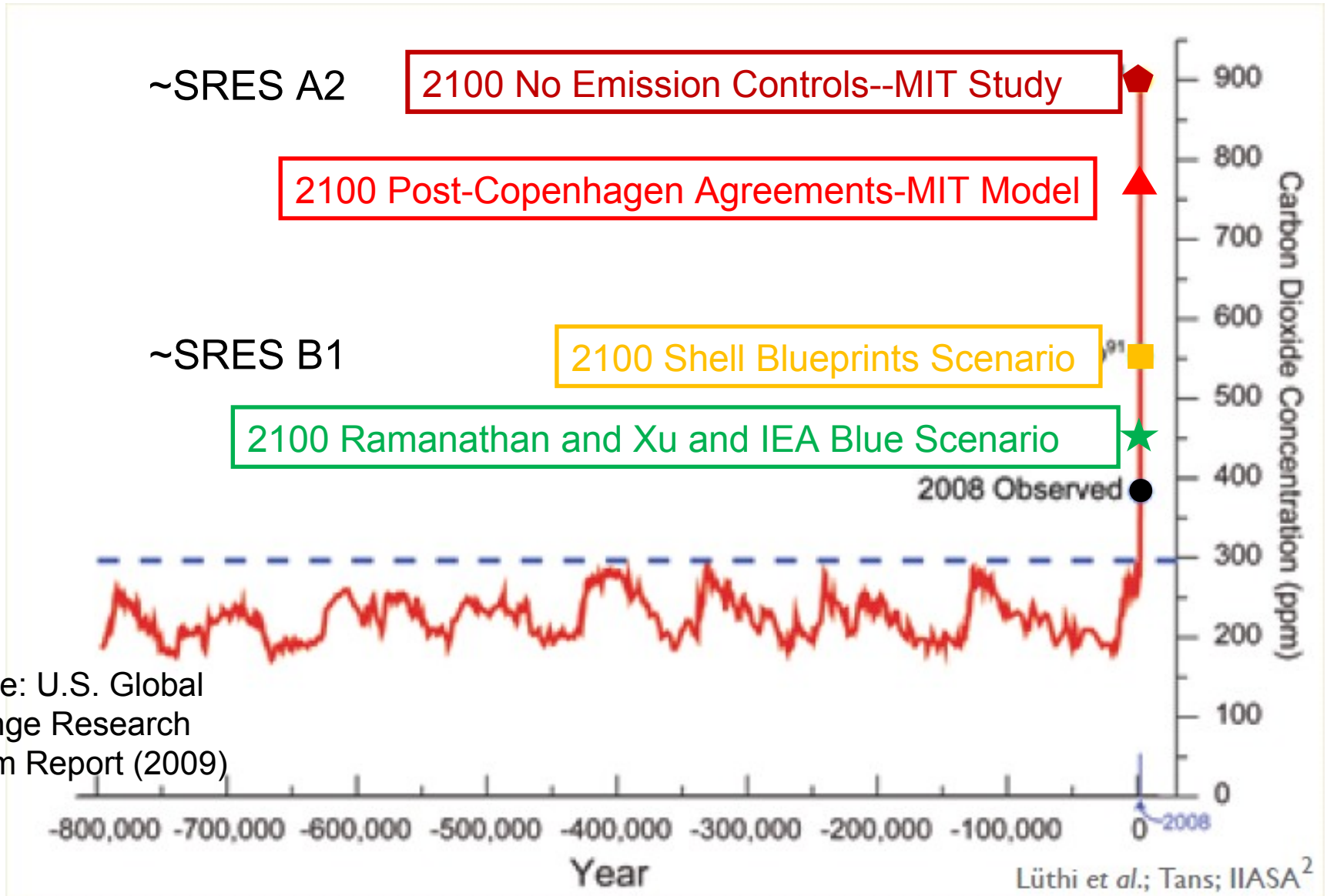
Since 1780, Earth has Warmed 0.8° C and CO_2 is at 390ppm

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http://mitsloan.mit.edu/newsroom/2010-sterman.php

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



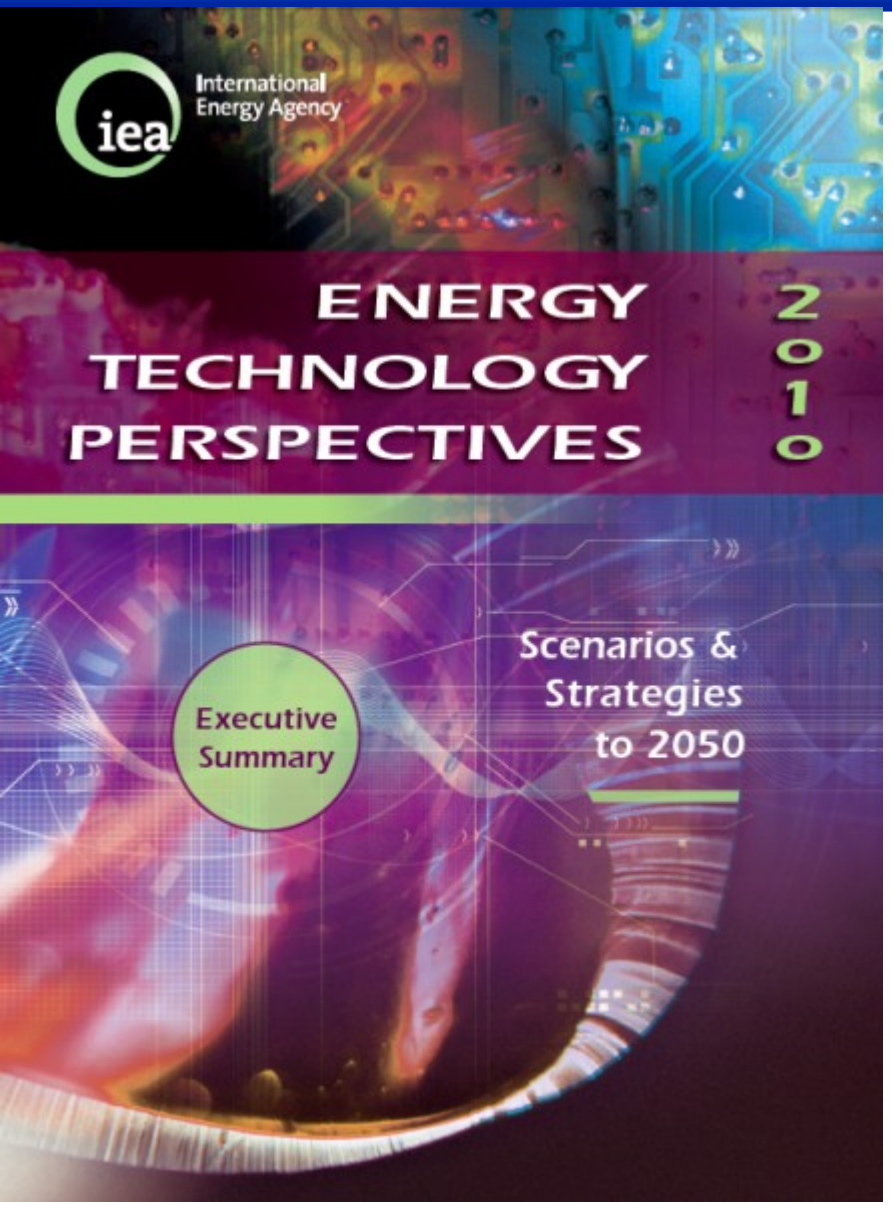
Source: U.S. Global Change Research Program Report (2009)

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

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IEA BLUE--A Global Energy System Scenarios For Limiting CO_2 to 450ppm

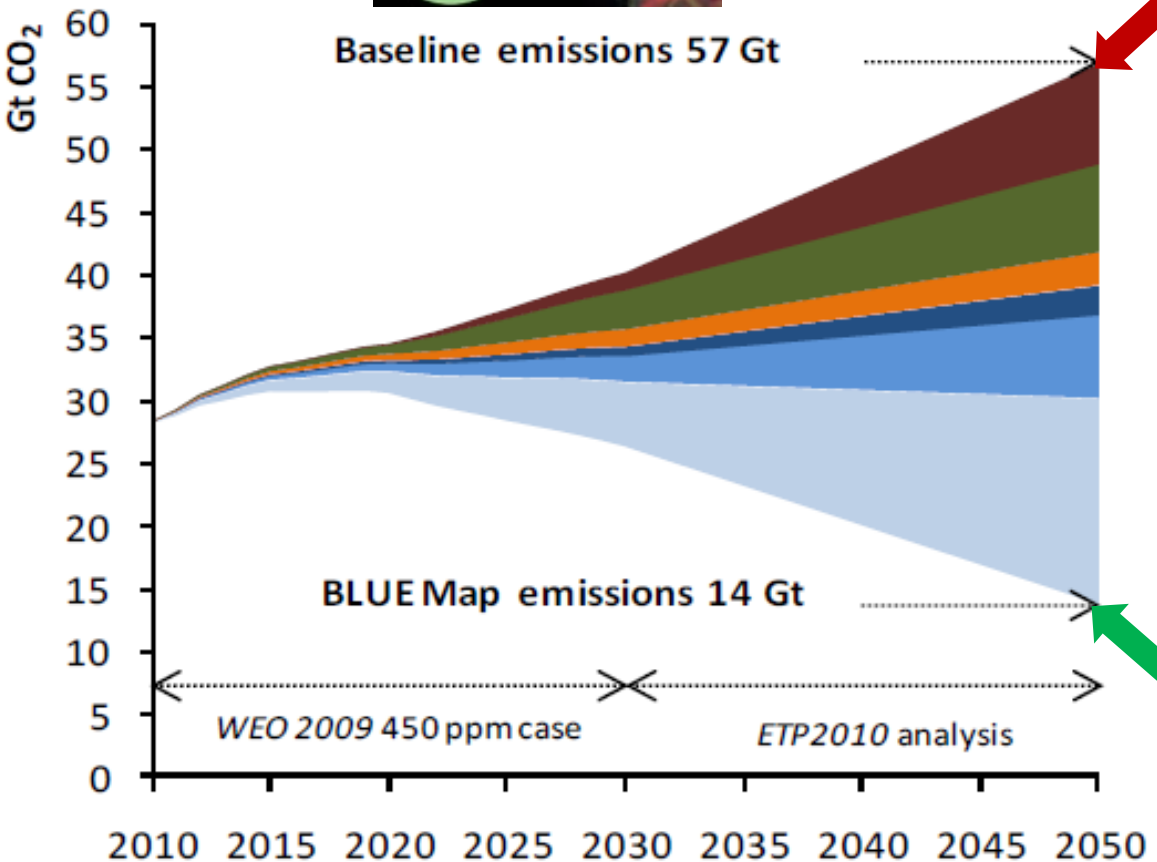


"The next decade is critical.
If emissions do not
peak by around 2020 and
decline steadily thereafter, achieving
the needed 50% reduction by 2050
will become much more costly.
In fact, the opportunity
may be lost completely.
Attempting to regain a 50% reduction
path at a later point in time
would require much greater
CO_2 reductions, entailing much more
drastic action on a shorter time scale
and significantly higher costs than may
be politically acceptable."

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To Cut Energy Related CO_2 Emissions 50% by 2050 Requires a Radically Different Global Energy System



Doubled

- CCS 19%
- Renewables 17%
- Nuclear 6%
- Power generation efficiency and fuel switching 5%
- End-use fuel switching 15%
- End-use fuel and electricity efficiency 38%

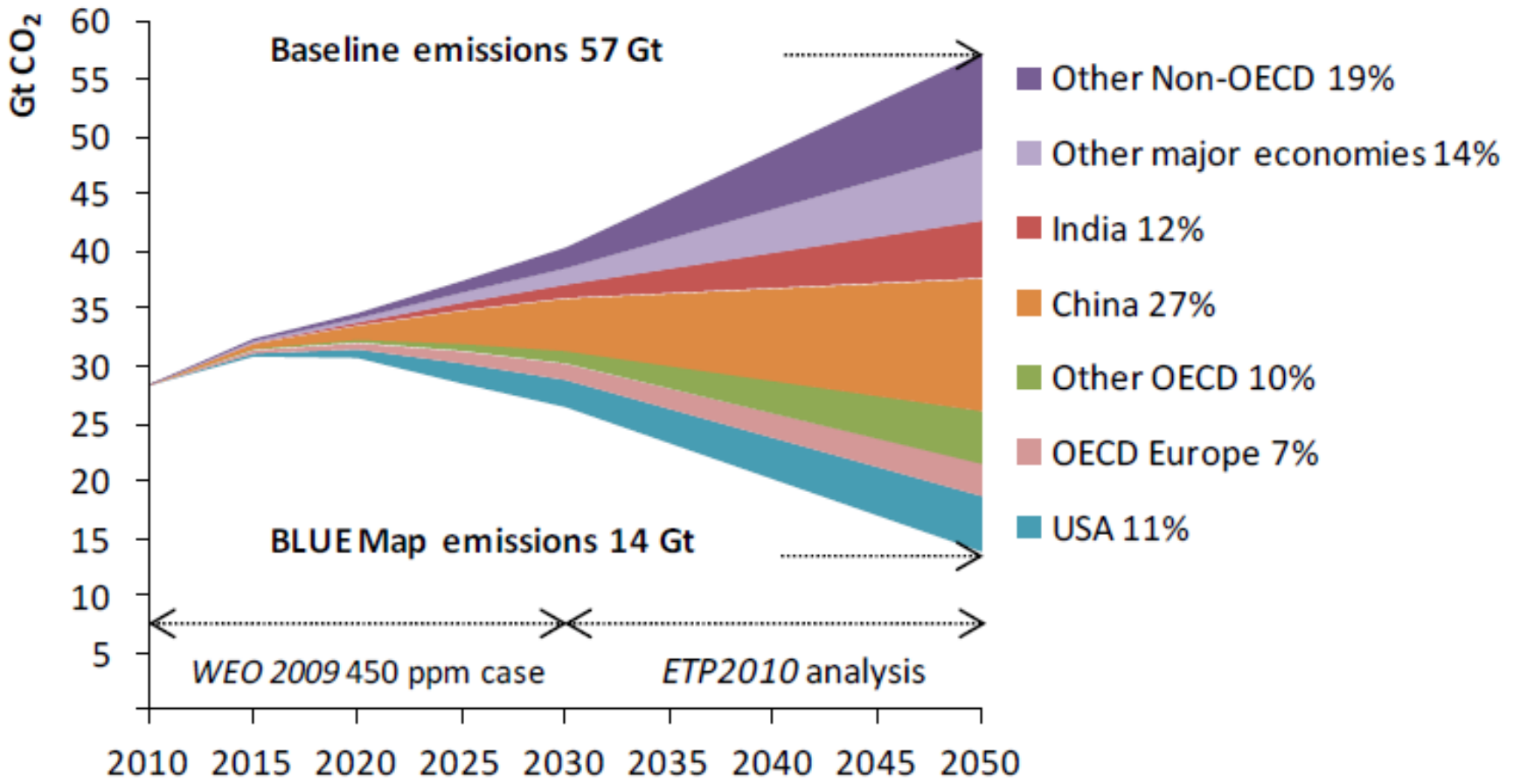
Halved



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IEA BLUE Map Scenario: Abatement Across All Sectors to Reduce Emissions to Half 2005 Levels by 2050

World Energy-Related CO_2 Emissions Abatement by Region





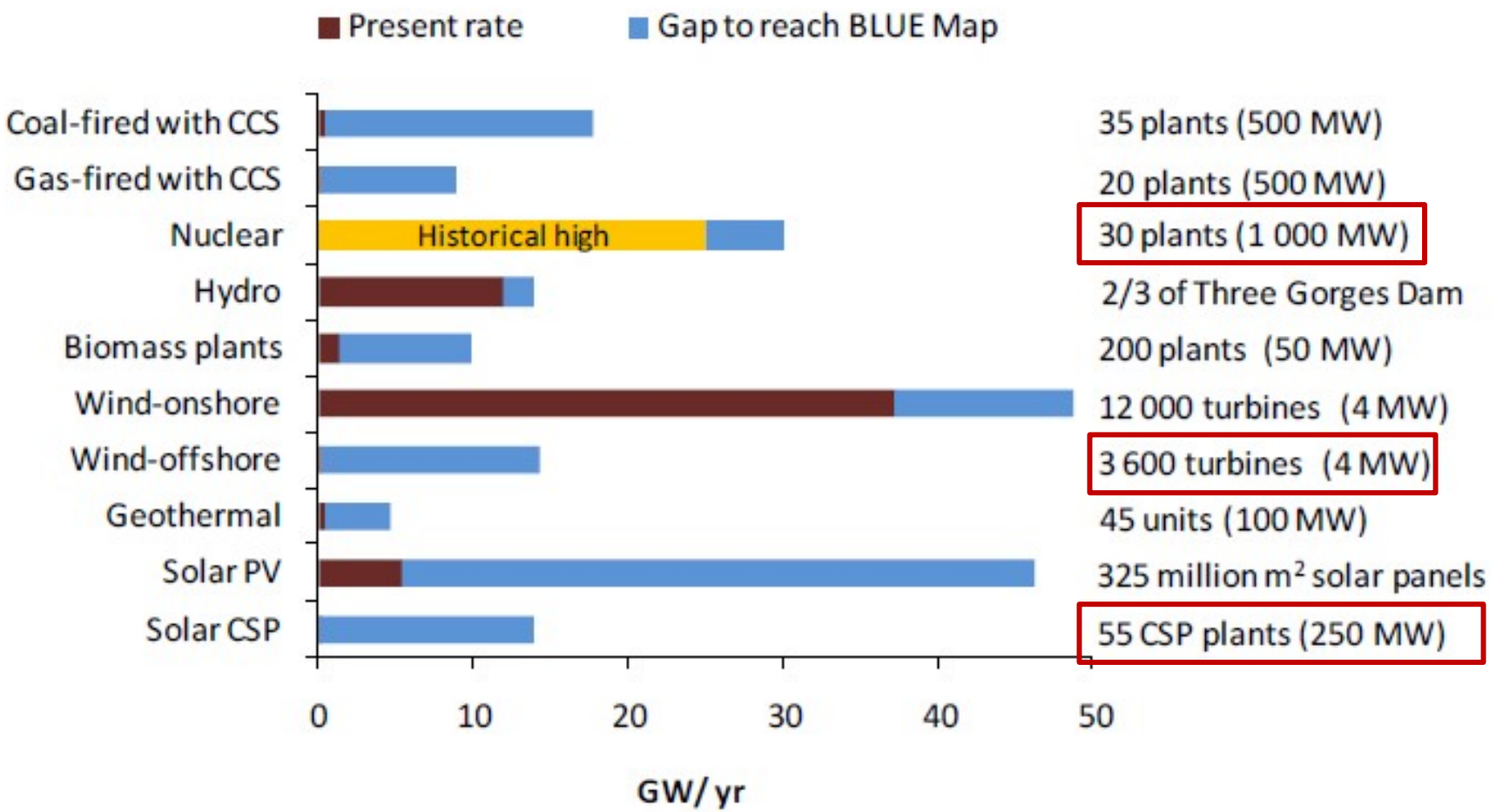
Most Abatement is Outside of OECD Countries
~40% China and India

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Average Annual Electricity Capacity Additions To 2050 Needed to Achieve the BLUE Map Scenario

Well Underway with Nuclear, On-Shore Wind, and Hydro, Massive Increases Needed in All Other Modes



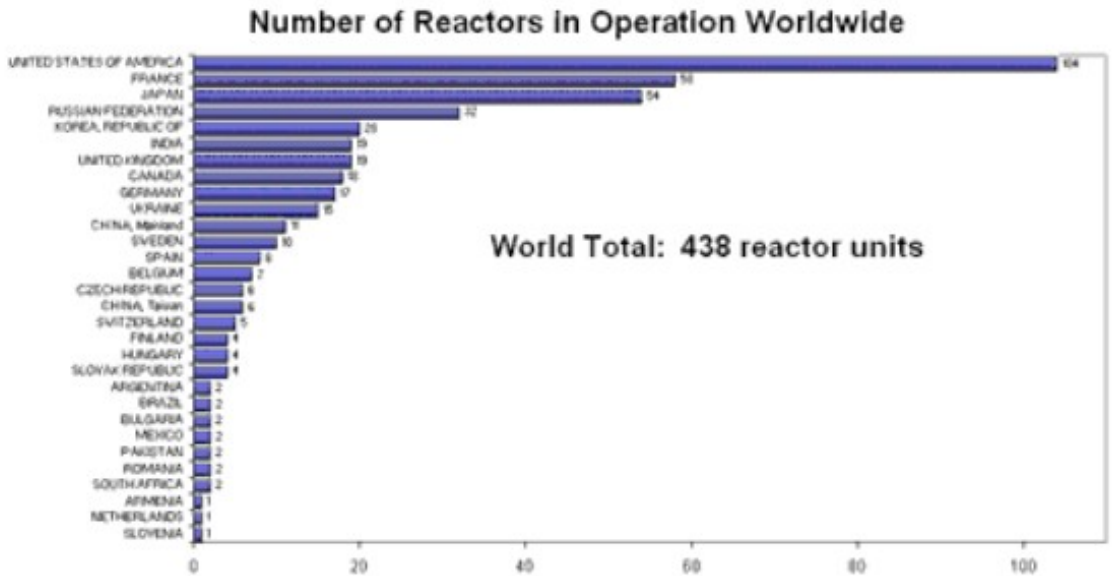


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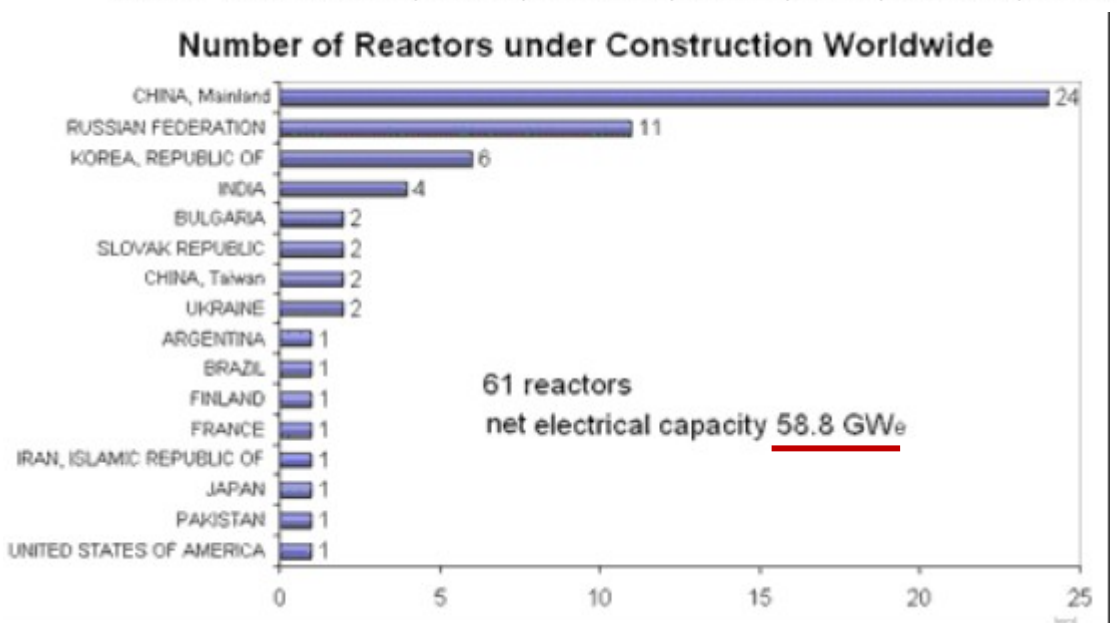
Nuclear Reactors Are Being Constructed At Roughly the IEA Blue Required Rate

www.euronuclear.org/info/encyclopedia/n/nuclear-power-plant-world-wide.htm



Number of reactors in operation, worldwide, June 30, 2010 (IAEA 2010, modified)

IEA Blue Requires 30GW Added Per Year



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Must Greatly Accelerate Installation of Off-Shore Wind and Solar Electricity Generation

Each of These Projects Has Been Underway for a Decade with Intense Public Controversy





Need to Install ~30 “Cape Wind’s” (170 Turbines, 0.5 GW) Per Year Off-Shore Wind Farms: ~15GW Total Every Year Till 2050

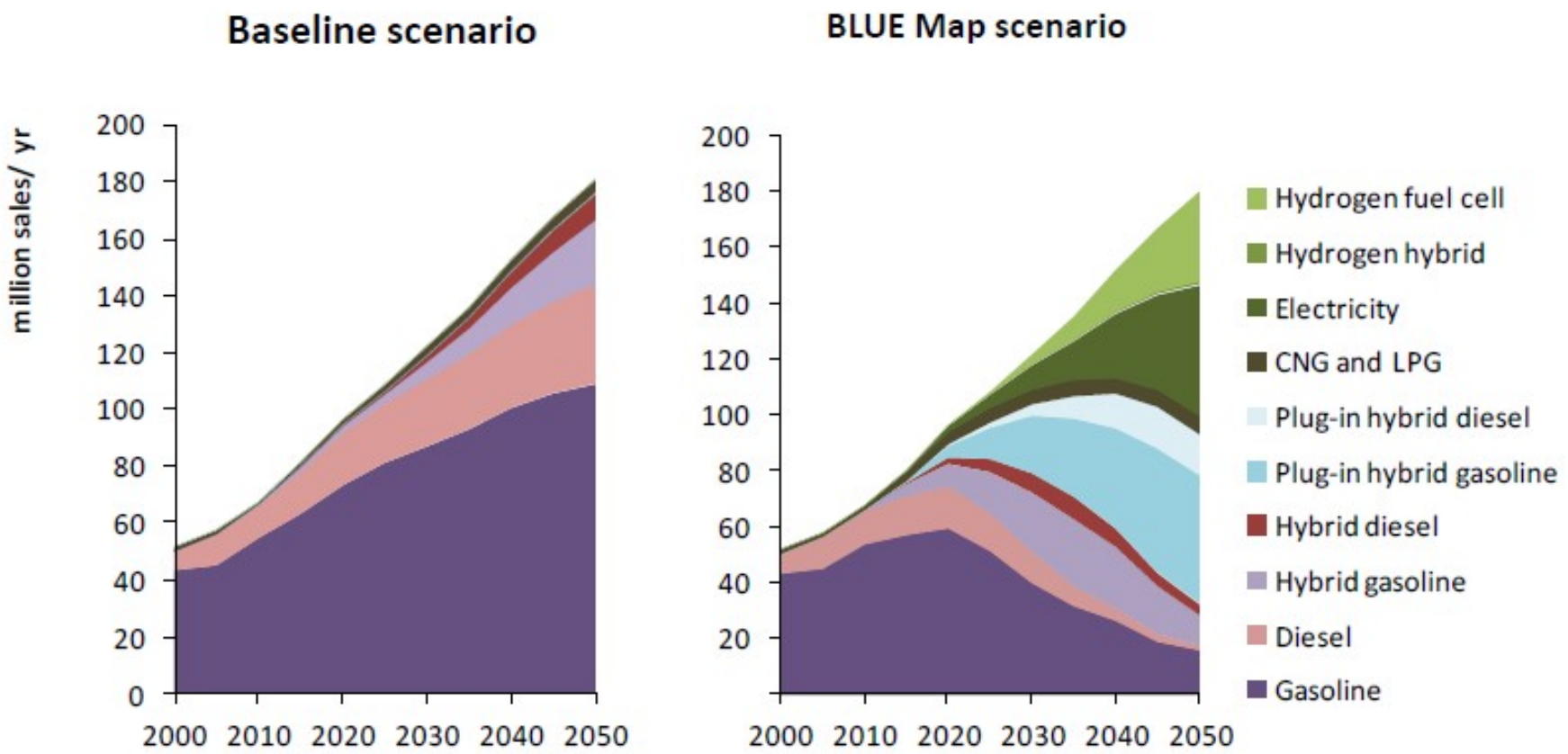
Need to Install ~20 “Anza Borrego” Arrays (30,000 Dishes, 0.75 GW) Per Year of Concentrated Solar Power: ~14 GW Total Every Year Till 2050

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IEA Blue Requires Rapid Transformation of Light Duty Vehicle Sales

Plug-In Hybrid, All-Electric & Fuel-Cell Vehicles Dominate Sales After 2030



OECD Transport Emissions are ~60% Less Than in 2007,
But Those in Non-OECD Countries are ~60% Higher by 2050



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Transition to Low Carbon Infrastructure: Race for Low-Carbon Industries is New Driver

Europe must up CO_2 cuts to 30%: EU

July 15, 2010 - 7:04PM

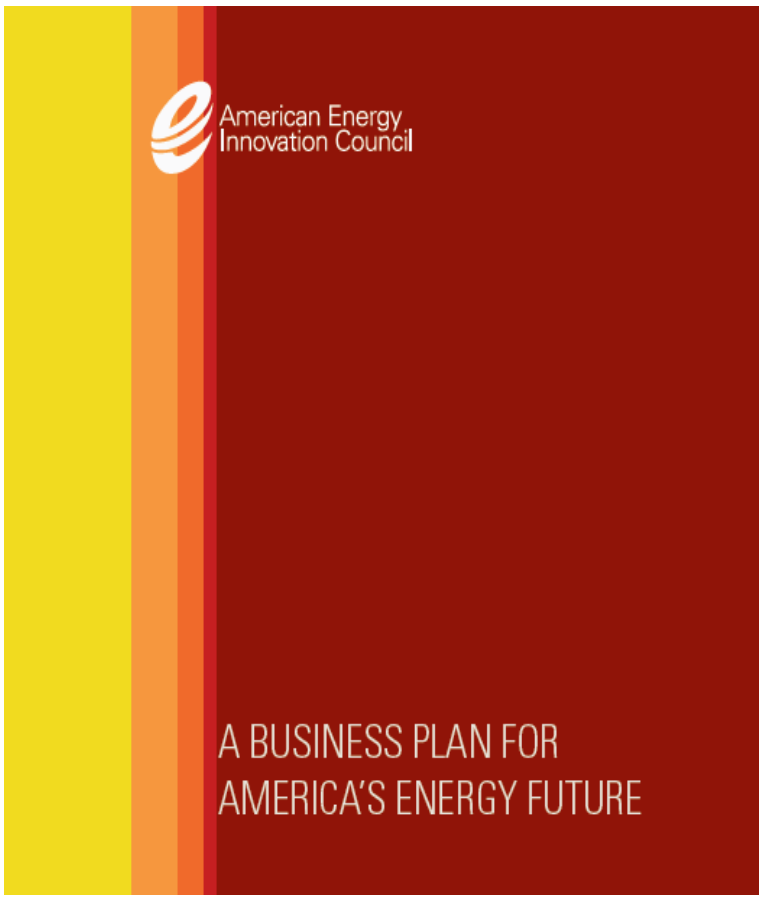
Previous Goal—By 2020, 20% Cut Below 1990 Levels

"If we stick to a 20 per cent cut, Europe is likely to lose the race to compete in the low-carbon world to countries such as China, Japan or the US - all of which are looking to create a more attractive environment for low-carbon investment," --British, French, and German Climate and Environmental Ministers

Source: Sydney Morning News

Top Corporate Leaders Call for Innovation Funding: A Business Plan for America's Energy Future







Our Recommendations (June 2010)

- Create an Independent National Energy Strategy Board
- Invest $16 Billion per Year in Clean Energy Innovation
- Create Centers of Excellence with Strong Domain Expertise
- Fund ARPA-e at $1 Billion Per Year
- Establish and Fund a New Energy Challenge Program to Build Large-scale Pilot Projects

www.americanenergyinnovation.org

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Visionary Low Carbon Infrastructure Plan: Zero Carbon Australia Decarbonizing Electricity Generation in Ten Years

FIGURE 6
ZCA2020 Proposed 100% Renewable Grid

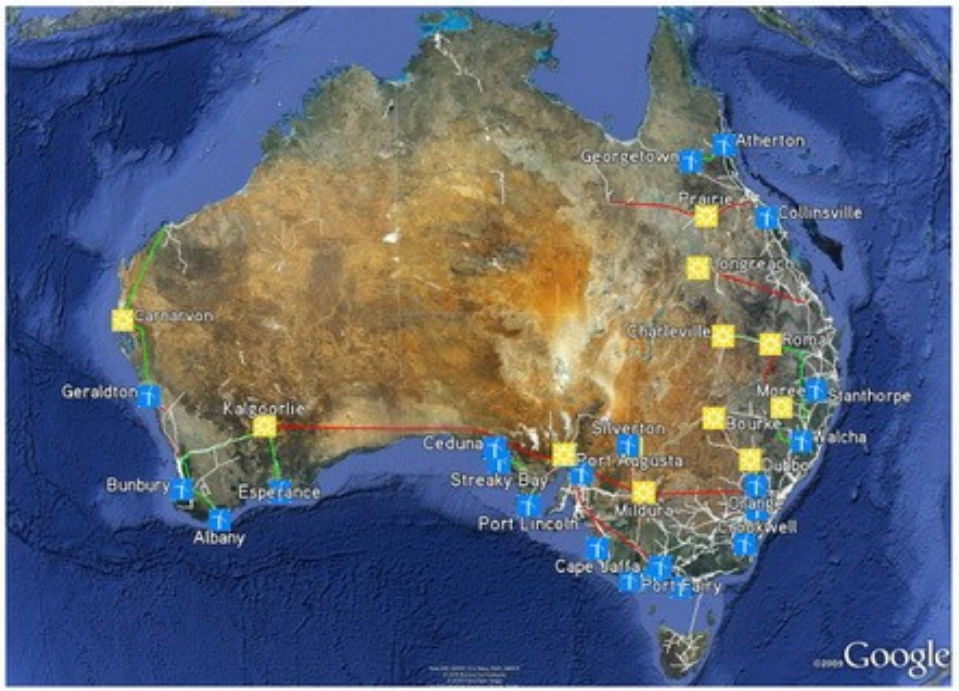


FIGURE 9
ZCA2020 Model Results (daily average data). 'Excess' is combined solar and wind energy in excess of demand.

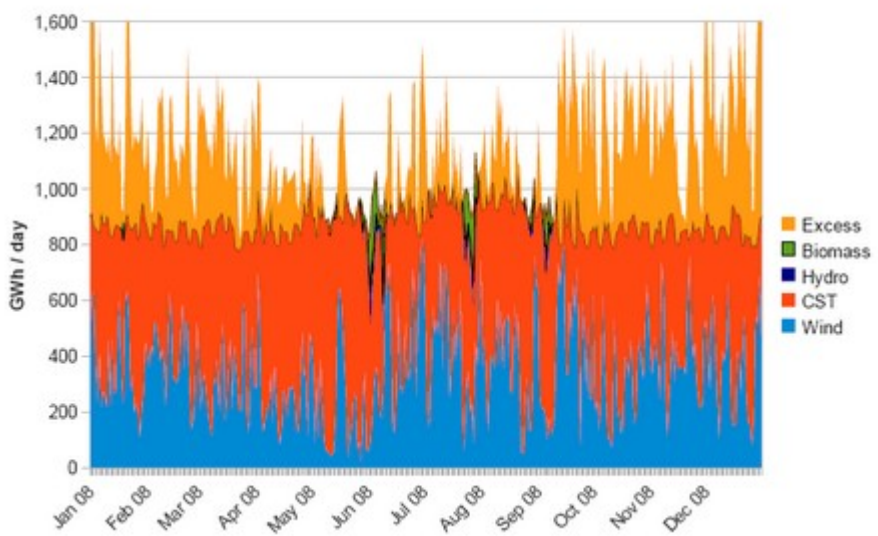
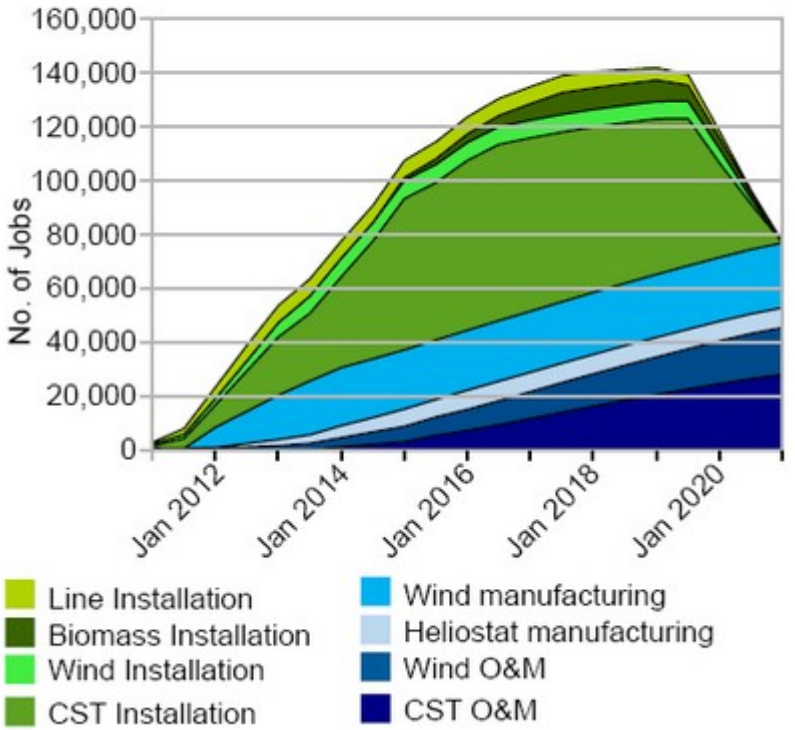


FIGURE 15
Total Jobs created by the ZCA2020 Plan



http://beyondzeroemissions.org/

Wind & Concentrating Solar Thermal (CST) Are Major Renewable Energy Sources

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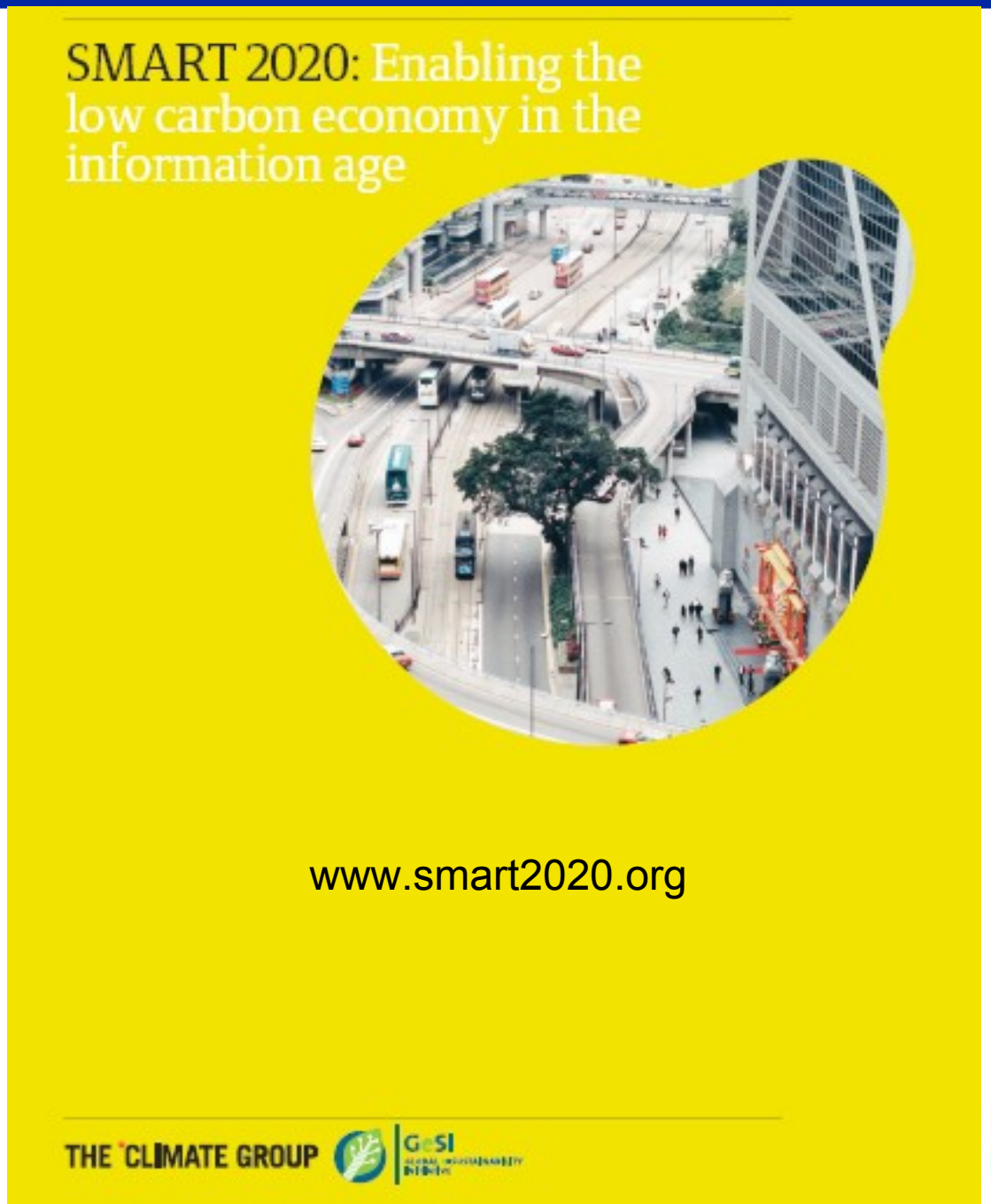
ICT is a Critical Element in Achieving Countries Greenhouse Gas Emission Reduction Targets

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 Transformation to a Smart Energy Infrastructure: Enabling the Transition to a Low Carbon Economy

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.





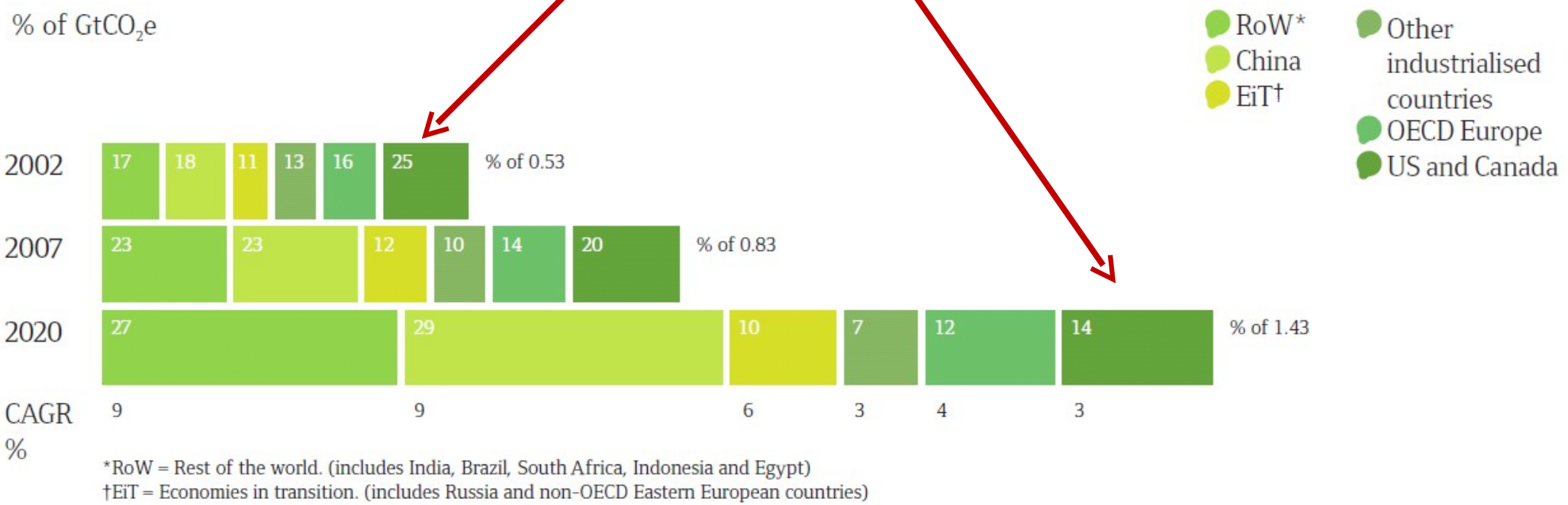
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www.smart2020.org

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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

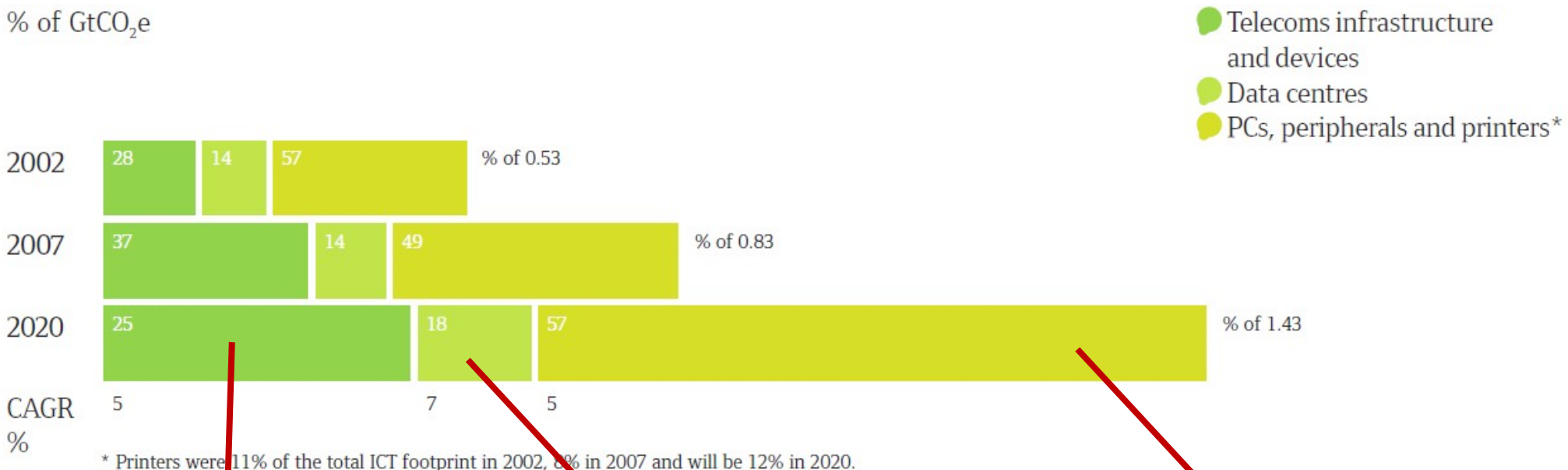


*RoW = Rest of the world. (includes India, Brazil, South Africa, Indonesia and Egypt)
†EiT = Economies in transition. (includes Russia and non-OECD Eastern European countries)

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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



Telecoms Infrastructure & Devices 2nd Largest

Data Centers Are Rapidly Improving

PCs Are Biggest Problem

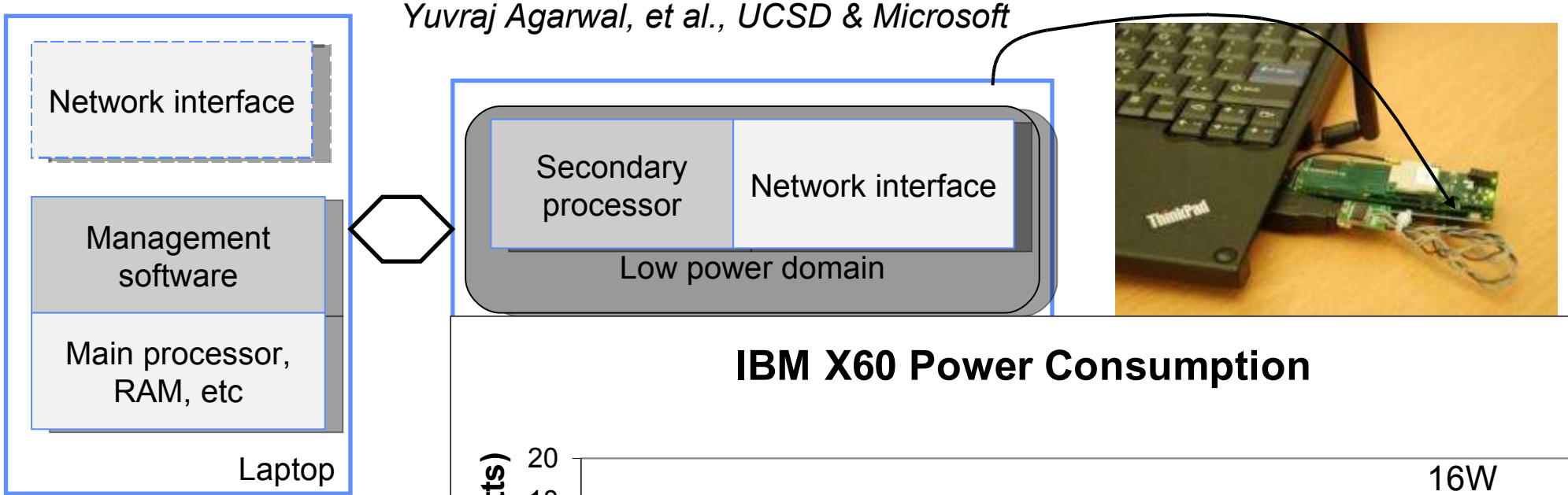
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www.smart2020.org

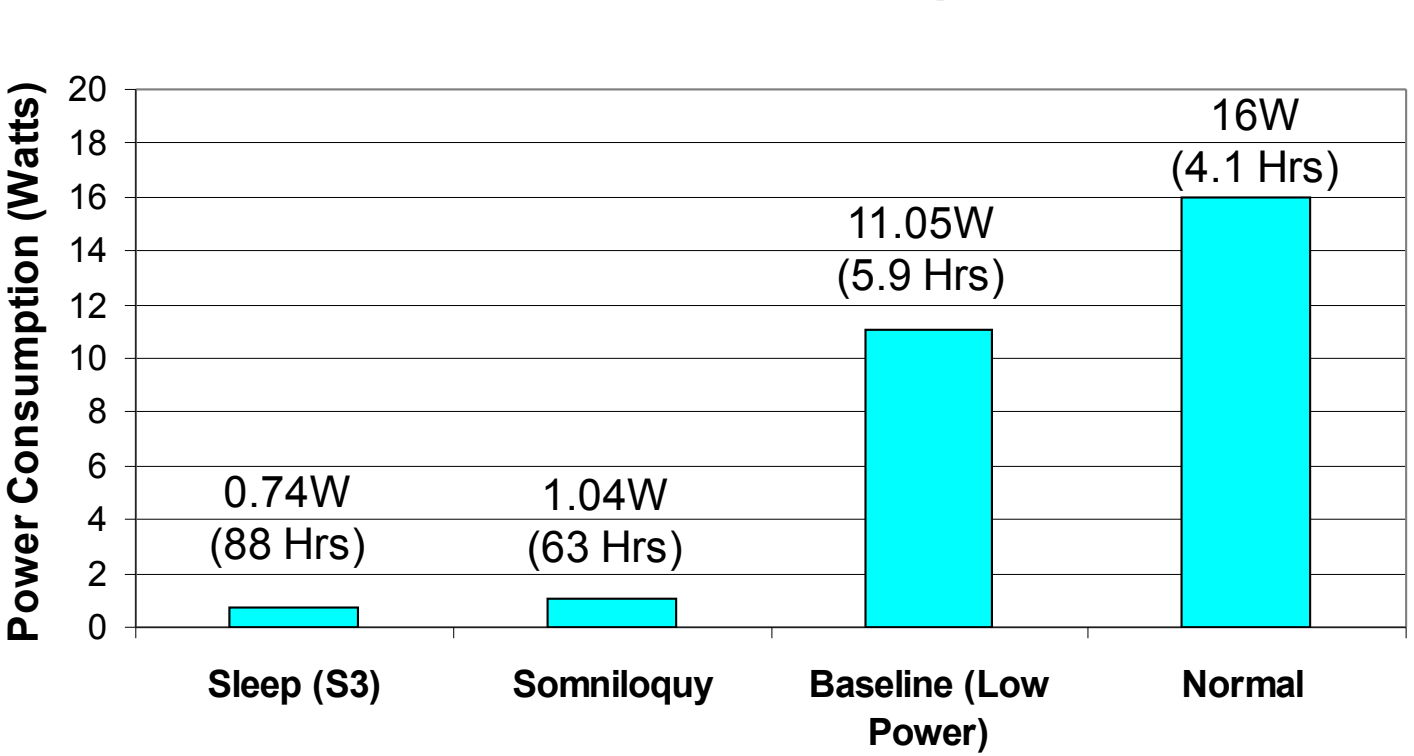
Somniloquy: Increasing Laptop Energy Efficiency

http://mesl.ucsd.edu/yuvraj/research/documents/Somniloquy-NSDI09-Yuvraj-Agarwal.pdf

Yuvraj Agarwal, et al., UCSD & Microsoft



Somniloquy Allows PCs in "Suspend to RAM" to Maintain Their Network and Application Level Presence



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Carbon Pricing Will Have Major Impact on Data Centers —A New Driver for Energy Efficiency

Will pending law make California too costly for data centers?

By John Parkinson, Contributor
23 Jul 2010 | SearchDataCenter.com

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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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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

see it2

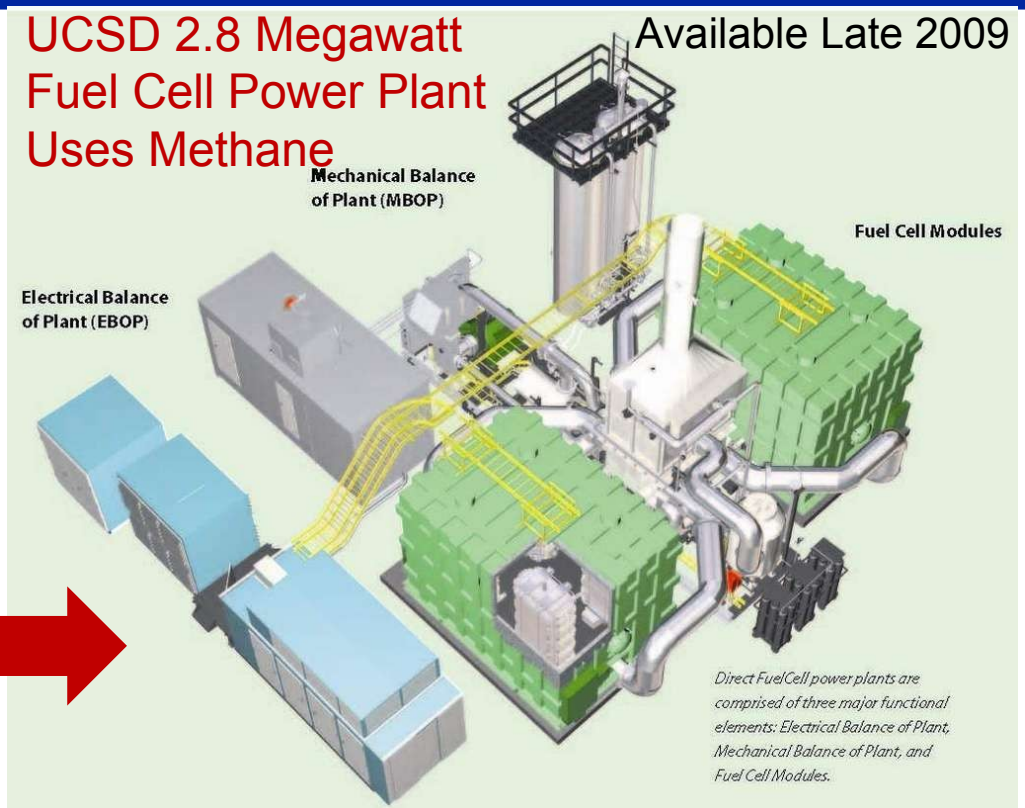
UCSD is Installing Zero Carbon Emission Solar and Fuel Cell DC Electricity Generators

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

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GreenLight Experiment: Direct 400v DC-Powered Modular Data Center

- **Concept—avoid DC To AC To DC Conversion Losses**
  - Computers Use DC Power Internally
  - Solar & Fuel Cells Produce DC
  - Can Computers & Storage Use DC Directly?
  - Is DC System Scalable?
  - How to Handle Renewable Intermittency?

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

- **Prototype Being Built in GreenLight Instrument**
  - Build DC Rack Inside of GreenLight Modular Data Center
    - 5 Nehalem Sun Servers
    - 5 Nehalem Intel Servers
    - 1 Sun Thumper Storage Server

All With DC Power Supplies

  - Building Custom DC Sensor System to Provide DC Monitoring
  - Operational August-Sept. 2010

Next Step: Couple to Solar and Fuel Cell

Source: Tom DeFanti, Greg Hidley, Calit2; Tajana Rosing, UCSD CSE

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

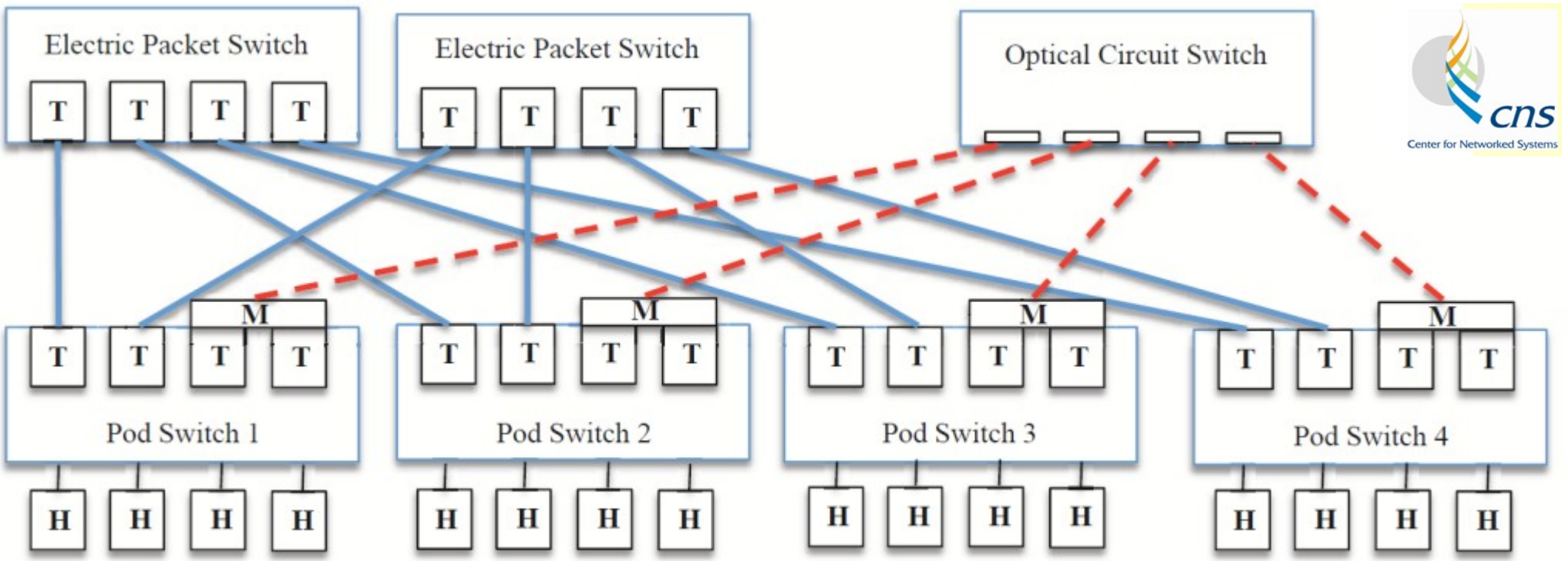


Source: Michael Manos

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UCSD Scalable Energy Efficient Datacenter (SEED): Energy-Efficient Hybrid Electrical-Optical Networking



- **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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PIs of NSF MRI: George Papen, Shaya Fainman, Amin Vahdat; UCSD

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Calit2 Photonics Systems Laboratory Is Investigating Novel Telecoms Energy Efficiency

- **Networking "Living Lab" Testbed Core**
  - **Real-Time Terabit/s Processing**
  - **Single 640Gbps Channel Transport Over >100km**
  - **Sub-Watt Transport of Terabit Channel**

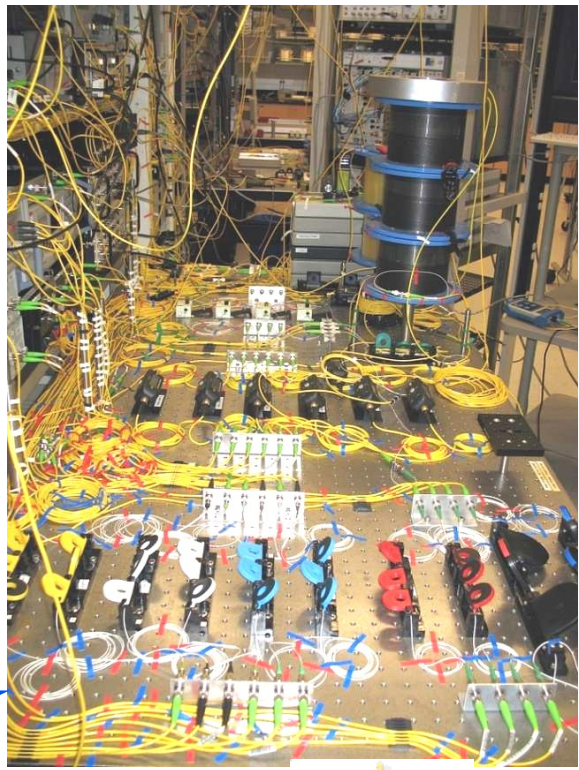
Alcatel·Lucent

AVANEX

ofs
A Furukawa Company

SUMITOMO ELECTRIC
LIGHTWAVE

LOCKHEED MARTIN



ECE Testbed Faculty



Stojan Radic
Optical communication networks; all-optical processing; parametric processes in high-confinement fiber and semiconductor devices.



George Papen
Advanced photonic systems including optical communication systems, optical networking, and environmental and atmospheric remote sensing.



Joseph Ford
Optoelectronic subsystems integration (MEMS, diffractive optics, VLSI); Fiber optic and free-space communications.



Shaya Fainman
Nanoscale science and technology; ultrafast photonics and signal processing



Shayan Mookherjea
Optical devices and optical communication networks, including photonics, lightwave systems and nano-scale optics.

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UCSD Photonics



NSF

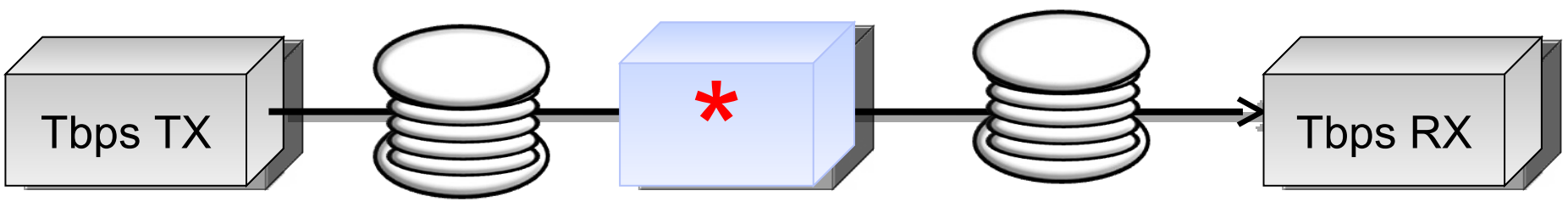
PPS
PARAMETRIC OPTICAL PROCESSES & SYSTEMS

MTO DARPA
MICROSYSTEMS TECHNOLOGY OFFICE

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Terabit Channel: Data Center, LAN/Metro: How to Minimize Terabit Dissipation

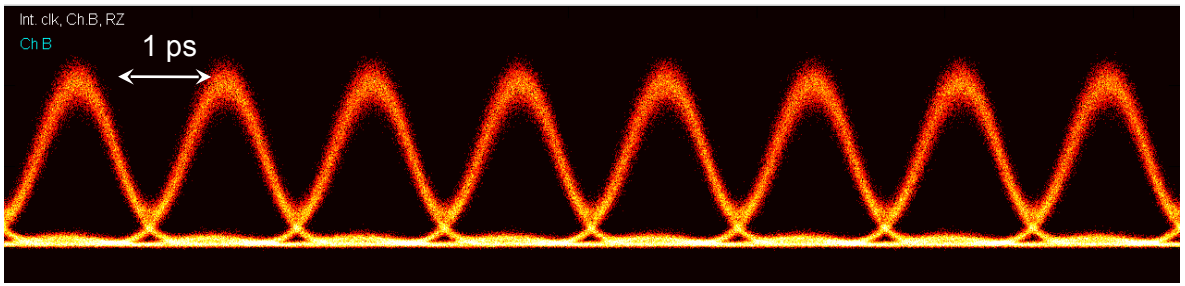
- **Maintain Channel Integrity in Optical Domain:**
  - **No Forward Error Correction (FEC)**
  - **No Regeneration**
  - **No Digital Signal Processing (DSP)**



Source: Nikola Alic, Stojan Radic, Calit2, UCSD

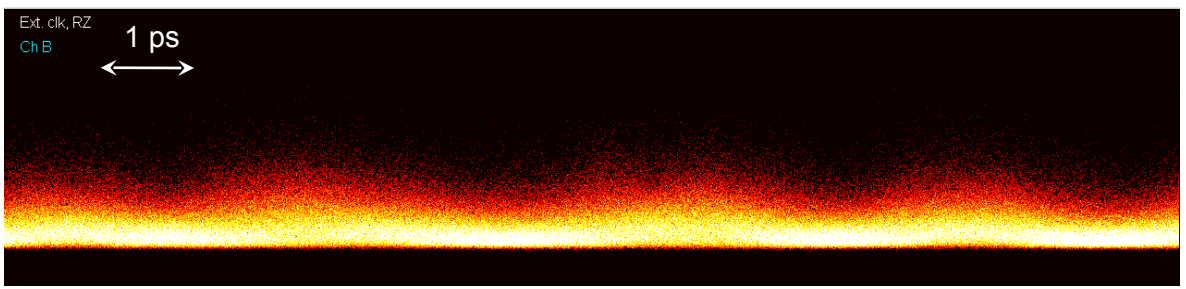
Sub-Watt Transport of Terabit Channel: 1000x Reduction in Transport Dissipation

Back-to-Back

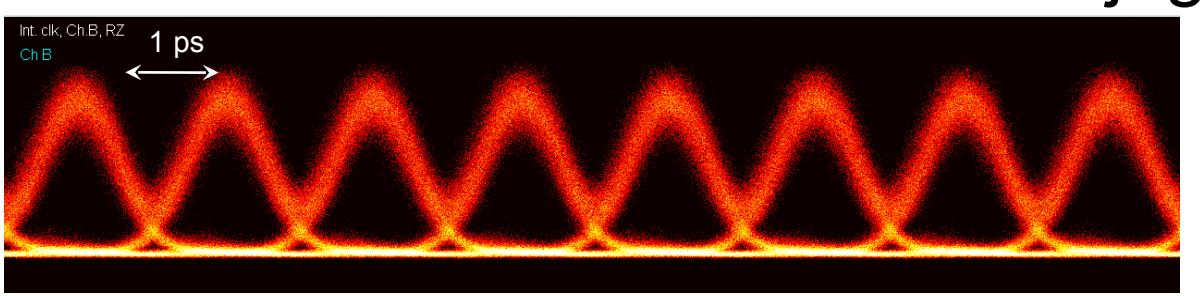


Pico-Joule per Bit Efficiency

Transmission 100 km without Conjugation



Transmission 100 km with Conjugation



Legacy Standard Single Mode Fiber (SMF-28)

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Source: Nikola Alic, Stojan Radic, Calit2, UCSD

DARPA

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Calit2@UCSD's Wireless Power Amplifier Lab: Making Wireless Telecom Infrastructure More Efficient

Oct. 2005 Calit2 Sets World Record 50% Efficiency for High-Power Amplifiers for Cellular Base Stations

freescale semiconductor

Power Transistor Tradeoffs

Si-LDMOS, GaN, & GaAs

Price & Performance

Eudyna

TriQuint SEMICONDUCTOR

Power Amplifier Tradeoffs

WiMAX & 3.9GPP LTE

Efficiency & Linearity

STMicroelectronics

HUAWEI

Digital Signal Processing Tradeoffs

Pre-Distortion, Memory Effects & Power Control

NOKIA

ERICSSON

MIPS & Memory

QUALCOMM

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IEEE Topical Symposium on Power Amplifiers for Wireless Communications was held Sept. 14-15, 2009

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Applying ICT – The Smart 2020 Opportunity for 15% Reduction in GHG Emissions

Smart Transportation

Smart Buildings

Smart Electrical Grid

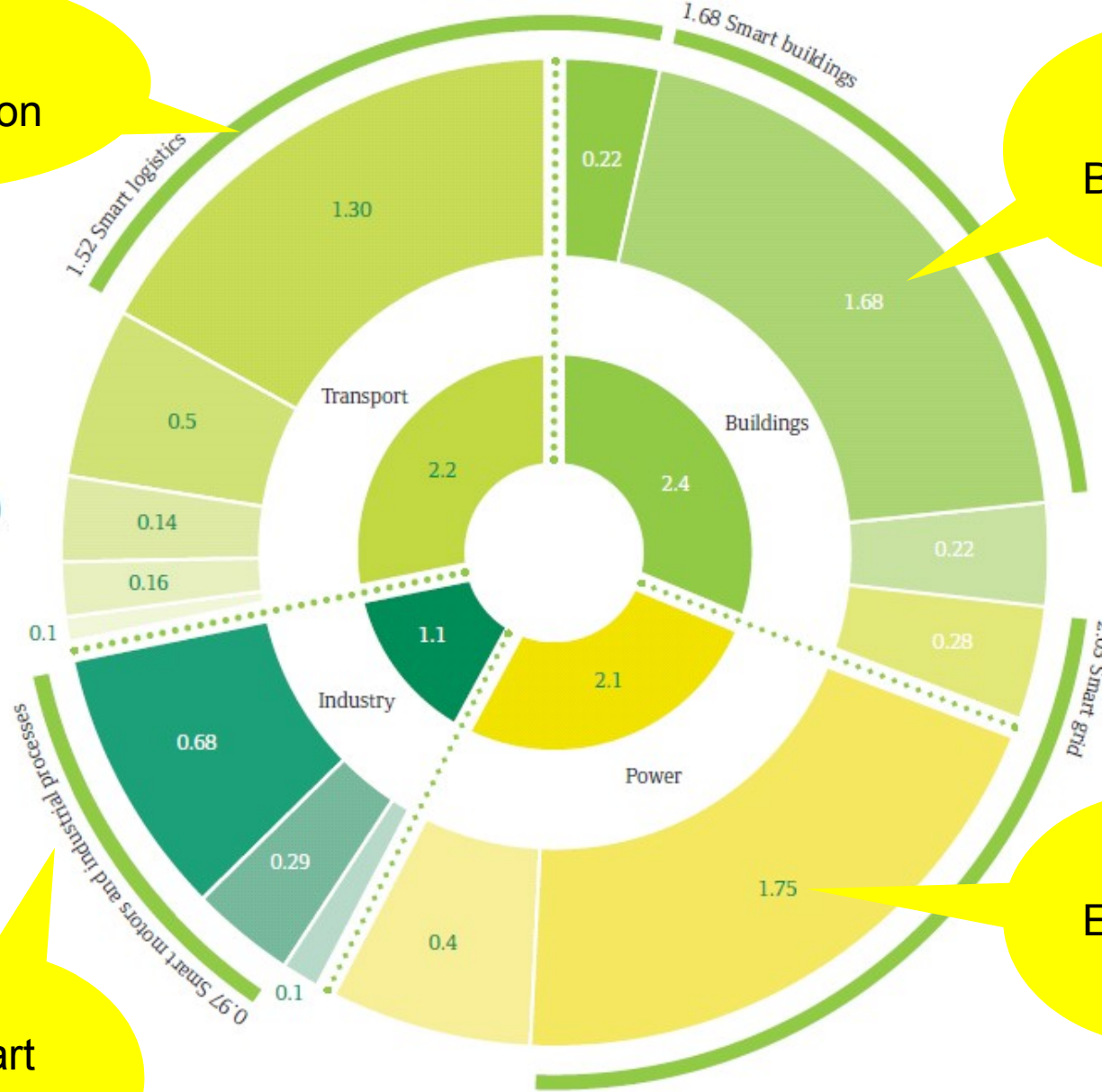
Smart Motors

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)



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www.smart2020.org

it²

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**

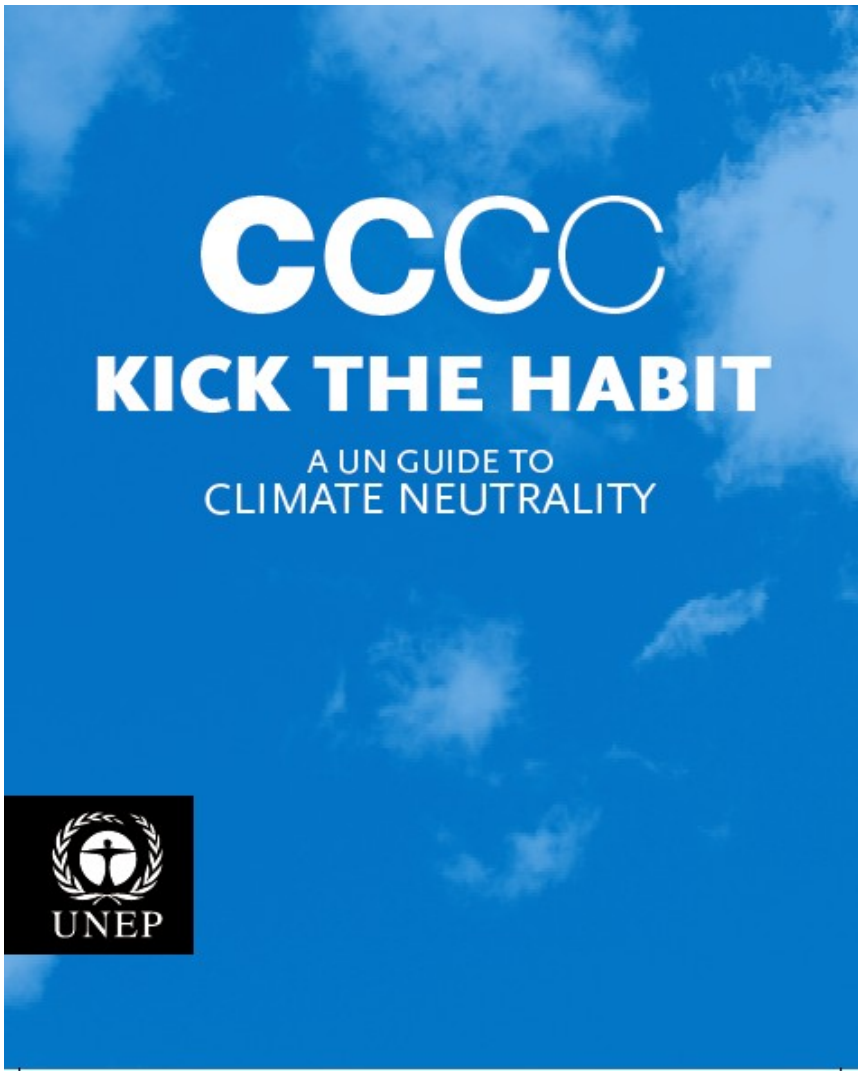
*** Smart 2020 United States Report Addendum**

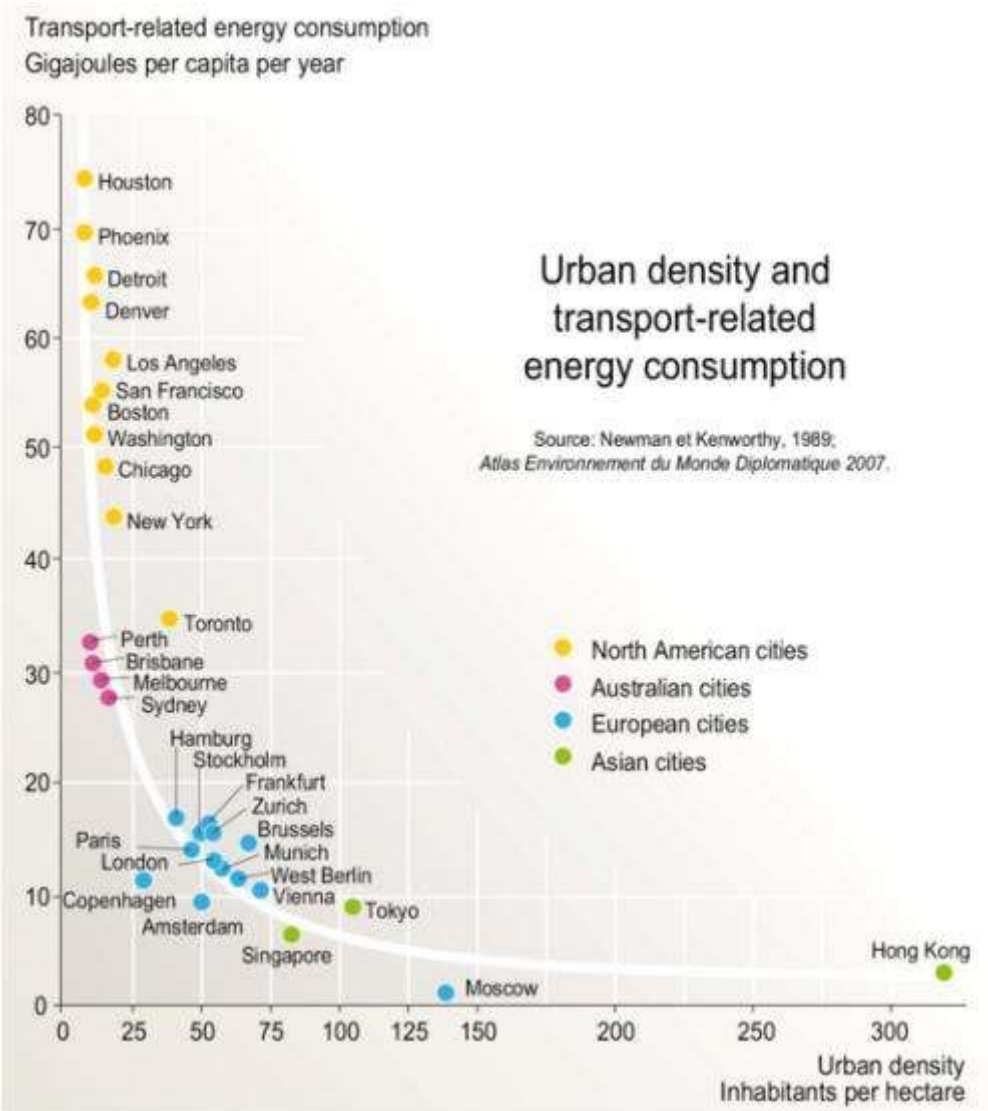
www.smart2020.org

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The Transition to a Low Carbon Society Requires Rethinking Our Cities Infrastructure





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www.unep.org/publications/ebooks/kick-the-habit/pdfs/KickTheHabit_en_lr.pdf

it2

Over 670 College and University President's Have Signed the Climate Commitment Pledge

Can Universities Live 5-10 Years Ahead of Cities -- Helping Accelerate the Climate Adaptation of Global Society?



- **"We recognize the need to reduce the global emission of greenhouse gases by 80% by mid-century.**
- **Within two years of signing this document, we will develop an institutional action plan for becoming climate neutral."**

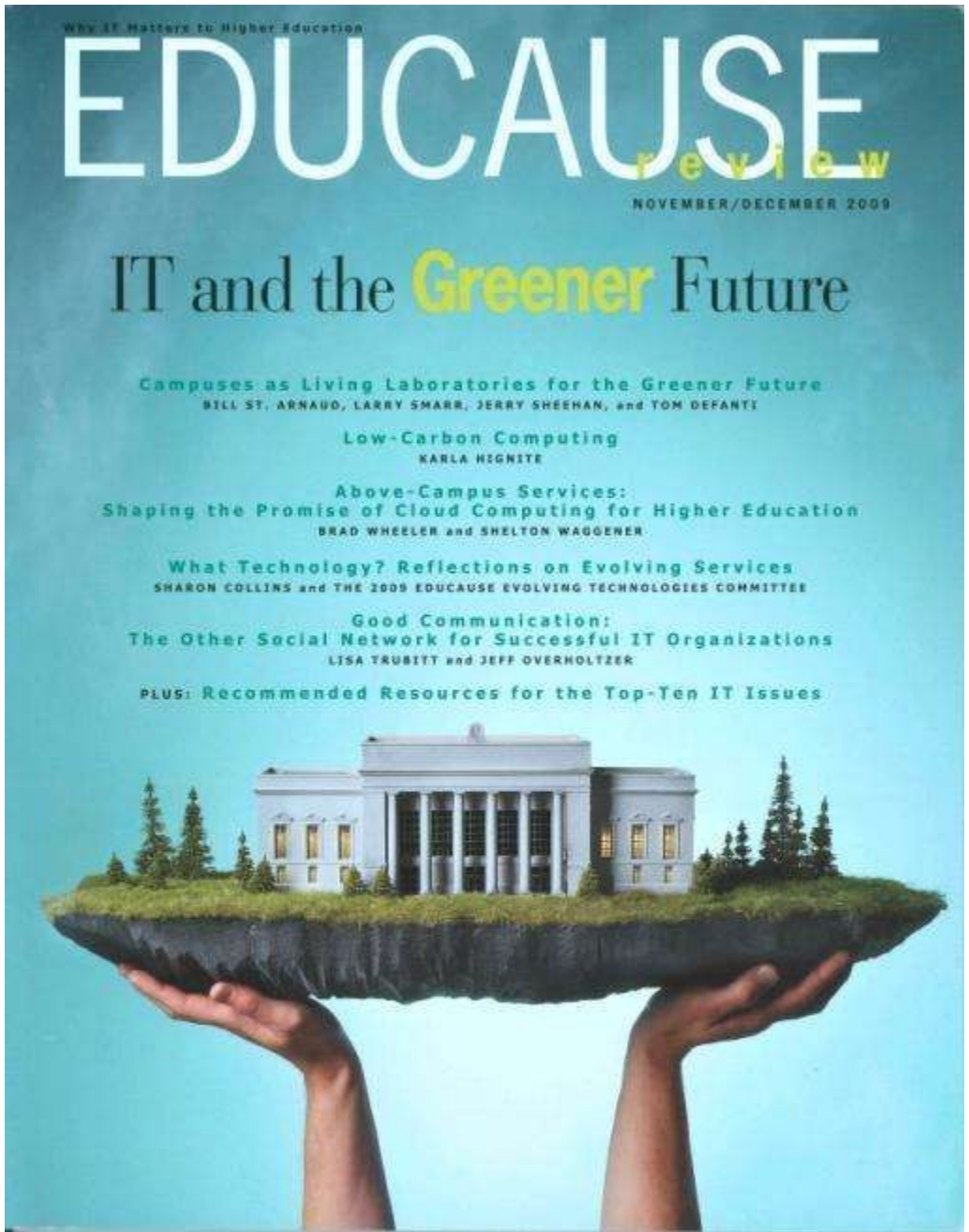
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www.presidentsclimatecommitment.org

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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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UCSD
as a Model Green Campus

- **Second-Largest User Of Electricity (~40 MW) In San Diego**
  - 45,000 Daily Occupants
  - After the City Itself, the Seventh-Largest City in the U.S.
- **Aggressive Program to De-Carbonize Generating Electricity**
  - Natural Gas Co-Gen Facility Supplies ~90% of Campus Electricity
    - Saves ~$8 Million Annually in Energy Costs
  - Installed 1.2 MW Of Solar Panels (With an Additional 2 MW Likely)
  - Acquiring a 2.8 MW Fuel Cell in 2011
    - Powered by Methane from San Diego Waste-Treatment Plant
- **UCSD Campus Fleet 45% Renewables**
  - 300 Small Electric Cars
  - 50 Hybrids
  - 20 Full-Size Electrics by 2011

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

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UC Irvine as a Model Green Campus

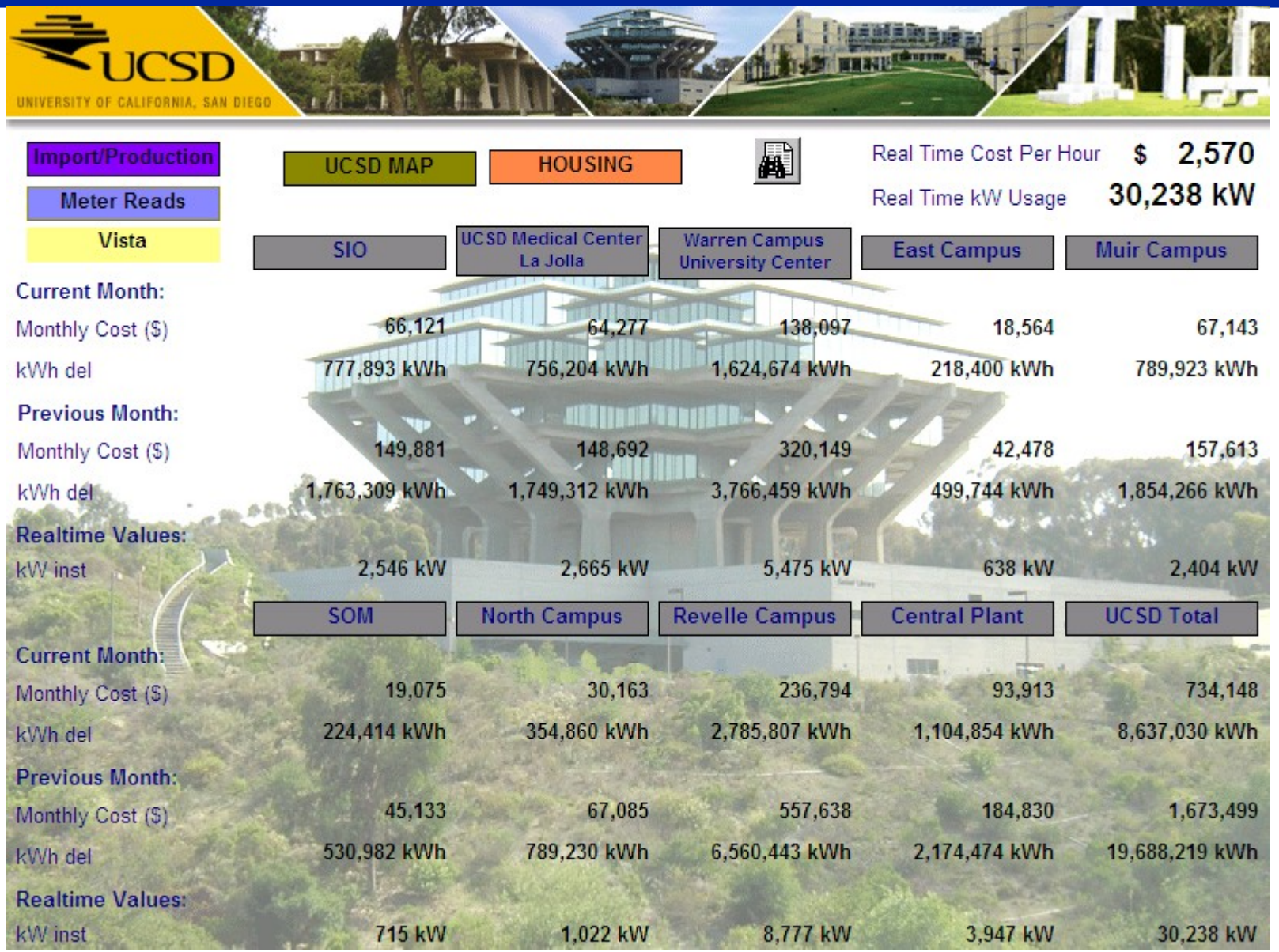
- California's "Flex Your Power" Statewide Energy-Efficiency Campaign Only University Campus Cited in "Best Overall"
  - UCI Led in Efficiency-Saving 3.7 Million KWh of Electricity During 07–08
    - Reducing Peak Demand by up to 68%
    - Saving Nearly 4 Million Gallons Of Water Annually.
  - UCI's 2008 GHG Reduction Program Annually Eliminates 62,000 $MtCO_2e$
    - Saves the Campus ~$30 Million
- SunEdison Financed, Built, & Operates Solar Energy System
  - In March 2009, UCI Began Purchasing Energy Generated by System
  - Will Produce >24 GWh over 20 Years
- 18 MW Combined Heating, Power, & Cooling Co-Gen Plant
  - Employs 62,000 Ton-Hour Chilled-Water Thermal Energy Storage System
  - Capable of Reducing up to 6 MW of Electrical Peak Demand
- UCI 1st US Campus to Retrofit Shuttles for Pure Biodiesel
- Research Program with Toyota Plug-In Prius in Nov 2007

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

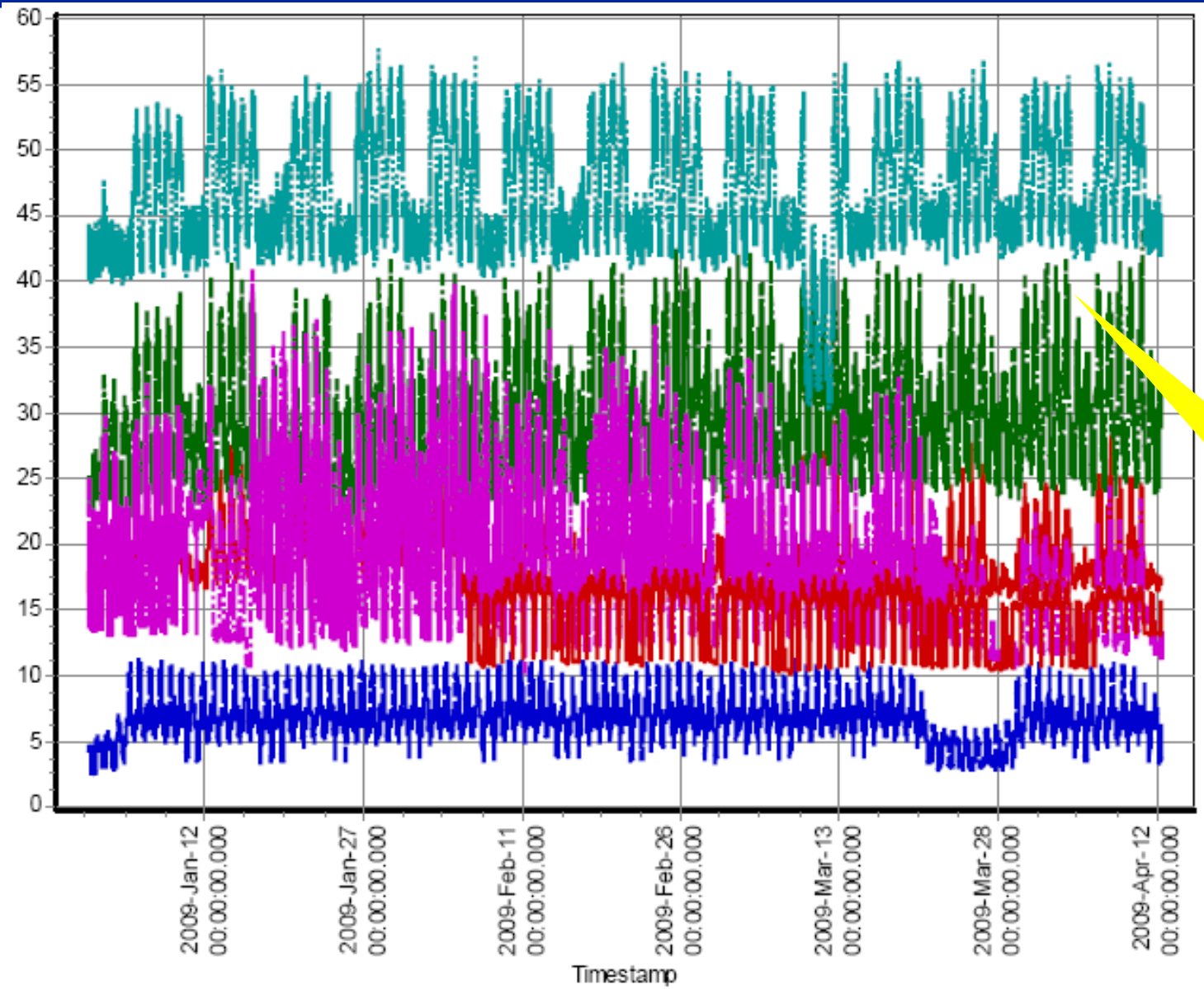
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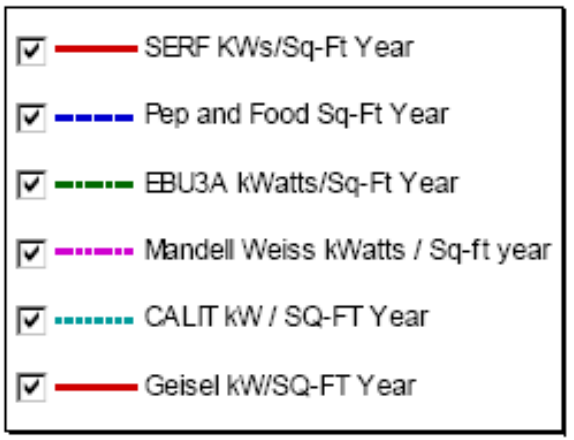
Real-Time Monitoring of Building Energy Usage: Toward a Smart Energy Campus



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Using the Campus as a Testbed for Smart Energy: Making Buildings More Energy Efficient





Calit2 and CSE are Very Energy Intensive Buildings

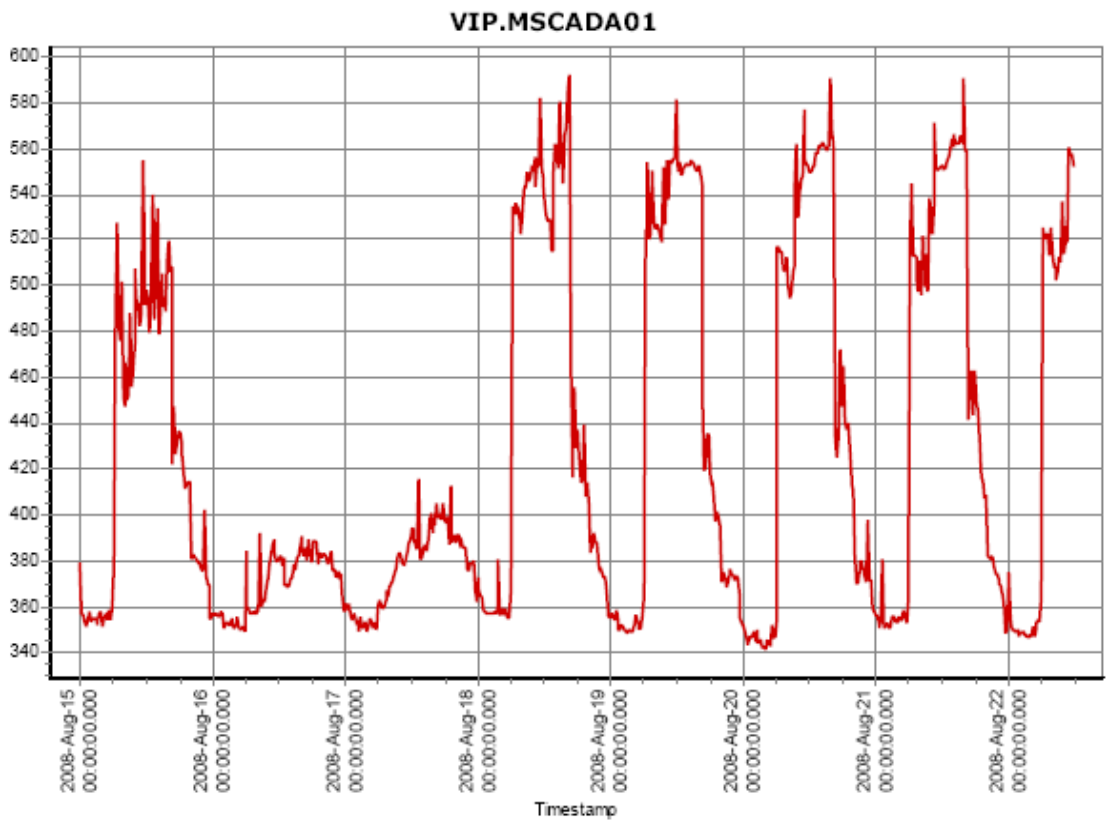
kW/sqFt Year Since 1/1/09

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Smart Energy Buildings: Active Power Management of Computers

- 500 Occupants, 750 Computers
- 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



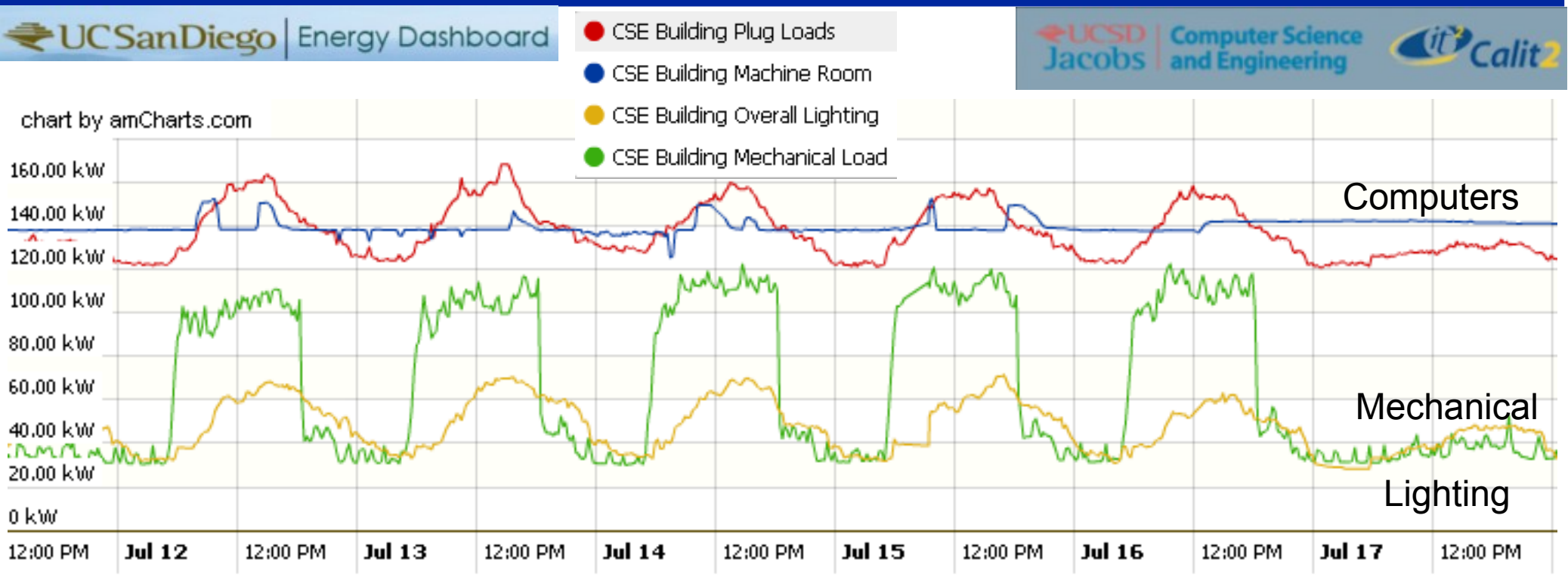


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Source: Yuvraj Agarwal, Thomas Weng, Rajesh Gupta, UCSD

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Contributors to Base Load
UCSD Computer Science & Engineering Building



- **IT Loads Account for 50% (Peak) to 80% (Off-Peak)!**
  - **Includes Machine Room + Plug Loads (PCs and Laptops)**
- **IT Equipment, Even When Idle, Not Put to Sleep**
- **Duty-Cycling IT Loads Essential To Reduce Baseline**

UCSD UCIrvine

Source: Yuvraj Agarwal, Thomas Weng, Rajesh Gupta, UCSD

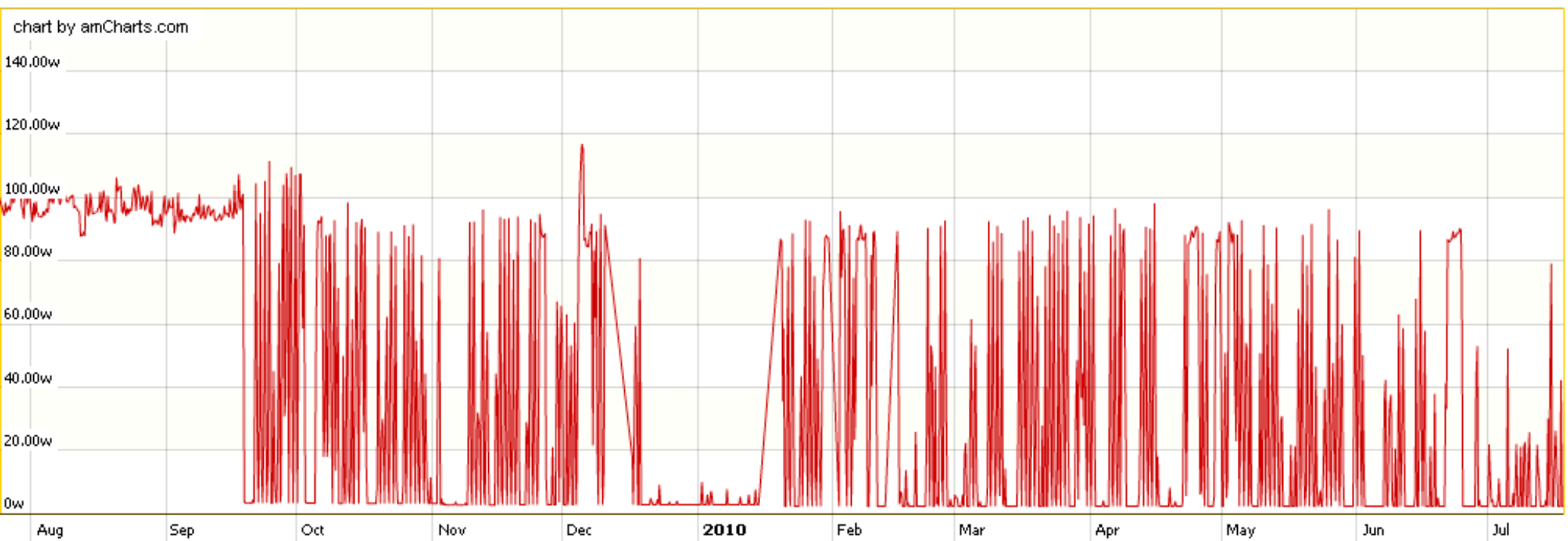
http://energy.ucsd.edu

Reducing Energy Requirements of Networked PCs: UCSD's Enterprise "Sleep Server" System



http://energy.ucsd.edu/device/meterdisplay.php?meterID=3091420330&mode=pastyear

Estimated Energy Savings
With Sleep Server: 46.64%



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UCSD Jacobs School of Engineering | Computer Science and Engineering | Calit2

Source: Yuvraj Agarwal, Thomas Weng, Rajesh Gupta, UCSD

it²

Reducing CO_2 From Travel: Linking the Calit2 Auditoriums at UCSD and UCI



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Photo by Erik Jepsen, UC San Diego

it²

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



NASA Interest in Supporting Virtual Institutes

LifeSize HD

NASA Ames
Lunar Science Institute
Mountain View, CA

UCSD
UCIrvine

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

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

www.calit2.net/newsroom/article.php?id=1498

First Southern California Smart Grid Symposium

Tuesday April 7, 2009



Greening the Internet Economy

ICT & GLOBAL CHANGE

January 22-23, 2009

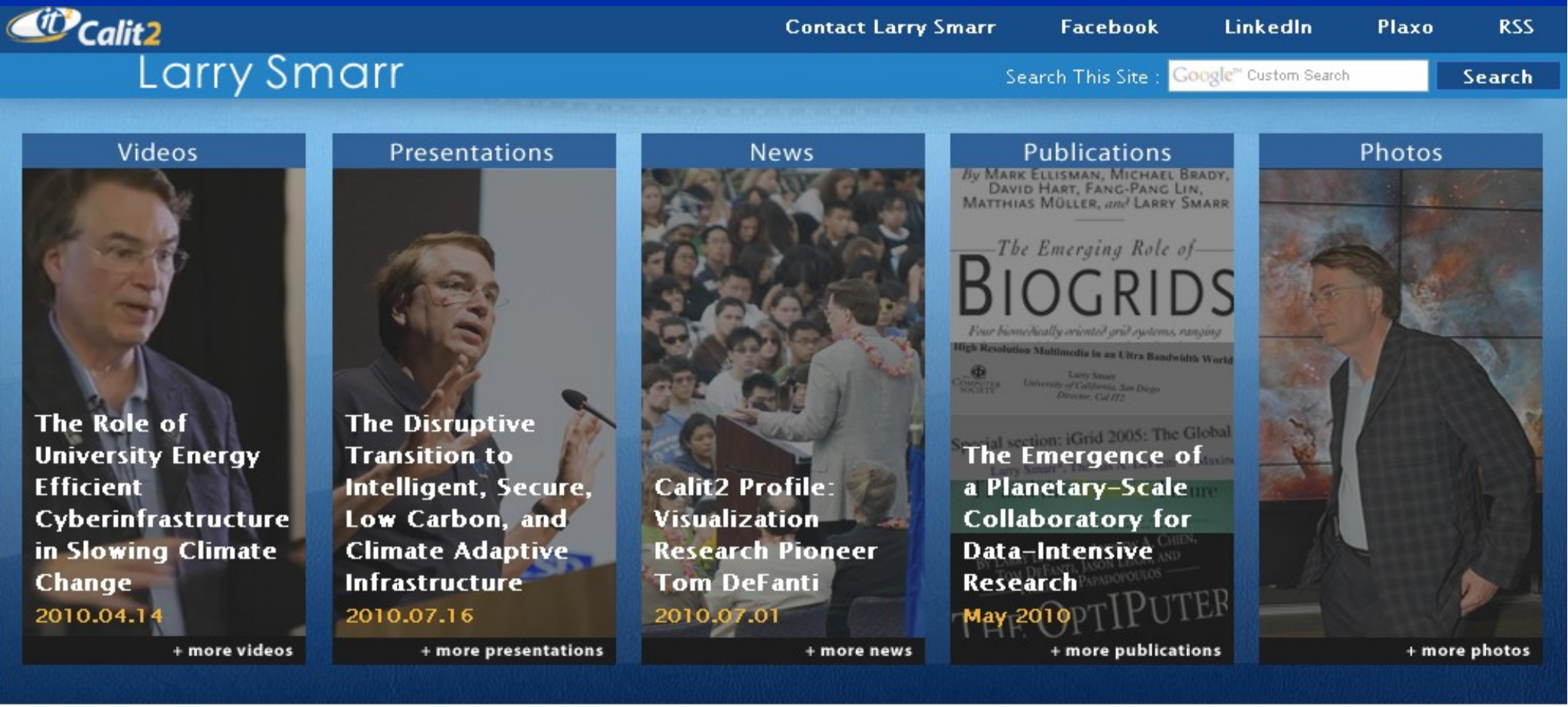


California Public Utilities Commission

Co-Hosted By Calit2 & CPUC

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

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

WHAT I'M READING

Complete List of Larry's Recommendations

Homo Britannicus: The Incredible Story of Human Life in Britain (2006)

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Ismarr: Taking train to NJ tomorrow to give Distinguished Lecture on Green IT and climate change at AT&T