IBM Zurich Research Laboratory

Building a Smarter Energy Future

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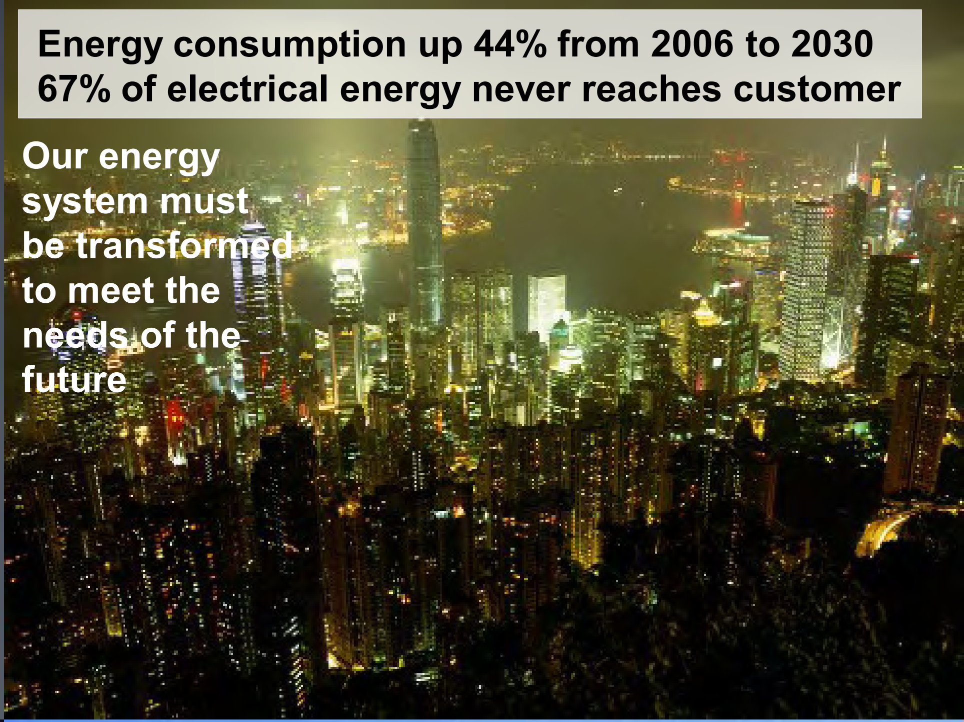
Smart Energy Day

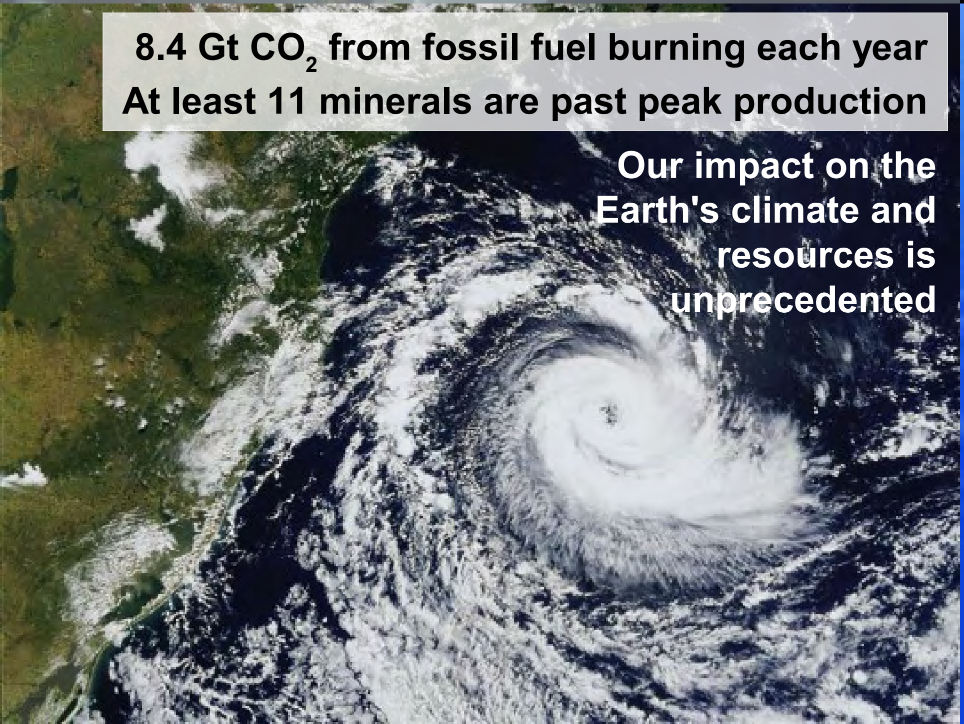
14th December 2010

École Polytechnique Fédérale de Lausanne

IBM


[redacted]
Almost everything can become digitally aware and interconnected


Energy consumption up 44% from 2006 to 2030
67% of electrical energy never reaches customer
Our energy system must be transformed to meet the needs of the future


8.4 Gt CO_2 from fossil fuel burning each year
At least 11 minerals are past peak production
Our impact on the Earth's climate and resources is unprecedented


Water scarcity for every other human in 2030
22% of freshwater use is industrial
Energy consumption severely impacts water availability

Building a Smarter Energy Future

1. Computing for energy
2. Energy in computing
3. Energy for computing

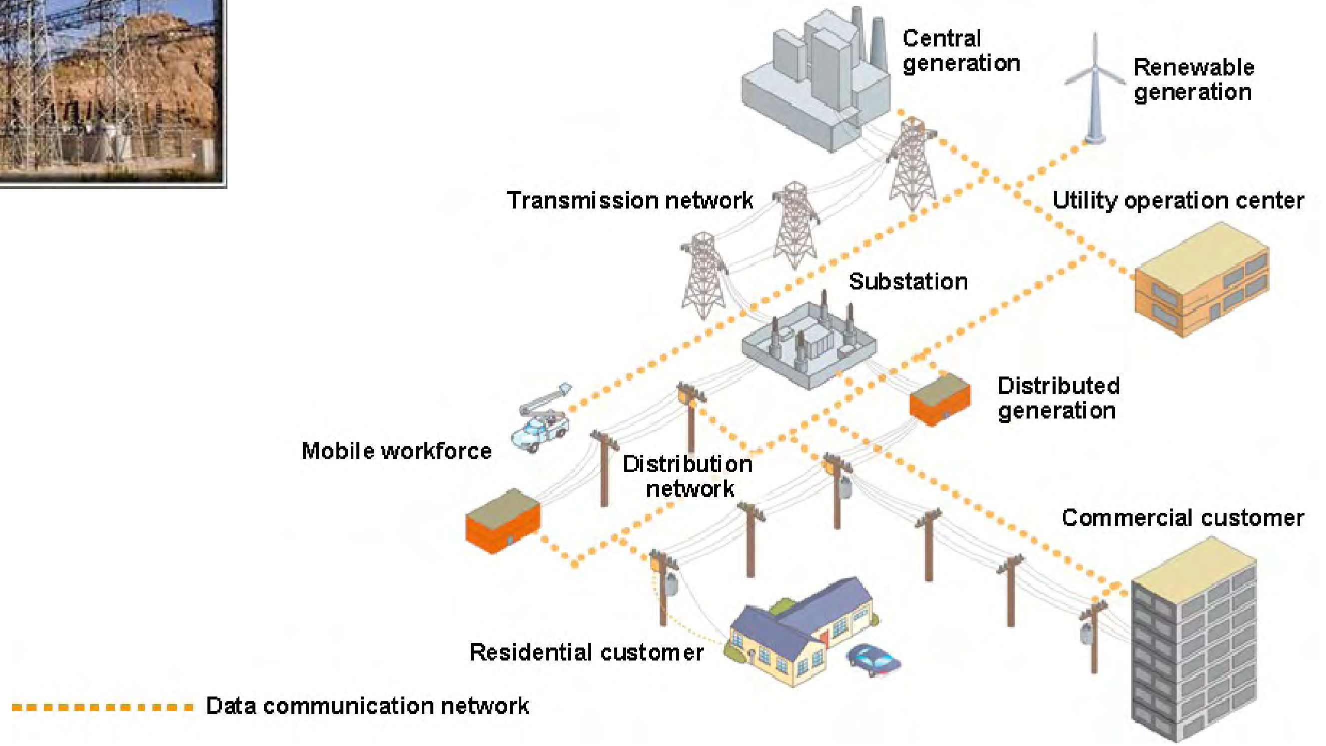
Computing for energy

Key aspects

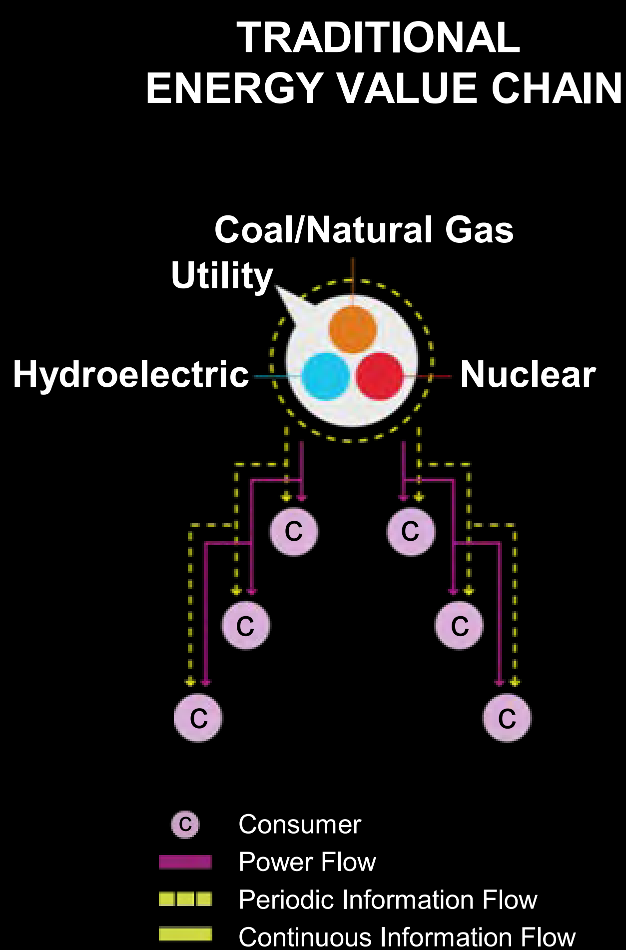
- Smart grids
- Analytics & modeling
- Simulation platforms
- Energy-efficient buildings
- Electric vehicles

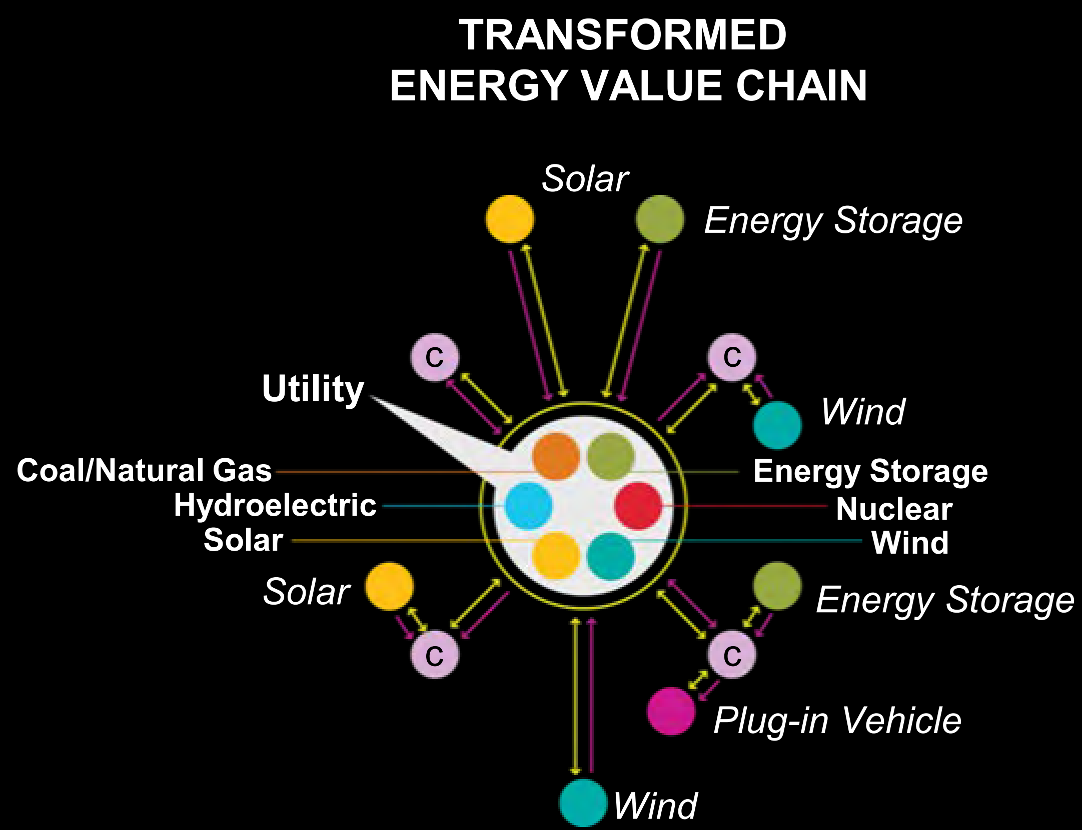
Smarter energy through computing

- Energy and utilities
- EDISON
- EcoGridEU



Energy and utilities

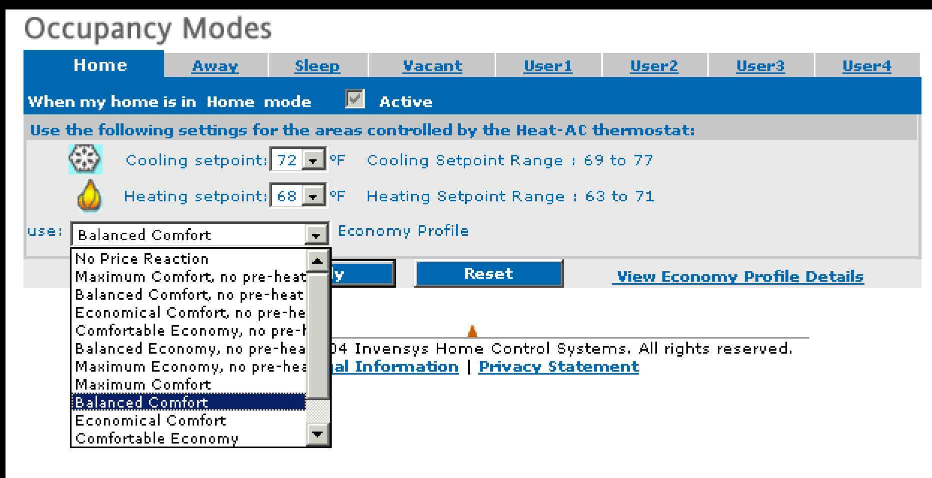


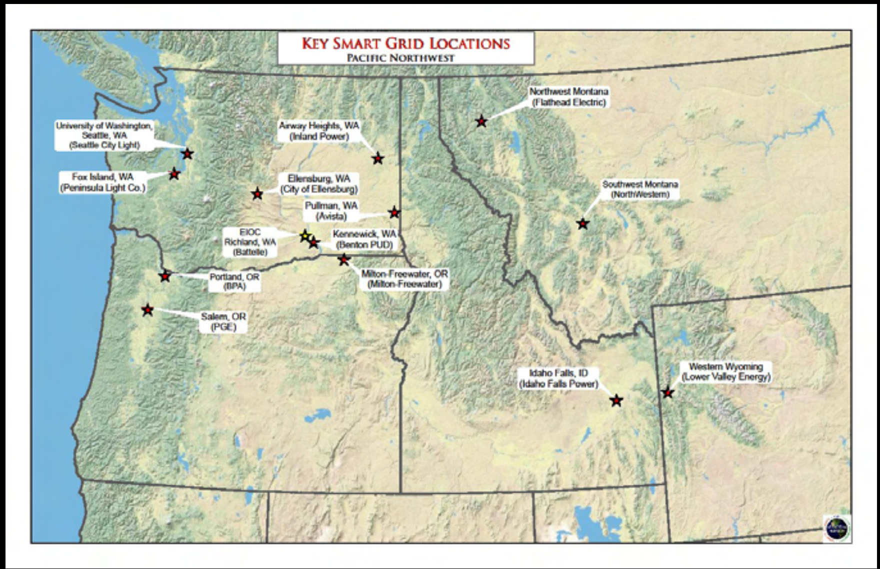


Drives transformation of policy and business models

Energy and utilities

Pacific Northwest Smart Grid: regional demonstration

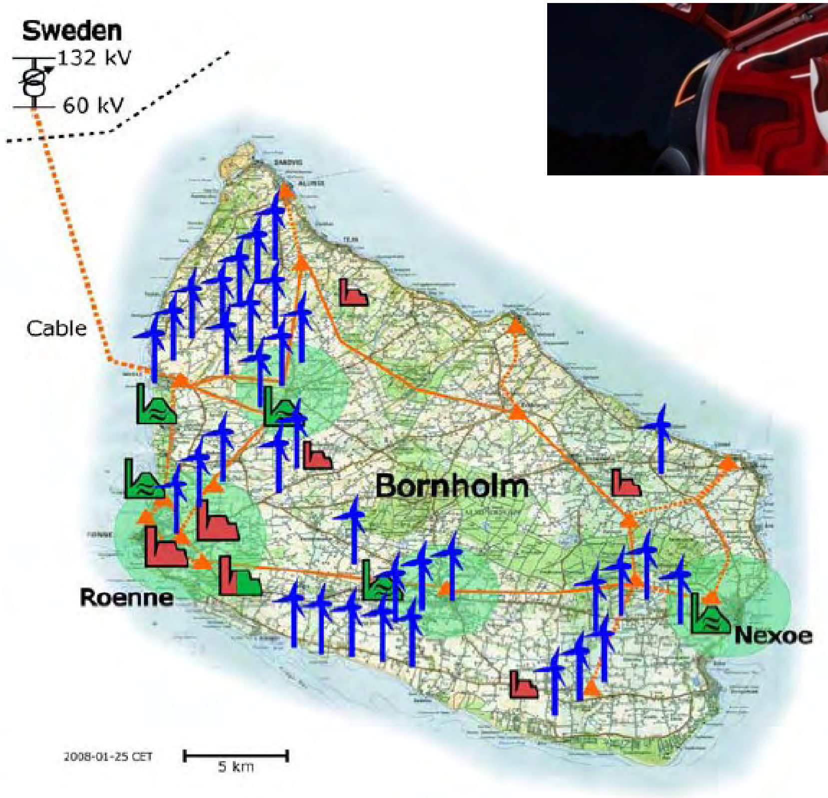




- Appliances, meters and sensors adjust consumption dynamically based on usage and preferences with dynamic pricing
- Average electricity bill reduction by 10%
- Reduced short-term peak distribution loads by 50%, overall peak loads by 15%
- Projected reduction in infrastructure spending of 70 $M
- Reduced impact of power shortages

EDISON

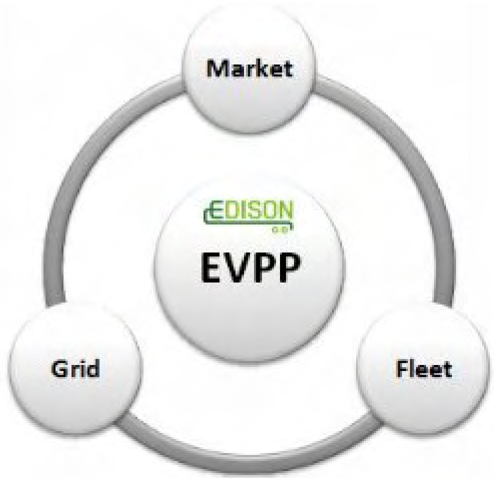
Electric vehicles in a distributed and integrated market using sustainable energy and open network



- Challenge: Maintain security of supply in an electric grid which incorporates a large fraction of fluctuating renewable energy and electric vehicles (EVs)
- Grid-connected EVs represent both a huge challenge and storage/regulation potential
- Develop management system for charging and storage
- Simulate behavior of a large EV fleet

EDISON

Grid connection at public or shared stations



Edison Virtual Power Plant

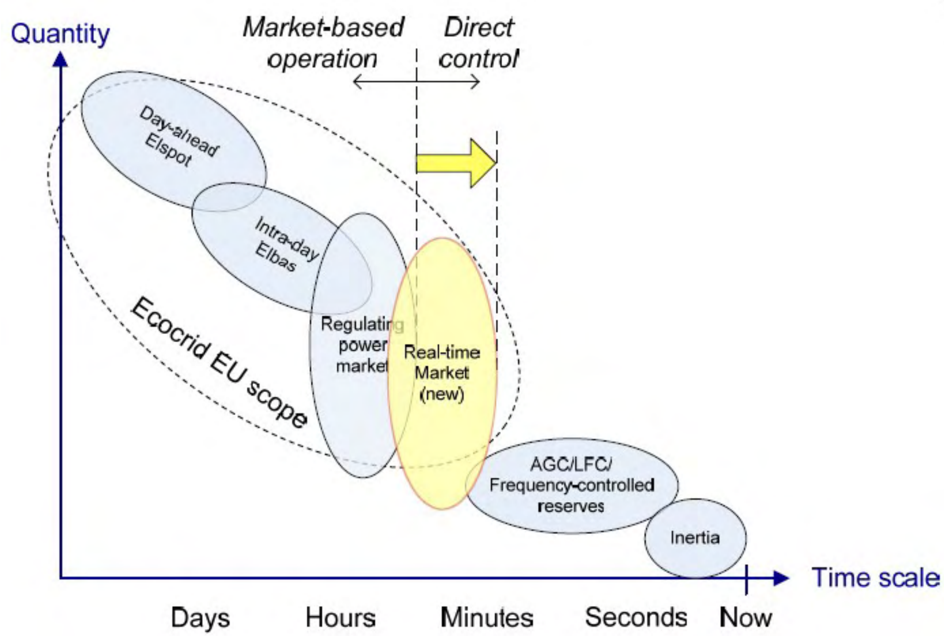
- Market-based pricing
- EV charging optimized without limiting driving behavior
- Adjusts optimization to local grid constraints

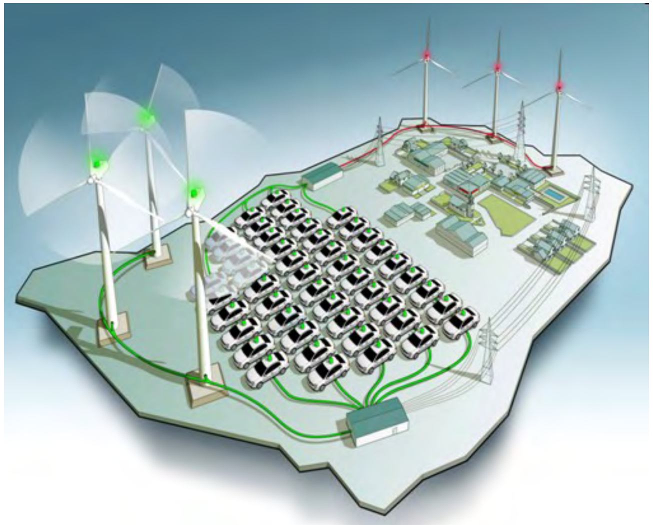
Source: http://www.flickr.com/photos/ibm_research_zurich/4882647022/in/set-72157622238483748/

EcoGridEU

EcoGrid eu
www.eu-ecogrid.net

March 2011 to 2014
Pending EU approval





Large scale smart grid demonstration of real time market-based integration of distributed energy resources and demand-response

SINTEF Energi AS	SINTEF ER	Norway
Energinet.dk	Energinet	Denmark
Østkraft Holding AS	Østkraft	Denmark
Danmarks Tekniske Universitet	DTU-CET	Denmark
Siemens AG	Siemens	Germany
IBM Research GMBH	IBM	Switzerland
EnCT GmbH	EnCT	Germany
ELIA System Operator	ELIA	Belgium
Fundacion LABEIN	LaBein	Spain
Österreichisches Forschungs- und Prüfzentrum Arsenal Ges.m.b.h	AIT	Austria
Stichting Energieonderzoek Centrum Nederland	ECN	Netherlands
Eandis cvba	EANDIS	Belgium
Tallinna Tehnikaülikool	TUT	Estonia
Operateur De Reseaux D'energies	ORES	Belgium

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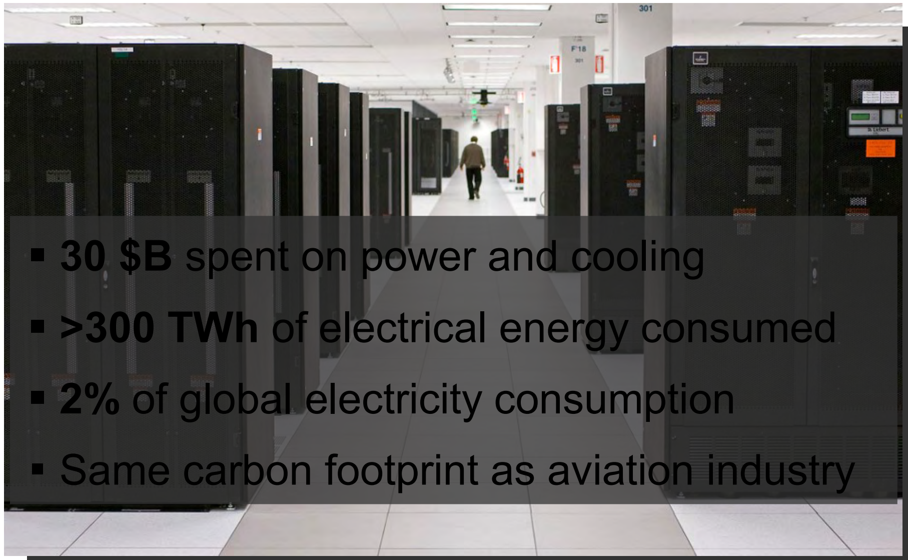
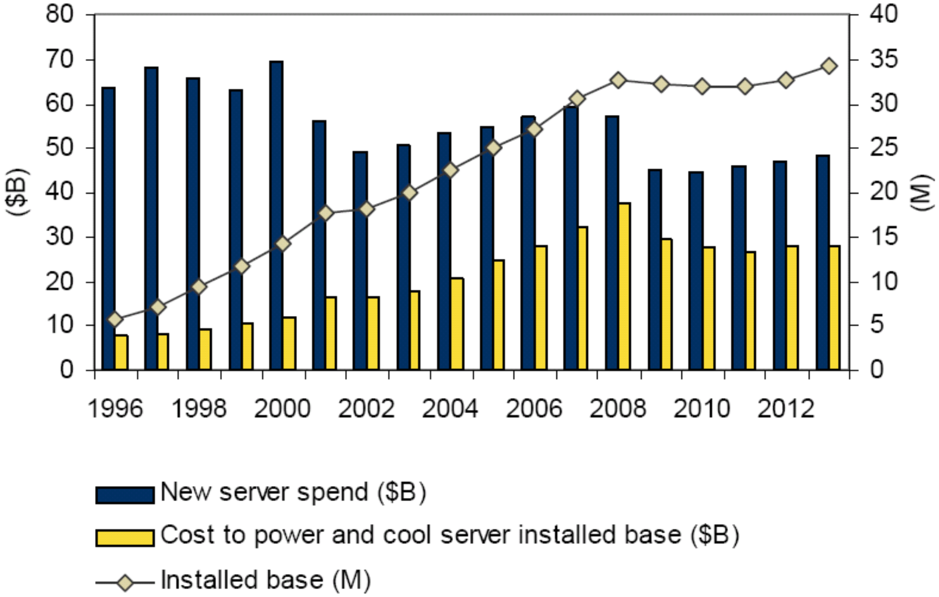
Energy in computing

Worldwide energy consumption of datacenters



- **30 $B** spent on power and cooling
- **>300 TWh** of electrical energy consumed
- **2%** of global electricity consumption
- Same carbon footprint as aviation industry



Green IT requires...

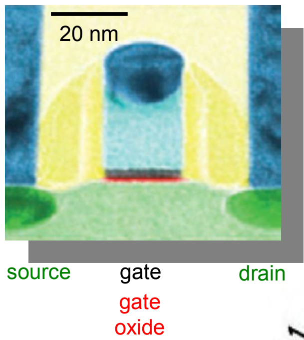
...**real** solutions

IDC, *Market Analysis* (2008)

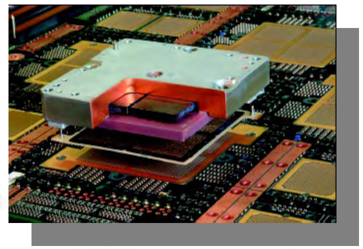
Energy in computing

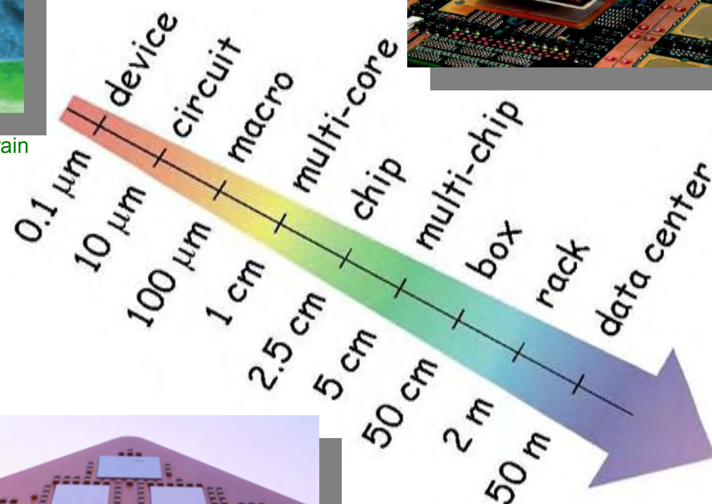
Power and heat: impact over multiple length scales

Field-effect transistor



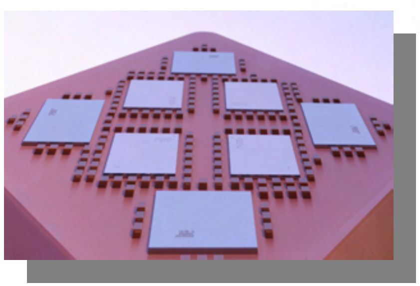
Chip-scale package





Smarter energy in computing

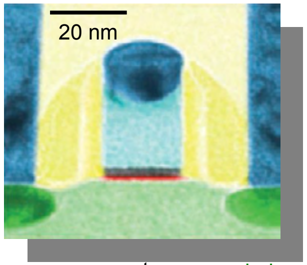
- Low-power transistors
- Measurement & Management Technologies
- Zero-emission datacenter

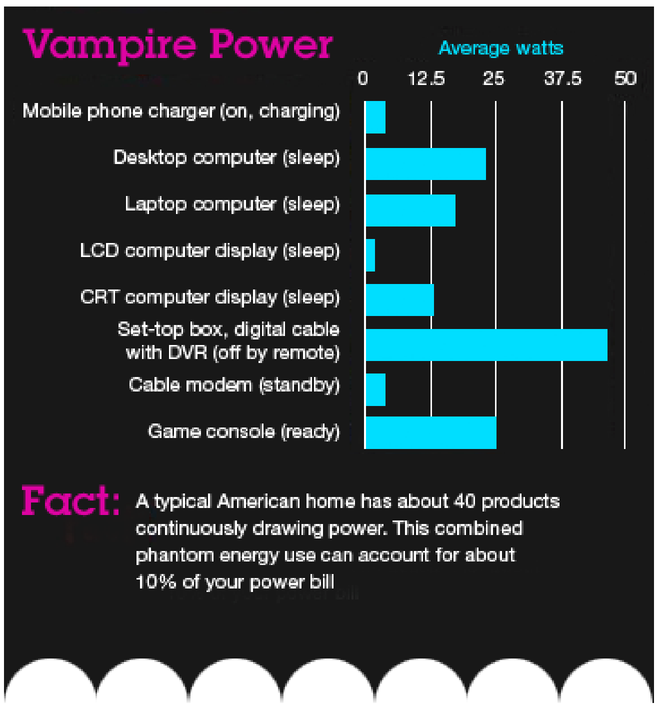


Multi-chip module

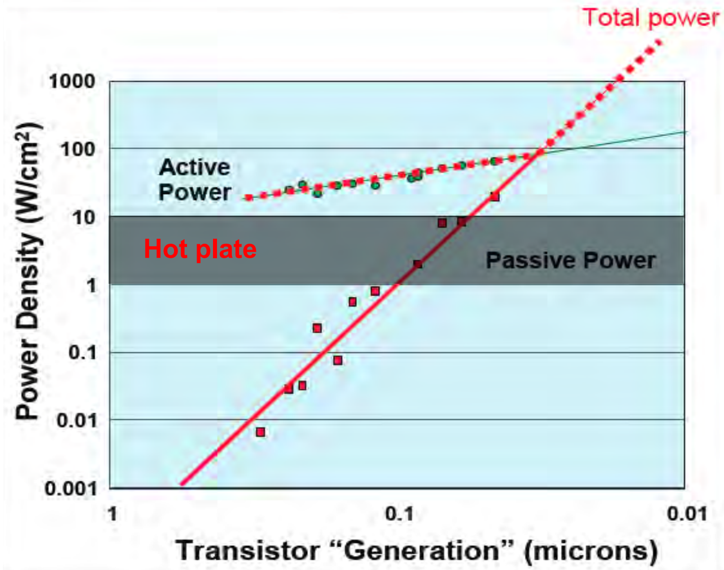
Datacenter

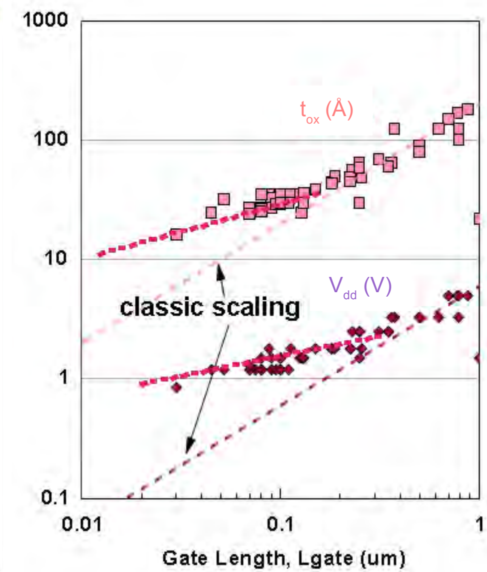
Low-power transistors





Sources: Standby Power, Lawrence Berkely National Laboratory, International Energy Agency (IEA), eXtension, IBM



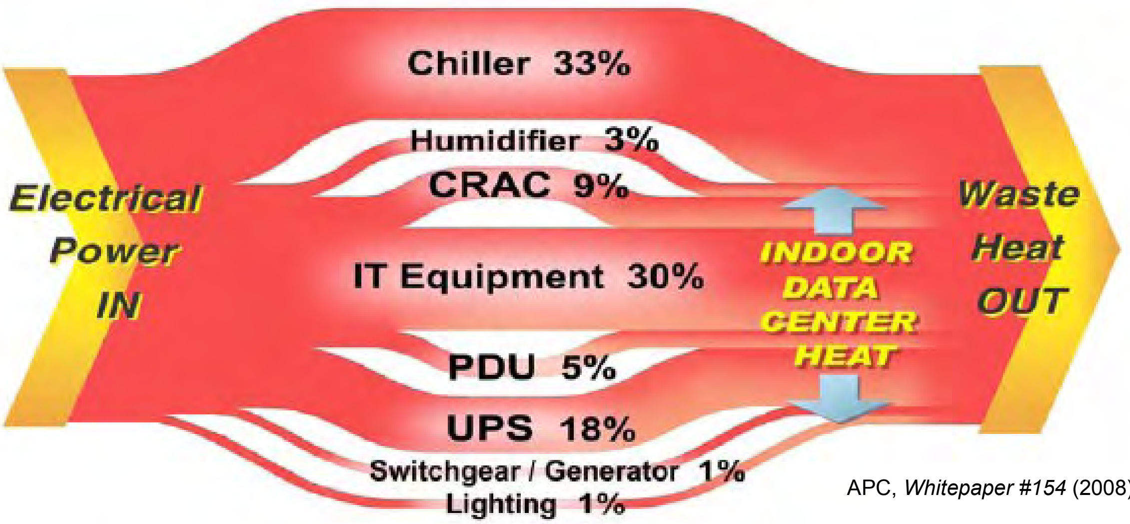


- Project STEEPER (EU FP7-ICT) coordinated by Prof. Ionescu, EPFL
- Develop low-power transistors and circuits working below 0.5 V
- Steep sub-threshold slope transistors
- Reduce power consumption by one order of magnitude

Nowak, *IBM Journal of R&D* **46** (2002) 169

Energy in computing

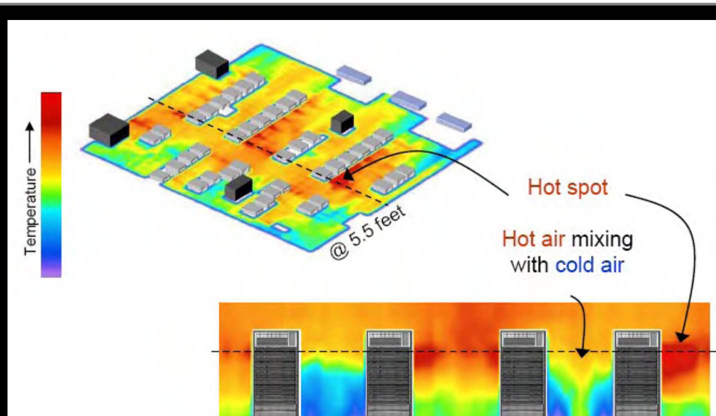
Energy partitioning in datacenters



APC, *Whitepaper #154* (2008)

- **1 W** of IT power requires **0.5–1 W of cooling**
- Need to **measure** datacenter cooling
- Need to **improve** datacenter cooling

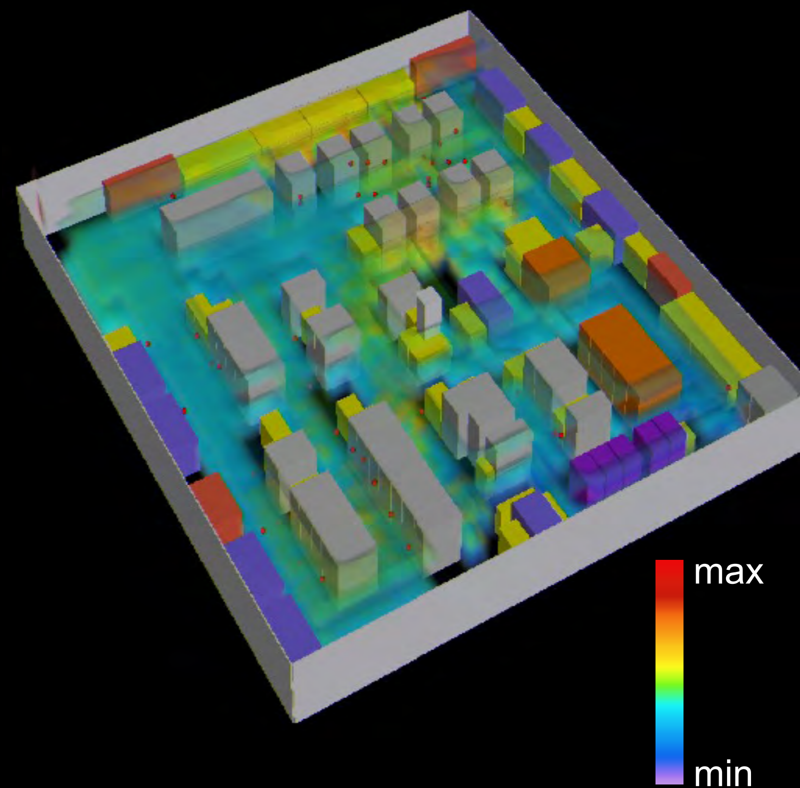
Measurement & Management Technologies



Data collection via mobile platform or real-time sensor network

MMT 3D datacenter profiling

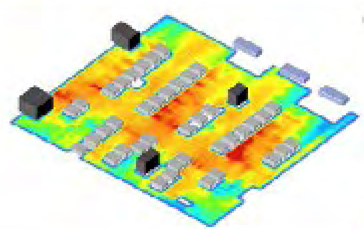
- 30 000 thermal readings
- 3000 humidity readings
- 200 air flow readings



1 Measure

2 Model

- Capture *high resolution temperature data*, *air flow data* and *infrastructure & layout data*



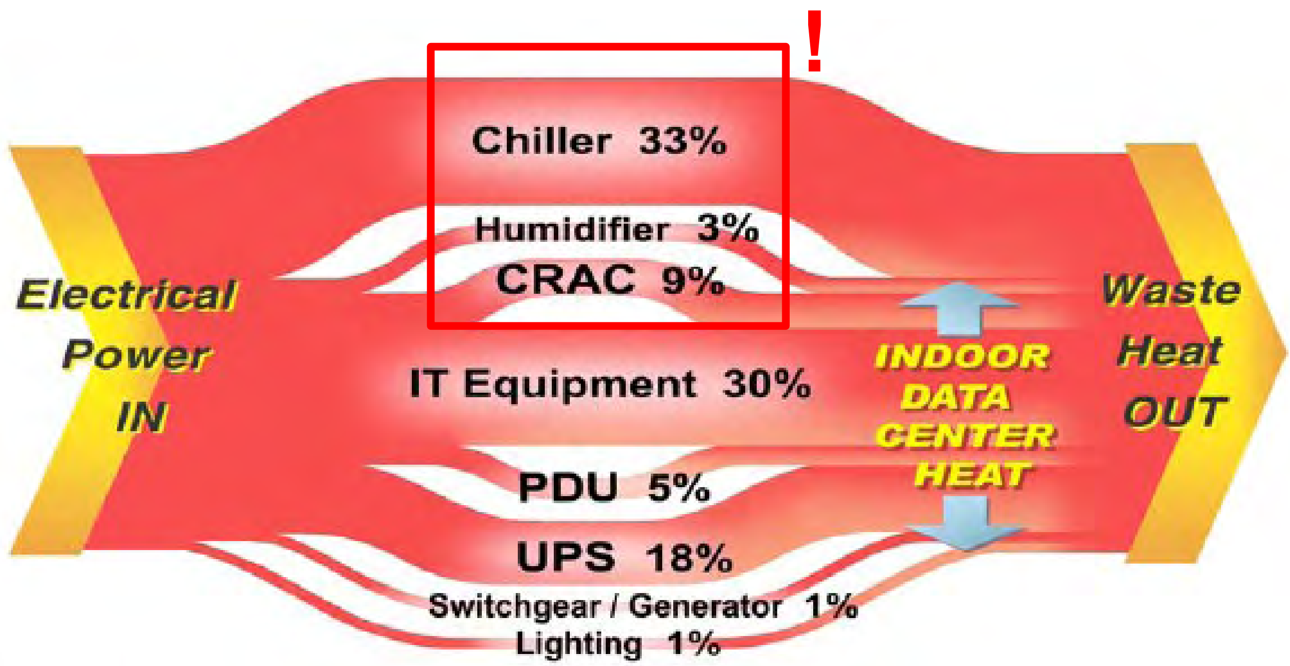
- To identify improvement opportunities *model the data center* and use optimization algorithms ("*best practices rules*")

3 Manage "*Best Practices*"

- Realize air transport energy savings
- Realize thermodynamic energy savings
  - → *Achieve reduced energy consumption*
  - → *Potential for deferring new investments*

Zero-emission datacenter

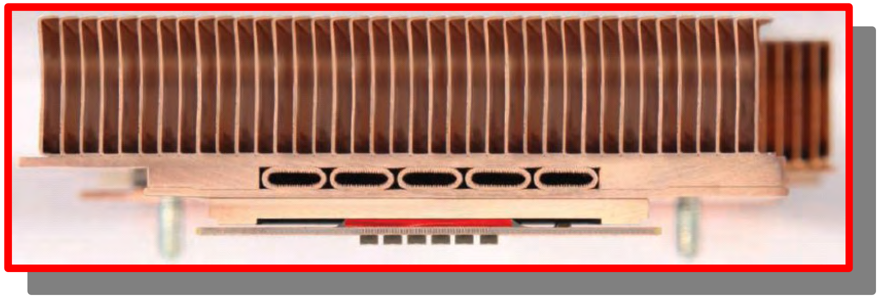
Energy partitioning in datacenters



APC, *Whitepaper #154* (2008)

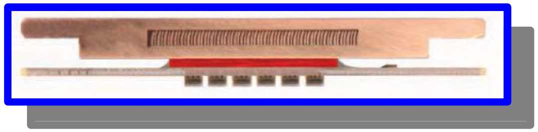
Zero-emission datacenter

Minimization of thermal resistances

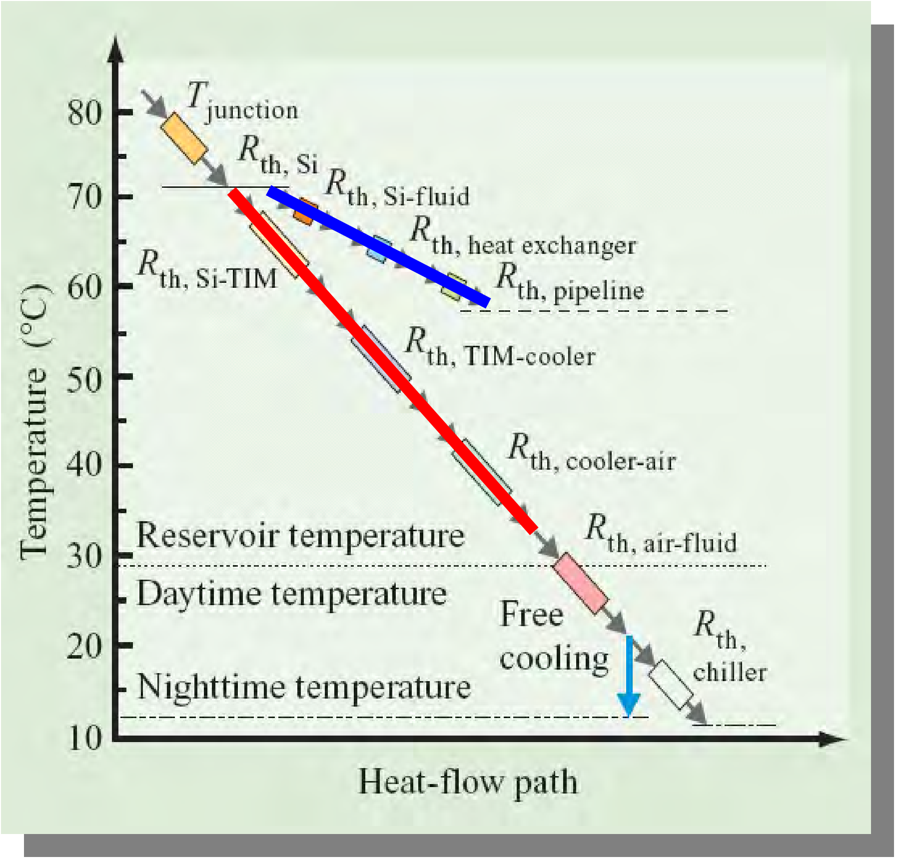


Air cooling

10 mm



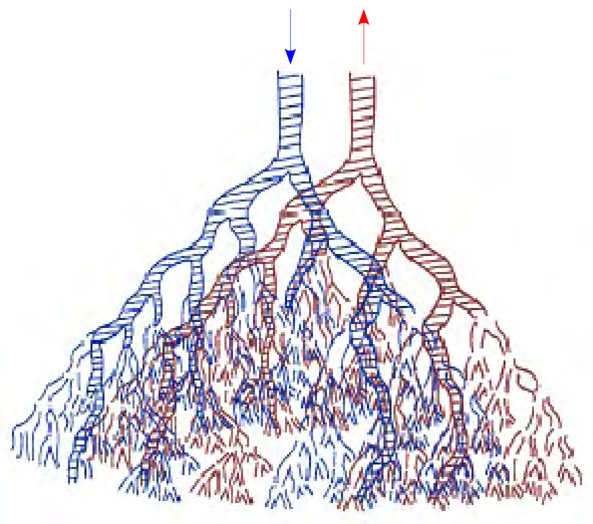
Water cooling



Brunschwiler et al., *IBM J. Res. & Dev.* **53** (2009) 11; Meijer, *Science* **328** (2010) 318; Escher et al., *Int. J. Heat Fluid Flow* **31** (2010) 586

Zero-emission datacenter

Minimization of thermal resistances in liquid water cooling

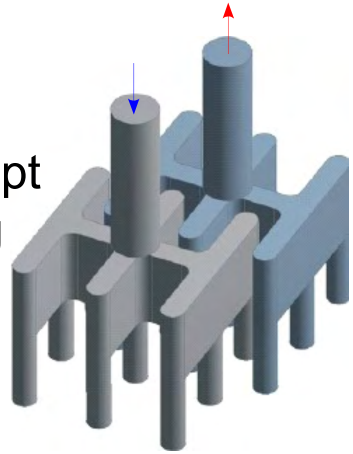


Biological vascular system

Hierarchical structure
Optimized for mass transport

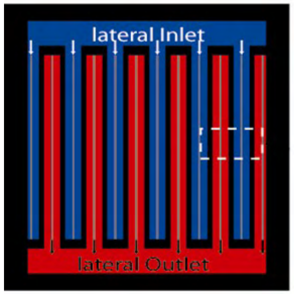
Example 1

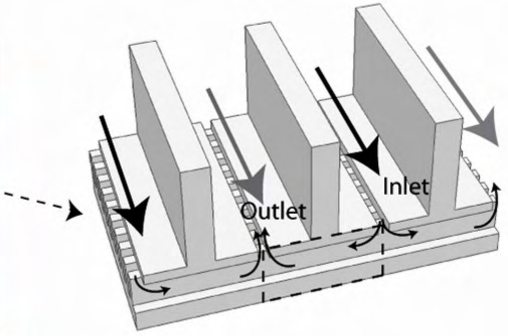
Double branching concept
Jet-impingement cooling
35 mm nozzle diameter



Example 2

Lateral fluid distribution
Ultra-thin form factor
Very low pressure drop



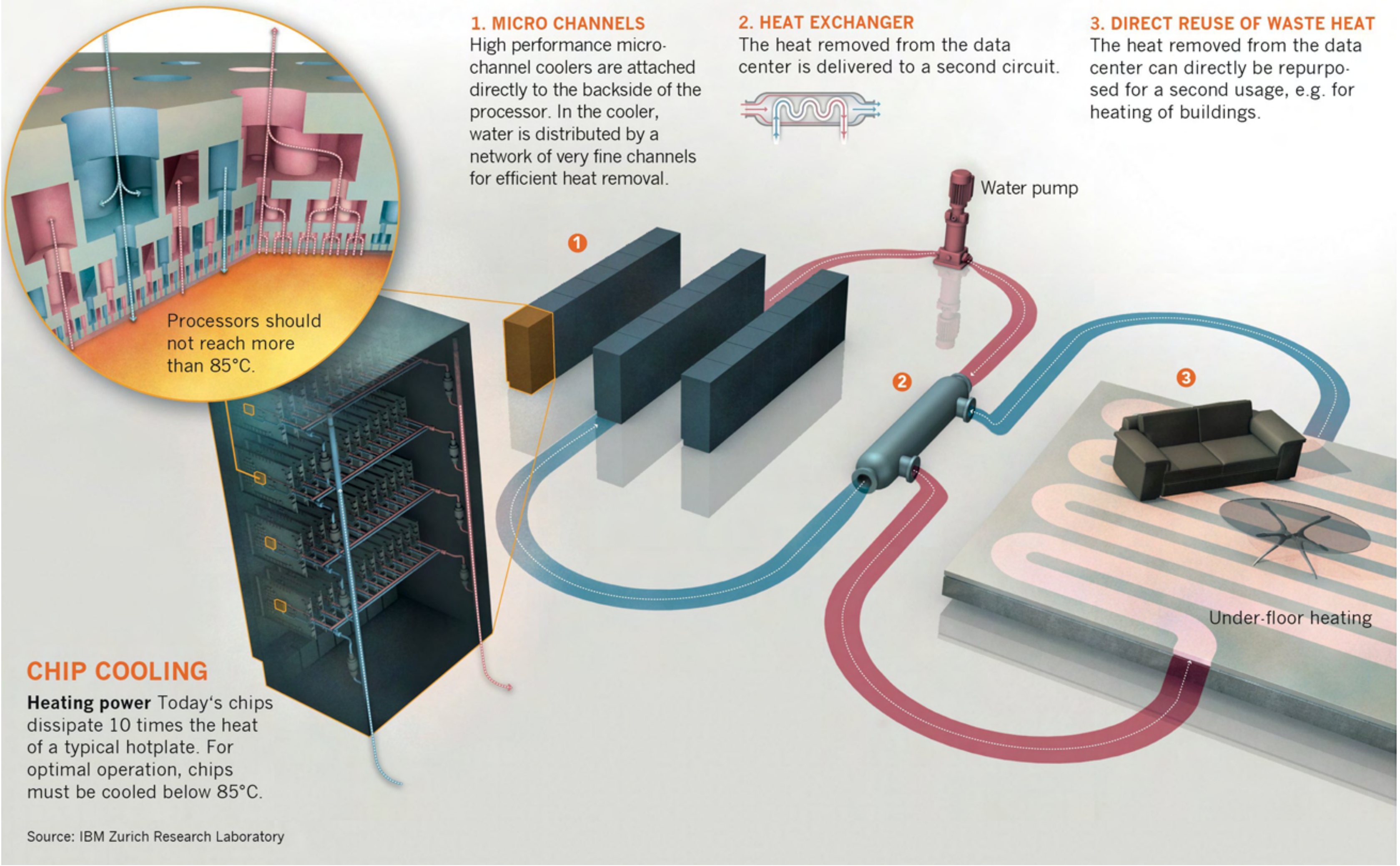


→ Microchannels (short heat flow paths)
→ Facile mass transport (low pumping power)

Brunschwiler et al., *ITHERM* (2006); Escher et al., *Int. J. Heat Fluid Flow* **31** (2010) 586

Zero-emission datacenter

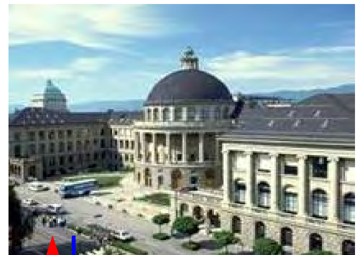
Zero-emission concept: waste heat reuse

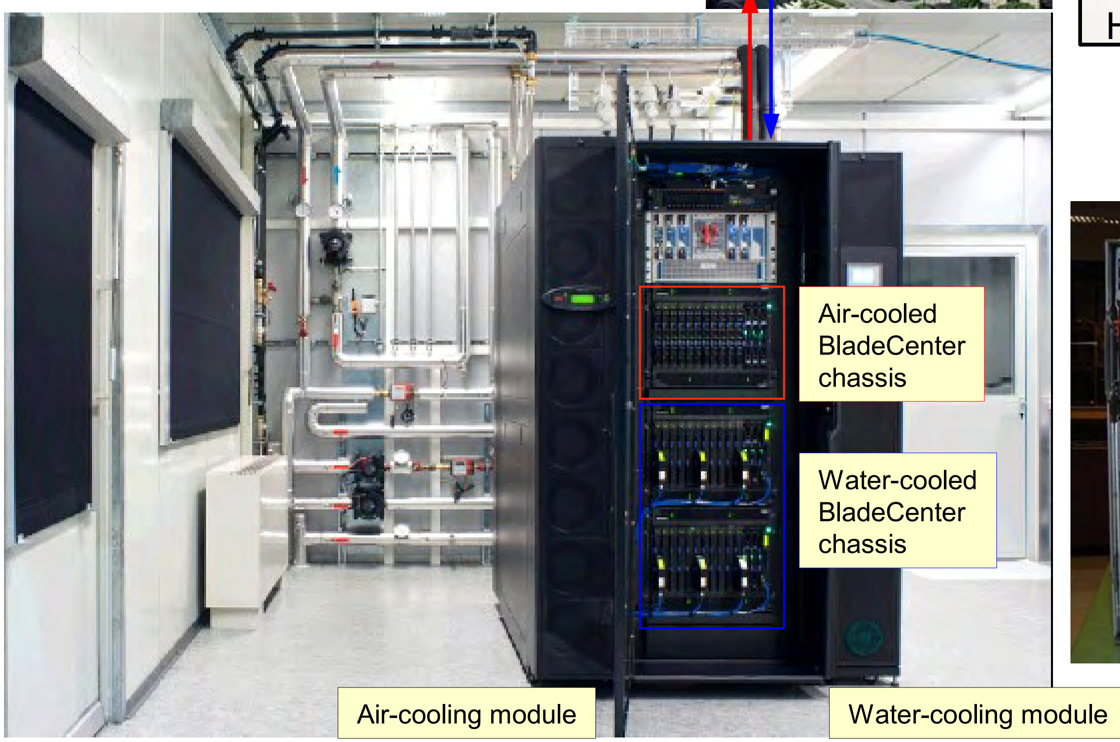


Zero-emission datacenter

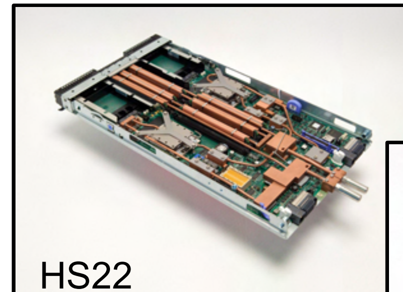
Hot-water cooled prototype at ETH Zurich

- >80% heat recuperation
- Feed-in to ETH heating system
- Record 7.9 TFLOP/gCO_2





Modified blade servers

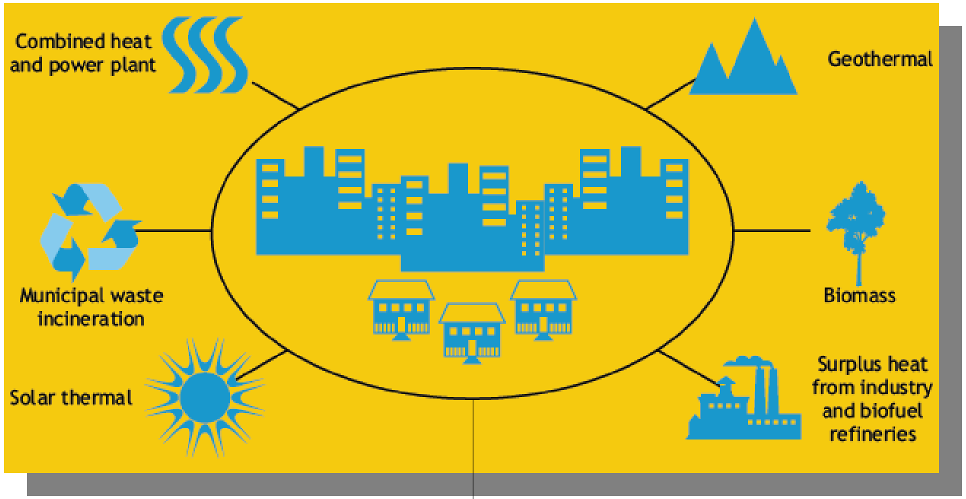


Modified chassis

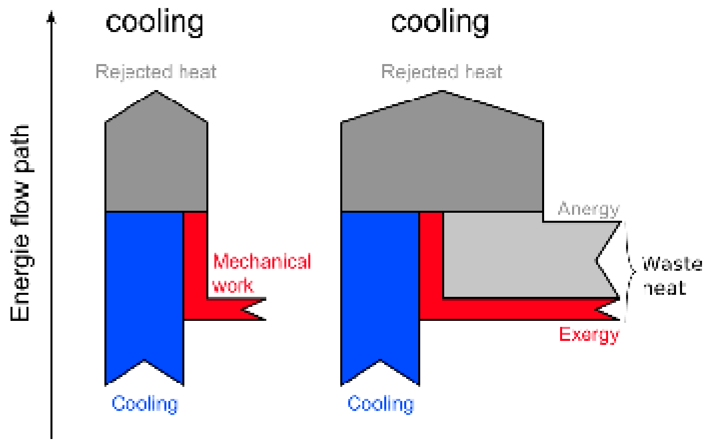
Zero-emission datacenter

Datacenters embedded in district heating and cooling grids

- Novel placement of datacenters in the energy landscape
- Change from pure energy consumers to participants in a distributed and interconnected energy grid
- Improvements in heat-driven cooling technology are being driven by IBM



IEA, *Cogeneration and District Energy* (2009)



Hot-water cooled datacenter

Green computing at IBM

Green500 (November 2010)

Green500 Rank	MFLOPS/W	Site*	Computer*	Total Power (kW)
1	1684.20	IBM Thomas J. Watson Research Center	NNSA/SC Blue Gene/Q Prototype	38.80
2	958.35	GSIC Center, Tokyo Institute of Technology	HP ProLiant SL390s G7 Xeon 6C X5670, Nvidia GPU, Linux/Windows	1243.80
3	933.06	NCSA	Hybrid Cluster Core i3 2.93Ghz Dual Core, NVIDIA C2050, Infiniband	36.00
4	828.67	RIKEN Advanced Institute for Computational Science	K computer, SPARC64 VIIIfx 2.0GHz, Tofu interconnect	57.96
5	773.38	Forschungszentrum Juelich (FZJ)	QPACE SFB TR Cluster, PowerXCell 8i, 3.2 GHz, 3D -Torus	57.54
5	773.38	Universitaet Regensburg	QPACE SFB TR Cluster, PowerXCell 8i, 3.2 GHz, 3D -Torus	57.54
5	773.38	Universitaet Wuppertal	QPACE SFB TR Cluster, PowerXCell 8i, 3.2 GHz, 3D -Torus	57.54
8	740.78	Universitaet Frankfurt	Supermicro Cluster, QC Opteron 2.1 GHz, ATI Radeon GPU, Infiniband	385.00
9	677.12	Georgia Institute of Technology	HP ProLiant SL390s G7 Xeon 6C X5660 2.8Ghz, nVidia Fermi, Infiniband QDR	94.40
10	636.36	National Institute for Environmental Studies	GOSAT Research Computation Facility, nvidia	117.15

* Performance data obtained from publicly available sources including TOP500

- IBM has built **15 of the top 25** most energy-efficient supercomputers
- **Hot-water cooling** features in planned 3 PFLOPS system in Leibniz Supercomputing Center, Germany (press release December 13, 2010)

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Energy for computing

Energy conversion

Electricity generation

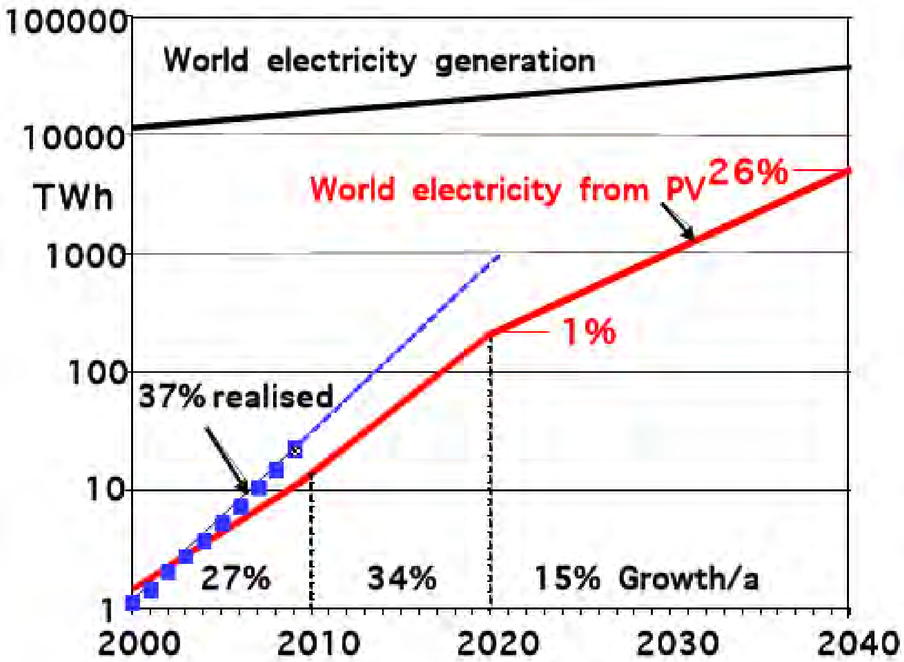
Energy storage

Smarter energy for computing

- Concentrated photovoltaics with heat reuse
- Energy storage in lithium-air battery

CPV with heat reuse for desalination

Photovoltaic contribution to future electricity generation

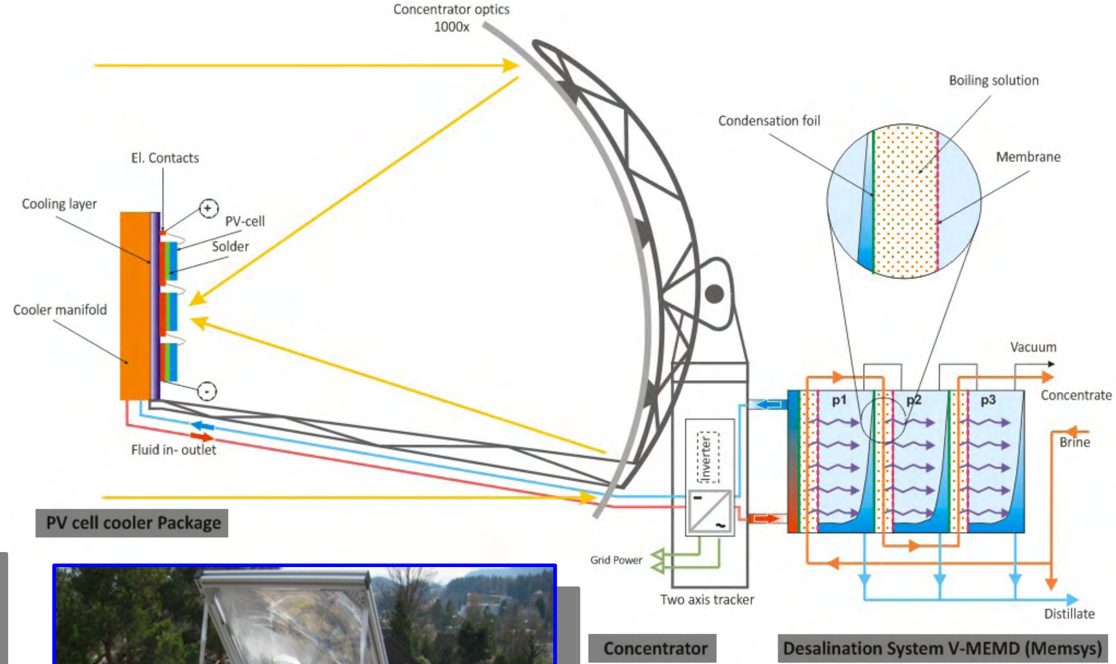


Source: Solar Generation and IEA-PVPS

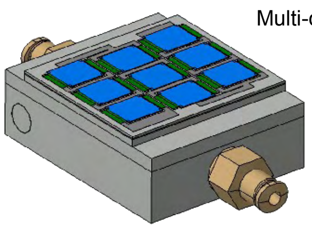
- 26% share of electricity generation in 2040 requires 9000 km^2 collector area
- Annual crystalline silicon production of semiconductor industry: 1 km^2
- Photovoltaic efficiency: 10–20% for Si, 40% for multi-junction cells
- Optical concentration decreases active area and cost
- Peak heat flux in CPV: 100 W/cm^2 at 1000x concentration

CPV with heat reuse for desalination

- Highly efficient module packaging for heat recovery
- Design of concentrator optics
- Coupling to thermal desalination system
- Joint development with Egypt Nanotechnology Center (EGNC)

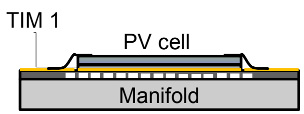


Multi-chip module



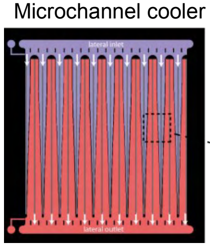
$R_{th,ref}$ = 0.26 Kcm²/W

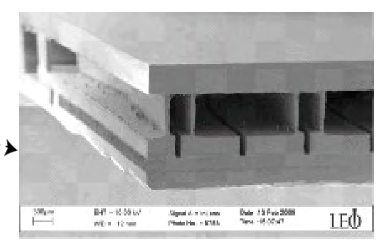
$R_{th,da}$ = 0.12 Kcm²/W

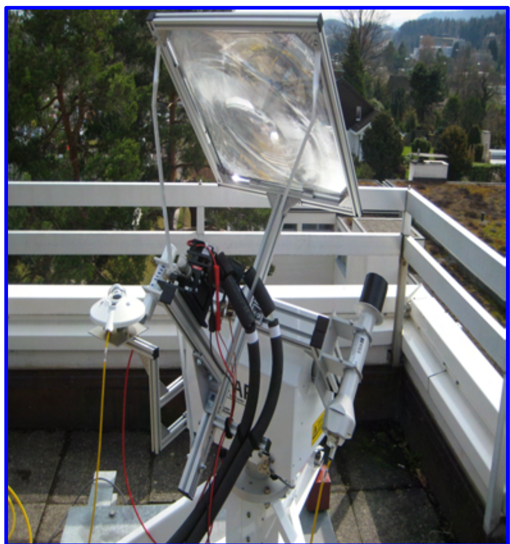


Directly attached PV cell

Microchannel cooler



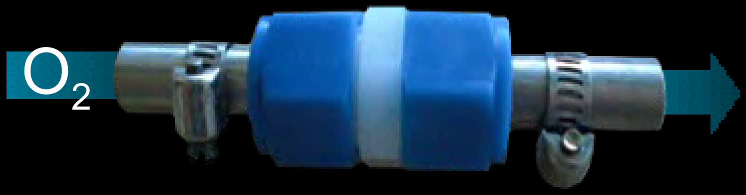


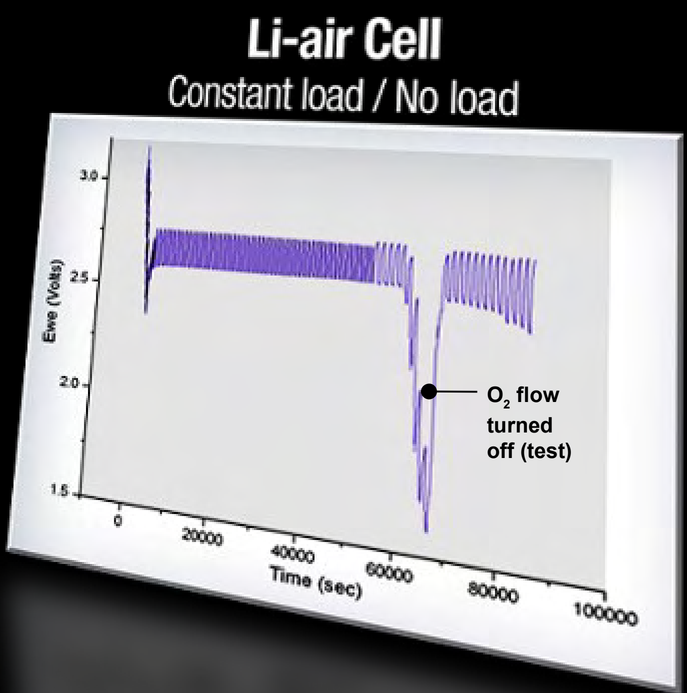


Energy storage: the lithium-air battery

Toward the lithium-air battery

- Increasing electrification of traffic is a crucial infrastructure change in the 21st century
- IBM Research is developing a large-scale lithium-air battery for electric cars
- Usable specific energy of 1500 Wh/kg (comparable to usable specific energy of gasoline)
- High risk / high reward, long horizon project
- Joint research effort with National Labs and commercial partners





IBM Research – Almaden: Battery 500

Summary

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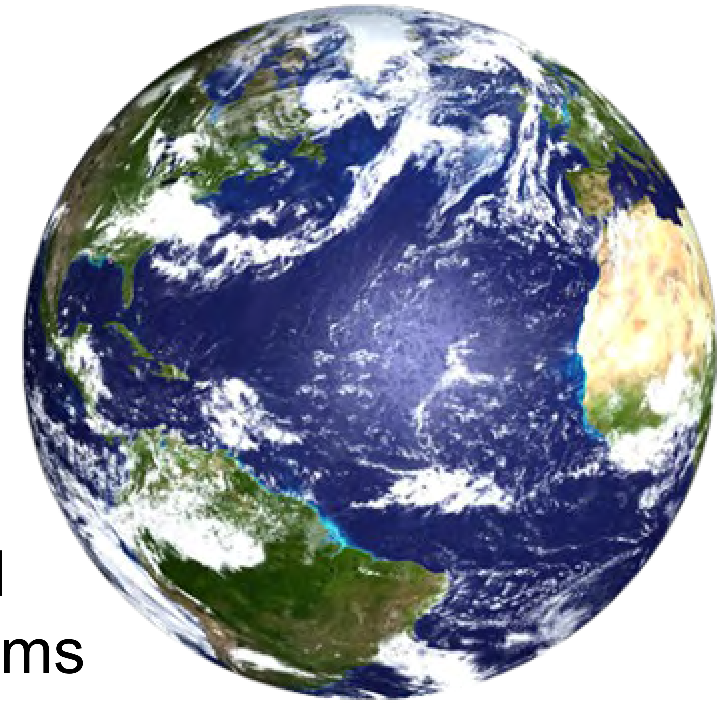

IBM Research drives innovation and development for future energy systems through internal efforts and joint collaborations

Acknowledgments

IBM Research – Zurich	I. Meijer, S. Zimmermann, S. Paredes, T. Brunschwiler, W. Escher, M. Müller, J. Ong, R. Ghannam, A. Khalil, D. Gantenbein, B. Jansen, C. Binding, O. Sundström, P. Chevillat, T. Scherer, H. Riel, M. Oestreicher, T. Kramp
Project support for IBM Research – Zurich	EGNC, KTI, FOAK, CCEM
	NanoTera (CMOSAIC, see talk of D. Atienza)
IBM Research – Yorktown	H. Hamann, J. Kephart, V. Lopez, H. Li
IBM Germany R&D	J. Marschall, M. Ries, W. Weber, M. Bachmeier, M. Kirschner, G. Goldrian
IBM Switzerland	B. Battaglia
ETH Zurich	D. Poulikakos
EPF Lausanne	J. Thome, A. Ionescu, D. Atienza, Y. Leblebici
Industry partners	Walter Meier AG Wolverine Tube Inc. APC by Schneider
IBM Research Smarter Energy Community	D. Gil

Building a Smarter Energy Future

Patrick Ruch and **Bruno Michel**
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Smart Energy Day
14th December 2010
École Polytechnique Fédérale de Lausanne

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