Energy Management in a Connected World

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2012/07/24 National Tsing-Hua University

Please Join the Discussion
請參與討論

Many questions require discussion and further studies.

Energy

- **Make solar energy economical**
- **Provide energy from fusion**
- **Develop carbon sequestration methods**
- **Manage the nitrogen cycle**
- **Provide access to clean water**
- **Restore and improve urban infrastructure**
- **Advance health informatics**
- **Engineer better medicines**
- **Reverse-engineer the brain**
- **Prevent nuclear terror**
- **Secure cyberspace**
- **Enhance virtual reality**
- **Advance personalized learning**
- **Engineer the tools of scientific discovery**

Grand Challenges

Challenges related to energy.
^ directly

- **Make solar energy economical**
- **Provide energy from fusion**
- **Develop carbon sequestration methods**
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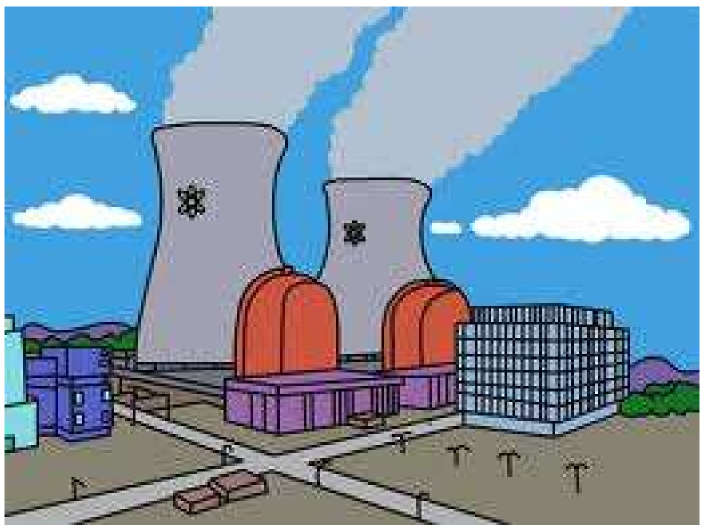
- **Advance personalized learning**
- **Engineer the tools of scientific discovery**

Outline

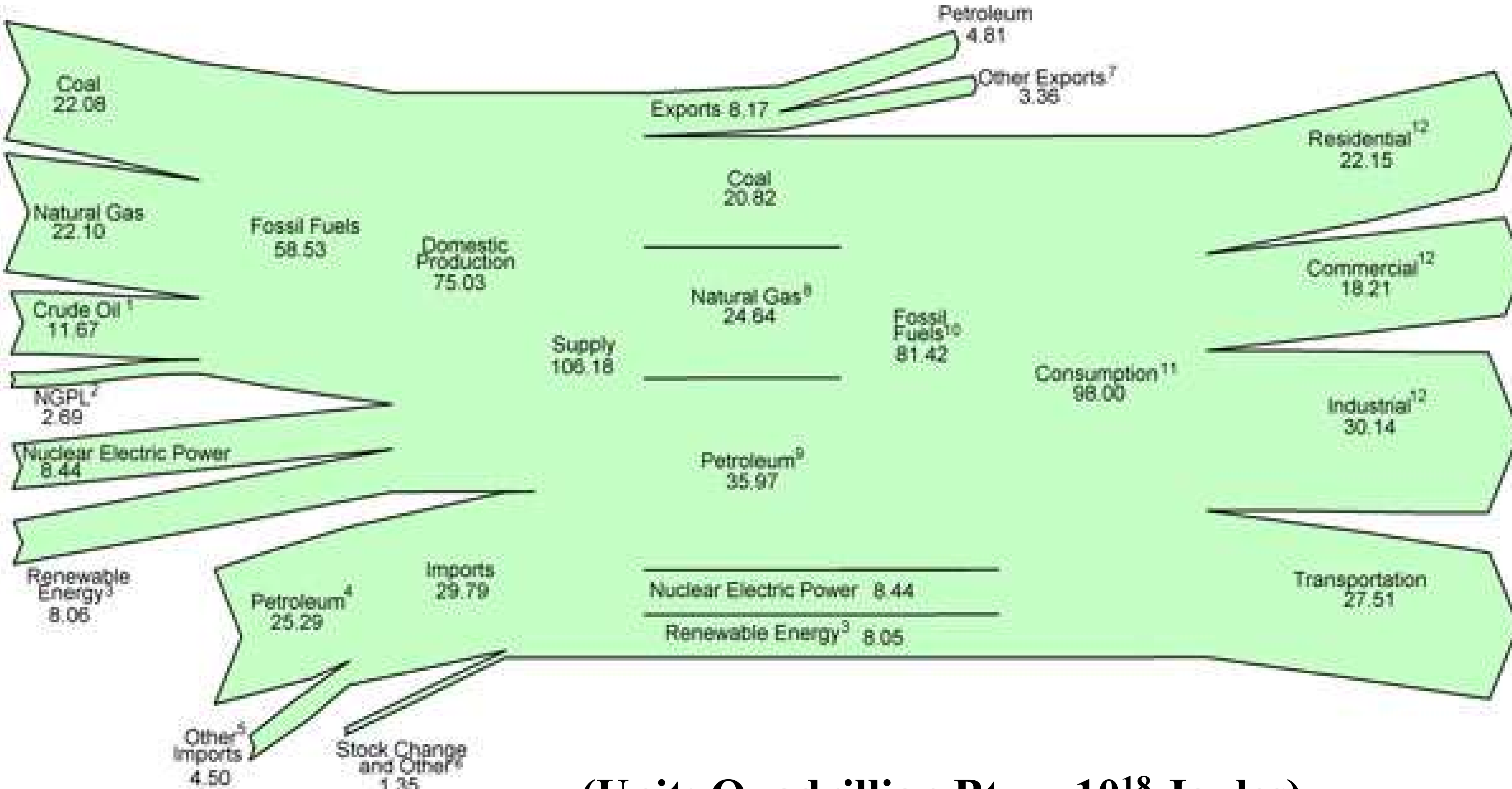
- Overview of energy consumption of information and communication technologies (ICT)
- Understand ICT's environmental impacts, other than energy consumption
- Designing sustainable energy supplies
- Cloud computing and sustainability
- Energy management at different levels
  – mobile systems
  – data center
- Research directions
- Conclusion

If we have time, I will talk about "Problems Inspired by Games."

Energy



Energy Flow (US EIA)



(Unit: Quadrillion Btu ≈ 10^{18} Joules)

TOTAL ENERGY

Annual Energy Review

October 2011 PDF | previous editions
Release Date: October 19, 2011
Next Update: September 2012

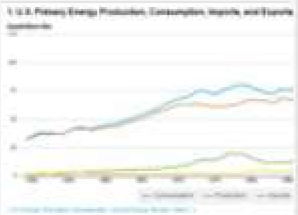
As of March 15, 2012, the data in Table 1.14 for fiscal years 2003-2010 are revised. Please see Appendix A in "Sales of Fossil Fuels Produced from Federal and Indian Lands, FY 2003 through FY 2011" for the revised data.

A report of historical annual energy statistics. For many series, data begin with the year 1949. Included are data on total energy production, consumption, and trade; overviews of petroleum, natural gas, coal, electricity, nuclear energy, renewable energy, as well as financial and environmental indicators; and data unit conversion tables. About the data

DATA CATEGORIES

Energy Perspectives

Forty-three interactive grapl
in U.S. energy production, c
trade from 1949-2010



Changes in AER 2010

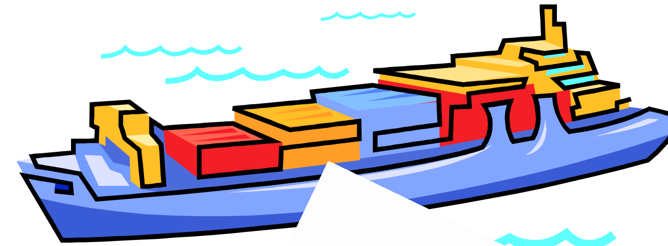
- Energy Resources ha
expanded to include s

ICT's Environmental Impacts

mining

manufacturing

shipping



using

disposal

ICT's Indirect Impacts

efficient transportation using GPS

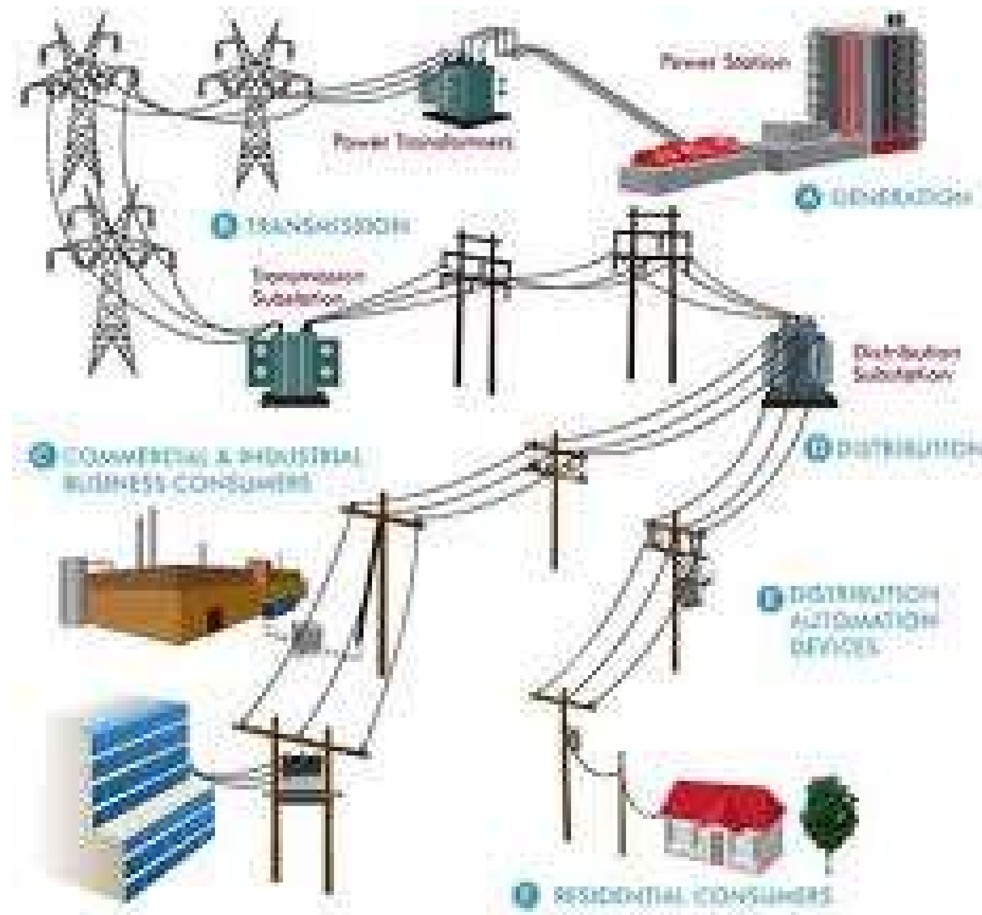
on-line search vs. library

video on demand vs. DVD

e commerce vs. shopping mall

Direct and Indirect Impacts of ICT

Smart Grids



Power Station
Power Transformers
GENERATION
TRANSMISSION
Transmission Substation
Distribution Substation
DISTRIBUTION
COMMERCIAL & INDUSTRIAL BUSINESS CONSUMERS
DISTRIBUTION AUTOMATION DEVICES
RESIDENTIAL CONSUMERS

Smart grid - Wikipedia, the fre

uses *computers* and other technology to gather and act on *information*, such as information about the behaviors of suppliers and consumers, in an automated fashion to improve the efficiency, reliability, economics, and sustainability of the production and distribution of electricity

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Smart grid

From Wikipedia, the free encyclopedia

The **neutrality of this article is disputed**. More details and relevant discussion may be found on the talk page. Please do not remove this message until the dispute is resolved. *(April 2009)*

A **smart grid** is an electrical grid that uses computers and other technology to gather and act on information, such as information about the behaviors of suppliers and consumers, in an automated fashion to improve the efficiency, reliability, economics, and sustainability of the production and distribution of electricity.[1]

Smart grid policy is organized in Europe as Smart Grid European Technology Platform.[2] Policy in the United States is described in 42 U.S.C. ch.152 subch.IX § 17381.

Roll-out of smart grid technology also implies a fundamental re-engineering of the electricity services industry, although typical usage of the term is focussed on the technical infrastructure.

Contents [hide]

Public infrastructure

Assets and facilities

Airports · Bridges · Broadband · Canals · Critical infrastructure · Dams · Electricity · Energy · Hazardous waste · Hospitals · Levees · Lighthouses · Parks · Ports · Mass transit · Public housing · State schools · Public spaces · Rail · Roads · Sewage · Solid waste · Telecommunications · Utilities · Water supply · Wastewater

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Smart 2020 Report: Global ICT Solution Cas...

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SMART 2020

In 2008, The Climate Group on behalf of the Global e-Sustainability Initiative (GeSI), with independent analysis by McKinsey & Company found that ICT is a key sector in the fight against climate change and could enable emissions reductions of 7.8 Gt CO2e in 2020, or 15% of business as usual emissions. But it must keep its own growing footprint in check and overcome a number of hurd on this potential.

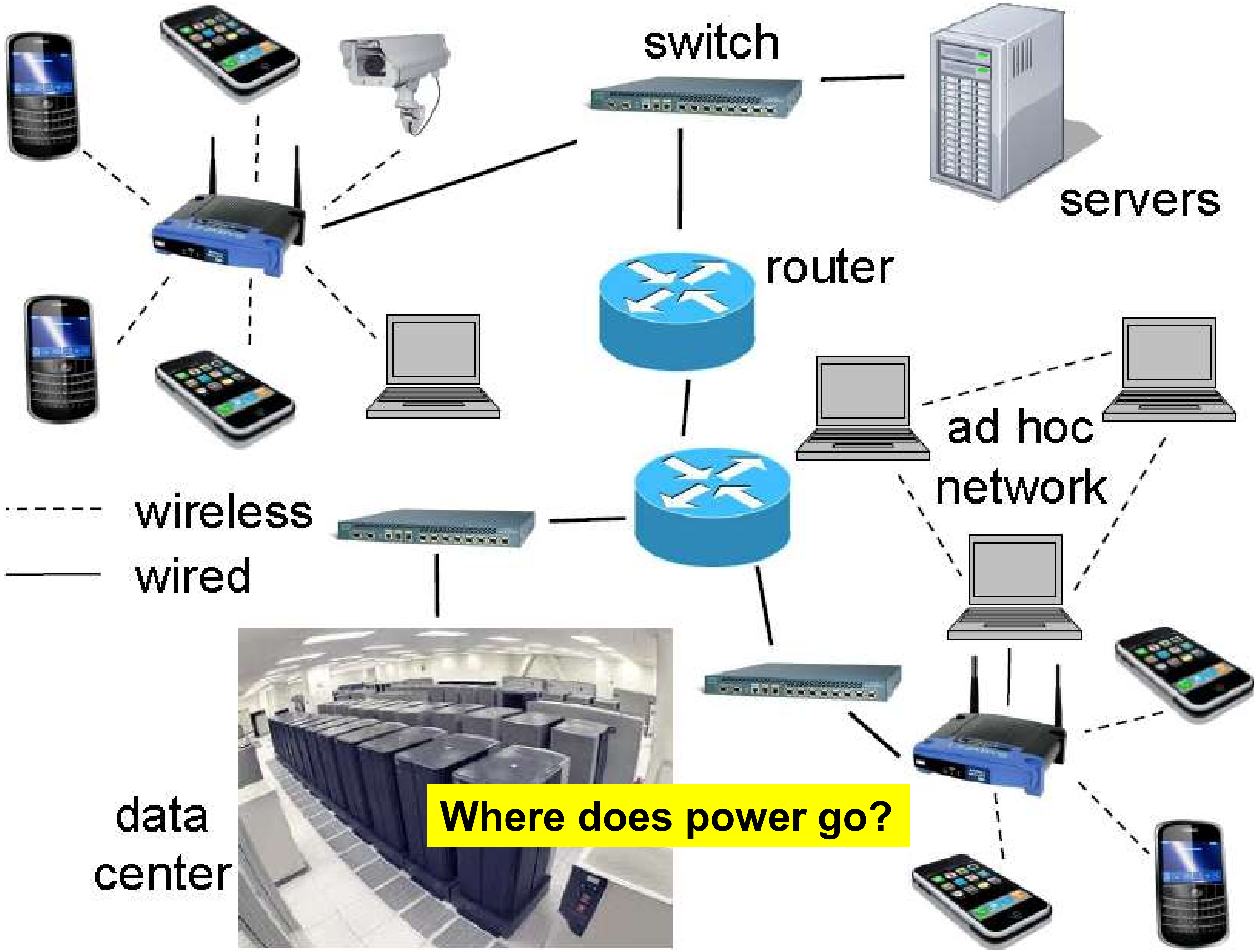
DOWNLOADS

Find the report and related materials here:

- Report summary (pdf)

How Do They Get the Numbers?

ICT's Energy Consumption


switch
servers
router
ad hoc
network
wireless
wired
data
center
Where does power go?

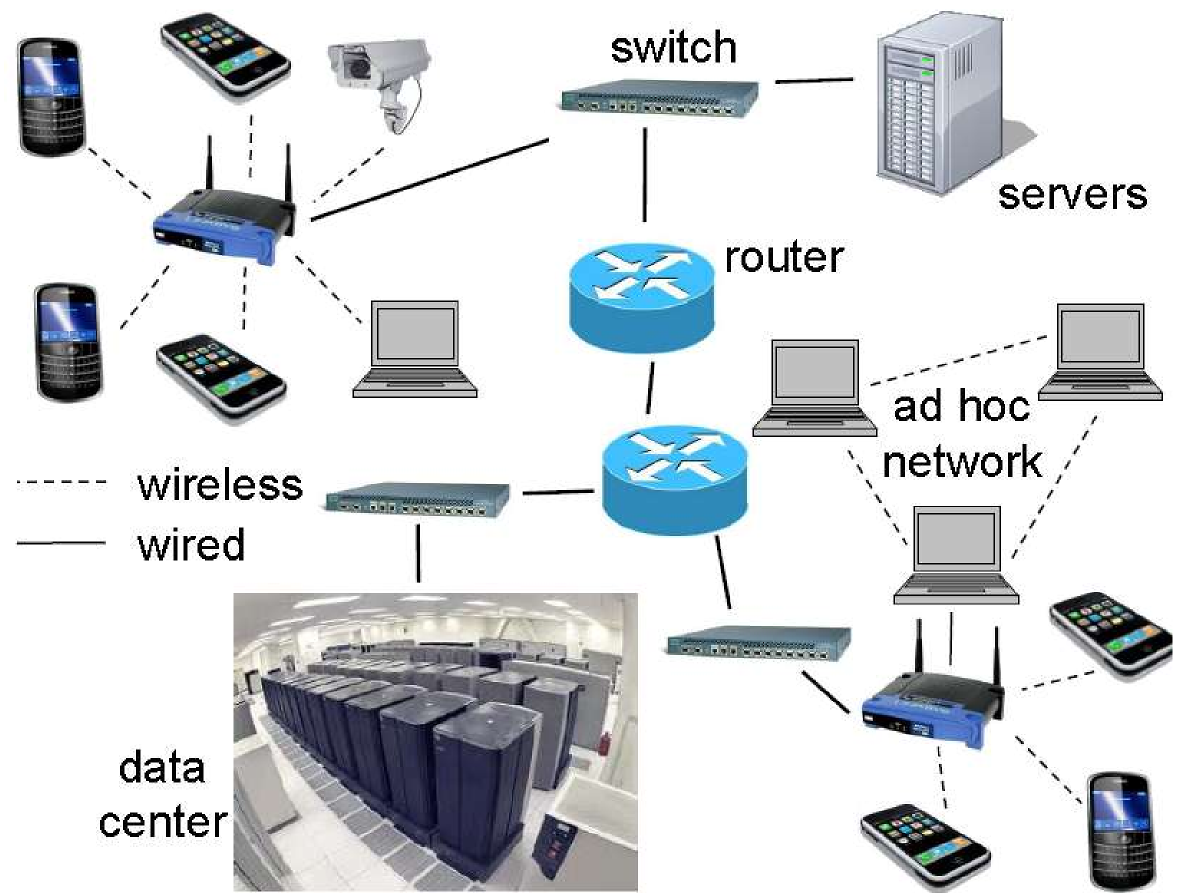
Difficulty in Finding ICT's Power

- Analysis is difficult because many systems are involved.
- No company has enough information about the whole ICT. Even if a company has information, the information is unlikely revealed publicly.
- Nevertheless, we try to put together estimates from multiple sources.
- Internet consumes about 1% electricity in developed countries [1].

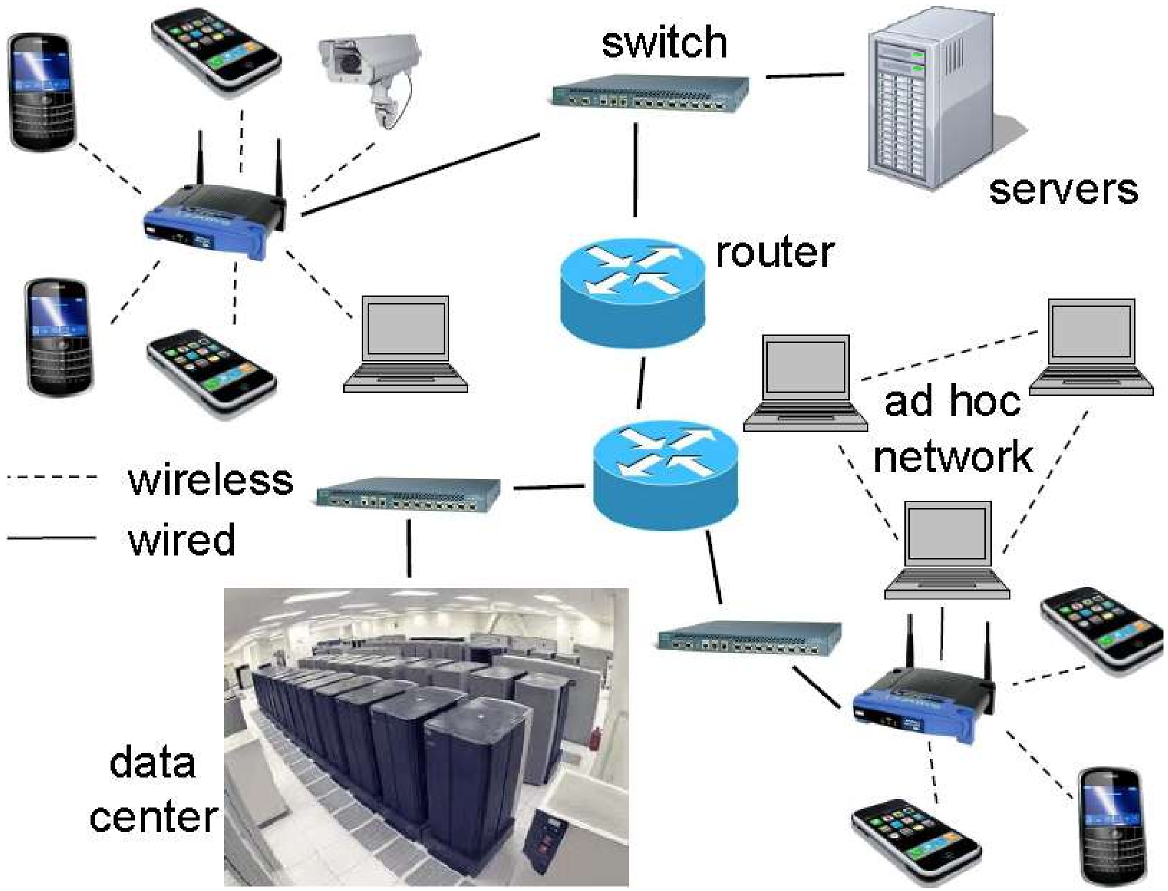
[1] K. Hinton, J. Baliga, M. Feng, R. Ayre, and R. S. Tucker. Power Consumption and Energy Eciency in the Internet. IEEE Network, 2:6-12, March/April 2011.

ICT's Power Consumption

- Consumer Systems
- Access Networks
- Edge and Core Networks
- Data Centers



Where does power go?



Consumer Systems

- smartphone: about 1W during operation; mW standby
- laptop: about 10W during operation; mW standby
- desktop: about 100 W during operation
- display: about 30 W
- power management widely adopted




Access Networks

- Connect consumer systems to Internet service providers (ISP)
- Power consumed by networks harder to estimate because they are shared. One Wifi access point should be shared by at most 25 users [1].
- A few W per user [2].
- Power management not widely adopted in access networks.

[1] P. Roshan and J. Leary. 802.11 Wireless LAN Fundamentals. Cisco Press, 2004.

[2] K. Hinton, J. Baliga, M. Feng, R. Ayre, and R. S. Tucker. Power Consumption and Energy Eciency in the Internet. IEEE Network, 2:6-12, March/April 2011.

Edge and Core Networks

- Edge: connect access networks to core networks.
- Core networks: backbone of the Internet.
- It is hard to estimate the number of network switches because many of them are hidden behind institution's firewalls.
- In 2010, about 21.4 TWh [1] was consumed for networks in Europe. There are about 476 million Internet users in Europe $\Rightarrow$ about 5 W/user. **Is this a valid method?**

[1] R. Bolla, F. Davoli, R. Bruschi, K. Christensen, F. Cucchietti, and S. Singh. The Potential Impact of Green Technologies in Next-Generation Wireline Networks: Is There Room for Energy Saving Optimization? IEEE Communications Magazine, 49(8):80-86, August 2011.

Data Centers

- In 2008, data centers in USA consumed 69TWh [1].
- In 2010, USA produced about 4.1QWh electricity [2]. Data centers consumed about 1.7% electricity.
- There are about 240 million Internet users in USA, about 32W/user.

[1] E. R. Masanet, R. E. Brown, A. Shehabi, J. G. Koomey, and B. Nordman. Estimating the Energy Use and Efficiency Potential of U.S. Data Centers. Proceedings of the IEEE,99(8):1440-1453, August 2011.

[2] US Energy Information Administration.

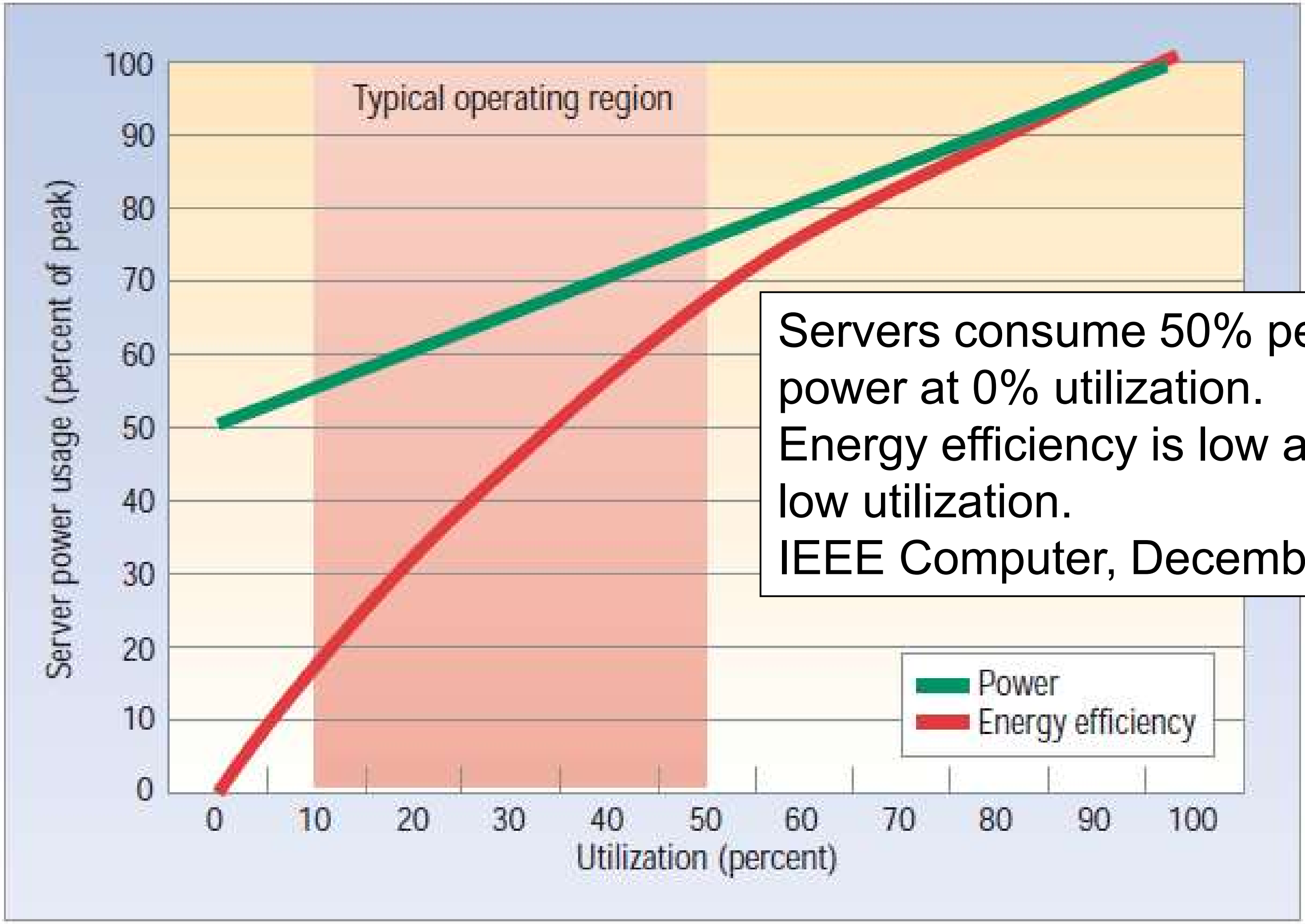
Other Studies

- Italian [1]
  - 79% power consumer systems
  - 16% access networks
  - network a small portion of ICT's power consumption
- Internet power consumption between 84GW and 143 GW [2]. There are 2.27 billion users, about 37W/user to 63 W/user.

[1] R. Bolla, F. Davoli, R. Bruschi, K. Christensen, F. Cucchietti, and S. Singh. The Potential Impact of Green Technologies in Next-Generation Wireline Networks: Is There Room for Energy Saving Optimization? IEEE Communications Magazine, 49(8):80-86, August 2011.

[2] B. Raghavan and J. Ma. The Energy and Emergy of the Internet. In ACM Workshop on Hot Topics in Networks, 2011.

Energy-Proportional Computing



Servers consume 50% peak power at 0% utilization.
Energy efficiency is low at low utilization.
IEEE Computer, December 2007

Figure 2. Server power usage and energy efficiency at varying utilization levels, from idle to peak performance. Even an energy-efficient server still consumes about half its full power when doing virtually no work.

Why Not Energy-Proportional?

- Many components require power to "stay on."
- Air conditioner
- Power distribution

Questions

- How do you quantify the energy consumption of the Internet?
- What are your methods? Why do they work?
- Can we reduce the energy consumption of individual components or systems to reduce the overall energy consumption?
- How do you count the energy consumption of a single user's request in a shared system (servers, networks, storage ...)?

GREEN IT

IEEE Computer, November 2011.

End-to-End Energy Management

Yung-Hsiang Lu, *Purdue University*
Qinru Qiu, *Syracuse University*
Ali R. Butt and Kirk W. Cameron, *Virginia Tech*

To improve energy efficiency, we must consider the end-to-end energy use of a task involving multiple computer systems.

Do you agree?

Summary

- It is difficult to estimate the power consumption of ICT. Data are scattered in multiple sources. Each paper can provide only "best guess."
- The data suggest that
  – The two ends (consumers and data centers) consume more power than the networks.
  – The direct power / energy impacts from ICT is "modest", about several percent of electricity.
- More effort is needed to fully understand where power goes.

How Heavy is a Memory Chip?

The 1.7 Kilogram Microchip: Energy and Material Use in the Production of Semiconductor Devices
Environmental Science and Technology, 36(24), 2002 by Ericd Willams, Robert U Ayres, and Miriam Heller

How do you quantify the environmental impacts of semiconductor industry?

The numbers in this paper are questionable but there are few comparable analyses.

Video

Making Silicon Wafer and Chips

財團法人國家政策研究基金會
National Policy Foundation
國政評論
NPF Commentary

永續(評)091-030號

中華民國九十一年 三月三日
March 3,2002

竹科缺水危機 資源開發警訊

國政會永續發展組政策委員　李建中

竹科缺水，各界正為停水與供水忙得焦頭爛額。其實相較之於全世界，台灣是一個缺水的國度。北部地區雖然有數個水庫可用，但是今年開春以來，仍然不敵暖冬的壓力，造成有始以來的竹科缺水事件。中部的水資源仰賴苗栗鯉魚潭水庫及數條河川供應，缺水危機也是時隱時現。南部地區水資源嚴重不足，嘉義及台南水源或有曾文、烏山頭及南化水庫供給，但是當地是台灣穀倉之地，農田用水甚殷，如遇枯水季，對高雄地區及南部科學園區不利的影響，恐將遠遠超越此次竹科缺水事件。

高科技工業研磨、刻蝕及清洗製程使用大量的水源，以世界先進公司第二、三晶圓廠為例，每天需水七千噸，等於是寶山水庫每日正常供水量七萬噸的十分之一。如果採用循環並回收用水，約可減少80%的耗水量，需水減為前項供水量的五十分之一。目前新科用水平均回收率約有60%，若干廠家已經有回收90%用水的能力，達到日本高科技工業的標準，將來如能陸續推動節水措施，對於減少缺水的衝擊必然有甚多的助益。

2010-3-19

南化水庫再不進帳／南科6月恐缺水 將買水因應

〔記者林毅璋、林孟婷、陳梅英／台北報導〕經濟部水利署署長楊偉甫昨日表示，假設六月前都不下雨，目前主要供應南科園區的南化水庫在六月之後恐將會有供水的問題。

曾文水庫尚足夠調度

楊偉甫說，水利署是假設最糟的天候狀況，也就是滴雨未下，南化水庫在六月將出現用水緊張的狀況；南化水庫與曾文水庫的系統下游端是互通的，現在曾文水庫的水量還足夠，因此可靈活調度水源，不成問題。

南科地區廠商表示，缺水確實對生產會有影響，包括南科園區與廠商自己都有儲水塔，短時間停水還可以因應，生產沒問題，但是停水時間如果拉長，對生產影響很大；目前南科幾個用水大戶，包括奇美電、台積電，聯電等。

南科擬撥一億多購水

南科管理局表示，如果水利署發布相關限水措施消息，南科園

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竹科缺水9年之最 台積電水車待命 - Yahoo!...

tw.news.yahoo.com/竹科缺水9年之最-台積電水車待命-095200248.html

竹科缺水9年之最　台積電水車待命

TVBS 作者： 侯力元 | TVBS – 2011年5月6日 下午5:52

-字 +字

高速公路上，運水車跑得飛快，直奔新竹科學園區，9年前台灣面臨嚴重的缺水危機，竹科廠商只能仰賴四處買水才能繼續維持運作。

今年春雨偏少，等不到降雨，西半部水庫水位幾乎都逼近下限水位，其中竹科的主要供水來源，寶山水庫蓄水量已經不到5成，另外聯合供應新竹地區民生及工業用水的寶二水庫，蓄水量更是只剩下3成左右，用水吃緊，也讓像是台積電等半導體大廠不得不提前繃緊神經。

台積電發言人孫又文：「因為很久沒有下雨，這個水庫的存水量在下降，所以我們在今年4月初，就是上個月月初，我們就已經開始自動的減少用水3%。」

為了因應可能無法避免的第二階段限水，除了減少不必要的用水外，台積電也加強回收水的使用，並研擬啟動水車買水的應變措施，預計工廠產能將不會受到衝擊，只是天公一天不下雨，竹科的缺水疑慮恐怕還是無法完全消除。

Facebook 讚 151 馬上按讚 加入Yahoo!奇摩新聞粉絲團

有關媒體報導竹科缺水問題,科管局之說明

有關媒體報導竹科缺水問題,科管局說明如下:

新竹科學園區每日用水量約13萬噸，計有下列供水來源，截至3/6各水庫水文狀況如下：1）寶二水庫（有效蓄水量約1,293.01萬噸，蓄水百分比約為41.26％）2）寶一水庫（有效蓄水量約307.2萬噸，蓄水百分比約為57.42％）3）頭前溪隆恩堰（正常每日約可取水20萬噸）4）永和山水庫（有效蓄水量約1,363萬噸，蓄水百分比約為48.51％）。

目前寶二水庫與寶一水庫合計有效蓄水量約1,600萬噸（約與99年元月份蓄水量相當）。惟為因應寶二水庫有效蓄水量不到5成，自來水公司已於2月15日起實施夜間減壓，並加強節約用水宣導，以延長水庫供水期程，儘可能延伸至梅雨季節之豪雨降臨，以解決枯水季節供水不足之問題。

近因2月下旬至3月上旬為春耕整田大量用水時期，致水公司自頭前溪隆恩堰取水不足，而整田用水期預計本週結束，故3月15日起水公司每日應可自頭前溪隆恩堰之取水將恢復正常，可望有效減緩水庫出水量。

依據水利署北區水資源局2月21日所召開「100年度水源調度協調第3次會議（台北、桃園、新竹暨離島馬祖地區）」結論所載，新竹地區日後縱不降雨，民生及工業用水仍可穩定供應至100年4月底。預估近日有春雨，科管局於3月4日與水公司聯繫，初步瞭解新竹地區民生及工業用水應可穩定供水至5月底。

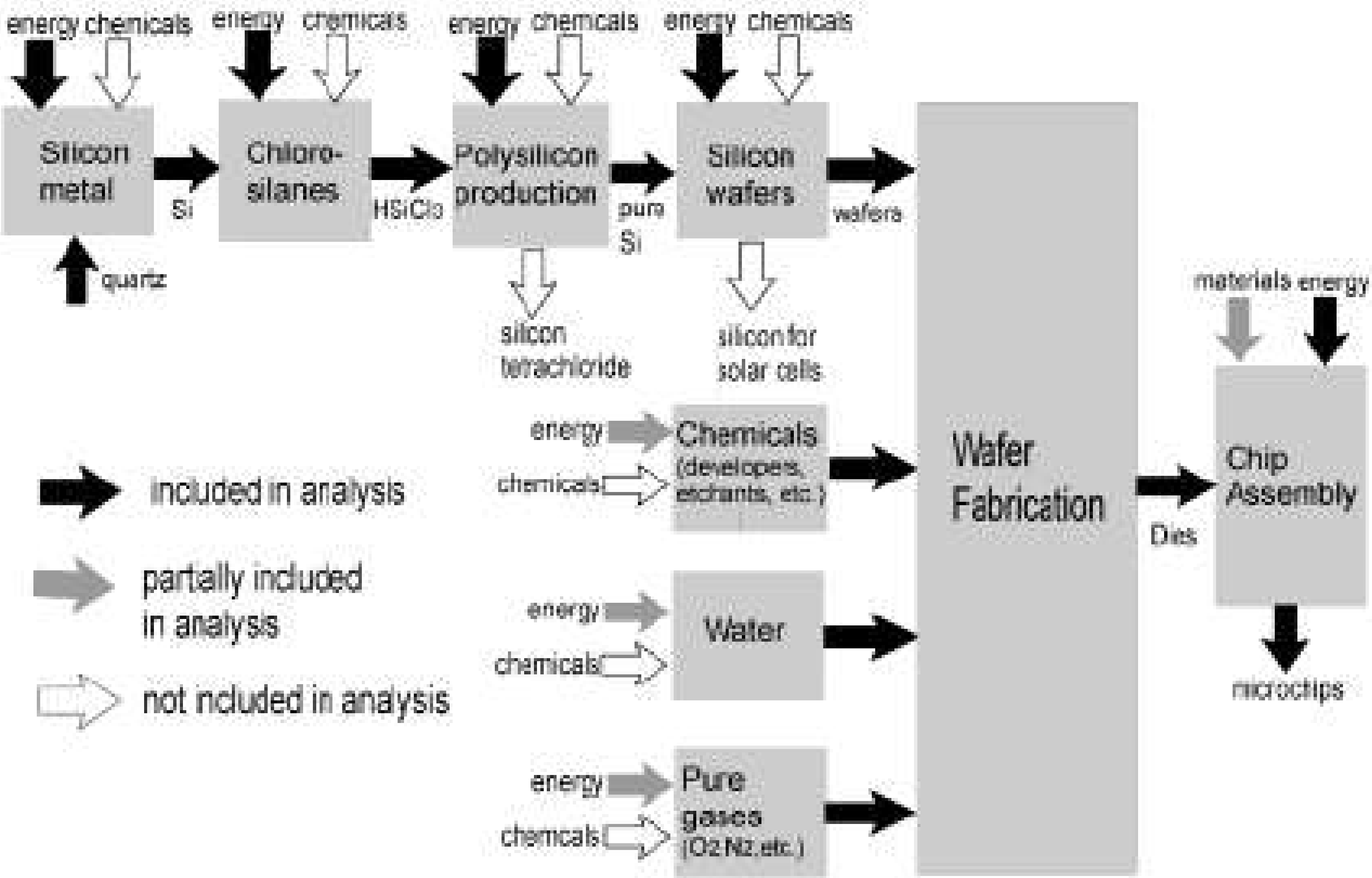
在水文狀況未改善前，水利署水資源局每二週均會召開一次水源調度協調會議（3月10日將召開第四次會議），科管局將持續與該局及水公司保持聯繫，以隨時配合因應相關措施。

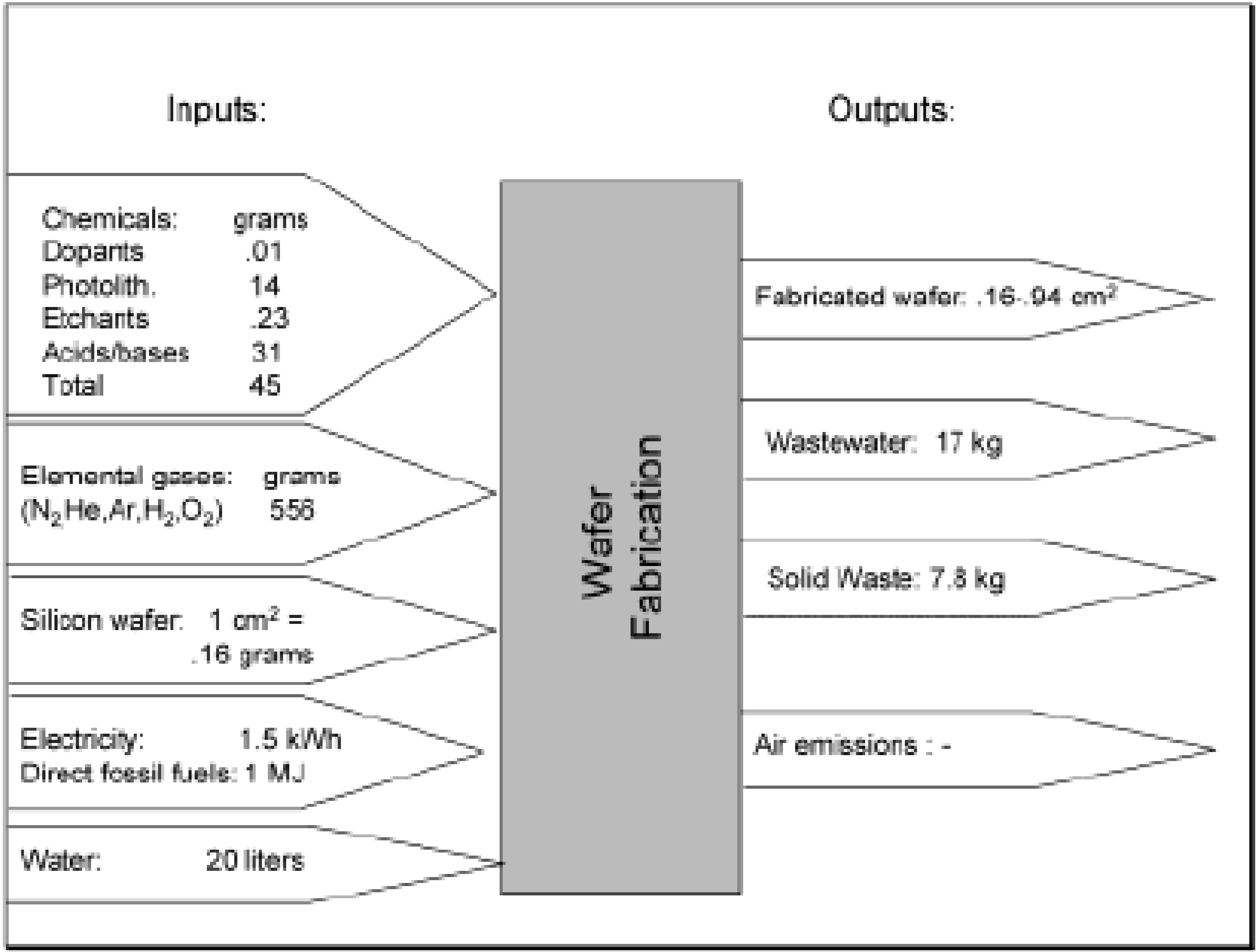
營建組柯季伯技正 03-5773311分機2523

Top

Making a 2g 32MB DRAM chip

- 1600g fossil fuel
- 72g chemicals
- 32000g water
- 700g gas (mostly N_2)
- Purifying silicon is energy intense due to the high organization and low entropy.


energy chemicals
Silicon metal
quartz
Si
energy chemicals
Chloro-silanes
HSiCl3
energy chemicals
Polysilicon production
silicon tetrachloride
pure Si
energy chemicals
Silicon wafers
silicon for solar cells
wafers
energy
chemicals
Chemicals (developers, etchants, etc.)
energy
chemicals
Water
energy
chemicals
Pure gases (O2,N2,etc.)
Wafer Fabrication
Dies
materials energy
Chip Assembly
microchips
included in analysis
partially included in analysis
not included in analysis


Inputs:
Outputs:
Chemicals: grams
Dopants .01
Photolith. 14
Etchants .23
Acids/bases 31
Total 45
Elemental gases: grams
(N_2 He, Ar, H_2, O_2) 556
Silicon wafer: 1 cm^2 =
.16 grams
Electricity: 1.5 kWh
Direct fossil fuels: 1 MJ
Water: 20 liters
Wafer Fabrication
Fabricated wafer: .16-.94 cm^2
Wastewater: 17 kg
Solid Waste: 7.8 kg
Air emissions : -

category	substance	input per wafer area (g/cm^2)
elemental gas	He	1.7E−01
	N_2	4.4E+02
	O_2	3.0E+00
	Ar	1.7E+00
	H_2	4.6E−02
	subtotal gas:	4.5E+02
deposition/dopant gases	silane (SiH_4)	7.8E−03
	phosphine (PH_3)	1.7E−05
	arsine (AsH_3)	4.3E−06
	diborane (B_2H_6)	4.3E−06
	dichlorosilane (SiH_2Cl_2)	1.4E−03
	subtotal deposition/dopants:	9.3E−03
etchants	ammonia (NH_3)	1.2E−02
	N_2O	7.2E−02
	Cl_2	4.8E−03
	BCl_3	8.7E−03
	BF_3	3.5E−05
	HBr	2.2E−03
	HCl	5.0E−03
	HF	9.5E−04
	NF_3	2.3E−03
	WF_6	4.3E−04
	SF_6	6.5E−03
	C_2F_6	5.0E−02
	CHF_3	3.1E−02
	CF_4	3.0E−02
	subtotal etchants	2.3E−01

category	substance	input per wafer area (g/cm^2)
acids/bases	HF 1 vol + NH4 30 vol mixture	2.84 E+00
	phosphoric acid H_3PO_4 86%	2.41 E+00
	hydrofluoric acid 0.5%	3.42 E+00
	hydrofluoric acid 5%	4.55 E−01
	hydrofluoric acid 50%	2.52 E−01
	nitric acid 70%	1.19 E+00
	sulfuric acid 96%	7.85 E+00
	hydrochloric acid 30%	2.52 E+00
	ammonia 28%	7.76 E−01
	slurry	2.86 E−01
	HCl 30%	5.06 E−01
	NaOH 50%	6.51 E−01
	subtotal acids/bases:	2.32 E+01
photolithographic chemicals	hydrogen peroxide 30%	4.43 E+00
	isopropyl alcohol	2.02 E+00
	tetramethylammonium hydroxide	4.31 E+00
	methyl-3-methoxypropionate	1.48 E+00
	acetone	5.54 E−01
	hexamethyldisilazane	2.20 E−02
	hydroxyl monoethanolamine	1.42 E+00
	subtotal photolithographic chemicals	1.42 E+01
	NaOH for neutralizing wastewater	7.60 E+00

total chemical input: 45.2 g/cm^2

Energy Use

- 83% electricity, about 1.4 kWh/cm^2; rest are oil, gas ...
- 35% process tools
- 26% ventilation
- 20% chilling
- 7% producing liquid nitrogen
- 5% purifying water (5 to 29 liters per cm^2)

TABLE 3. Energy Use in Stages of Production of Silicon Wafers

stage	electrical energy input/kg silicon out	silicon yield (%)	data sources
quartz + carbon → silicon	13 kWh	90	(*29*–*31*)
silicon → trichlorosilane	50 kWh	90	(*32*, *33*)
trichlorosilane → polysilicon	250 kWh	42	(*32*–*34*)
polysilicon → single crystal ingot	250 kWh	50	(*32*)
single-crystal ingot → silicon wafer	240 kWh	56	(*32*, *35*)
process chain to produce wafer	2130 kWh	9.5	

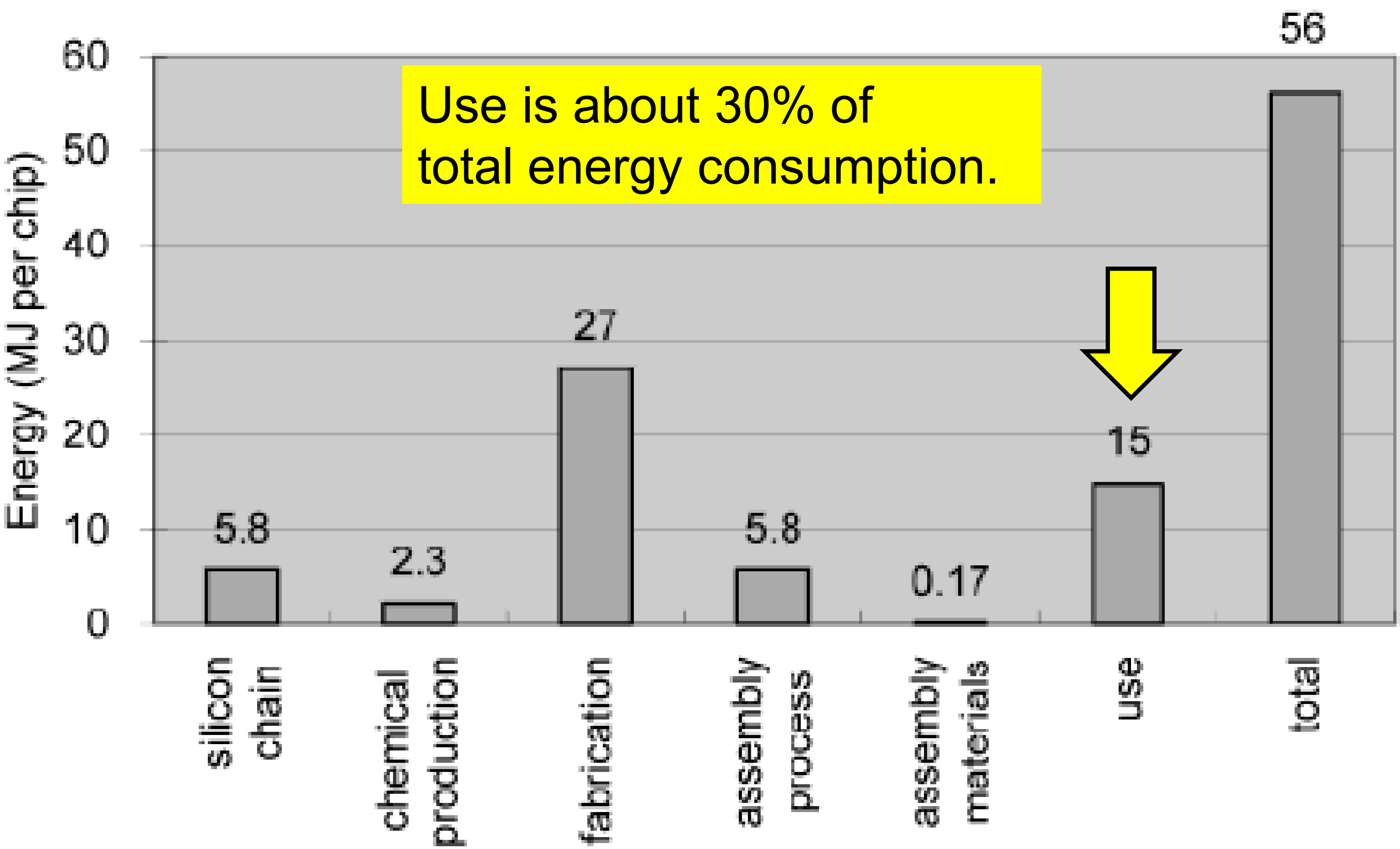


FIGURE 3. Energy consumption in production and use of a 32MB DRAM chip.

One kg coal can produce about 24 MJ energy.

Summary

- ICT's environmental impacts start from materials.
- Many chemicals are used; some are toxic.
- Large quantity of water is needed.
- Semiconductor is energy-intense due to the high purity (low entropy).
- The data are obtained from many sources, mostly indirectly, so the accuracy is questionable (acknowledged by the authors).
- There are few similar studies since 2002.

Electronic Waste

Where do your old computers go?

Video

E Waste

IEEE

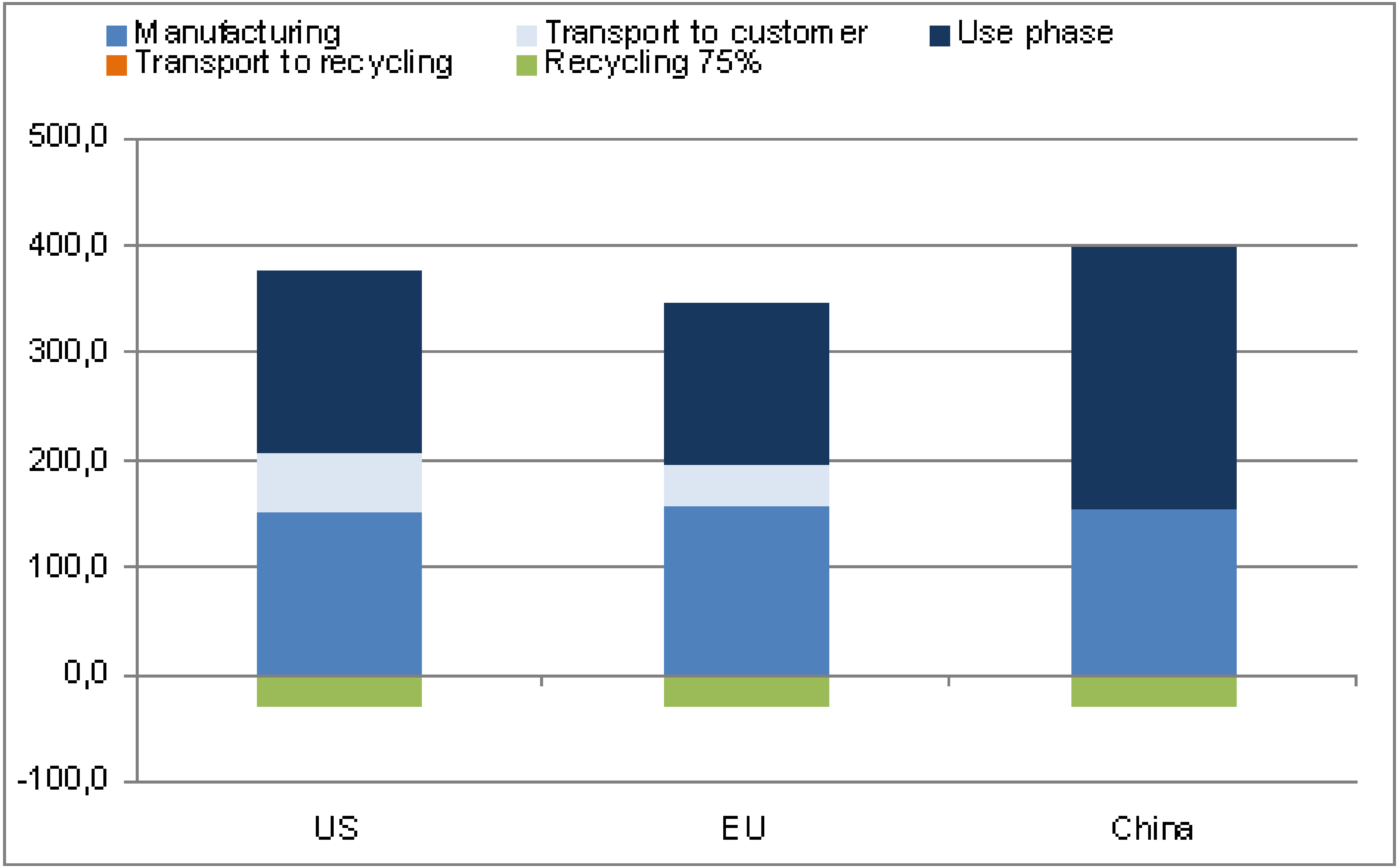
Is it possible to build a second market for electronics?

People buy used cars and houses.
How about computers?

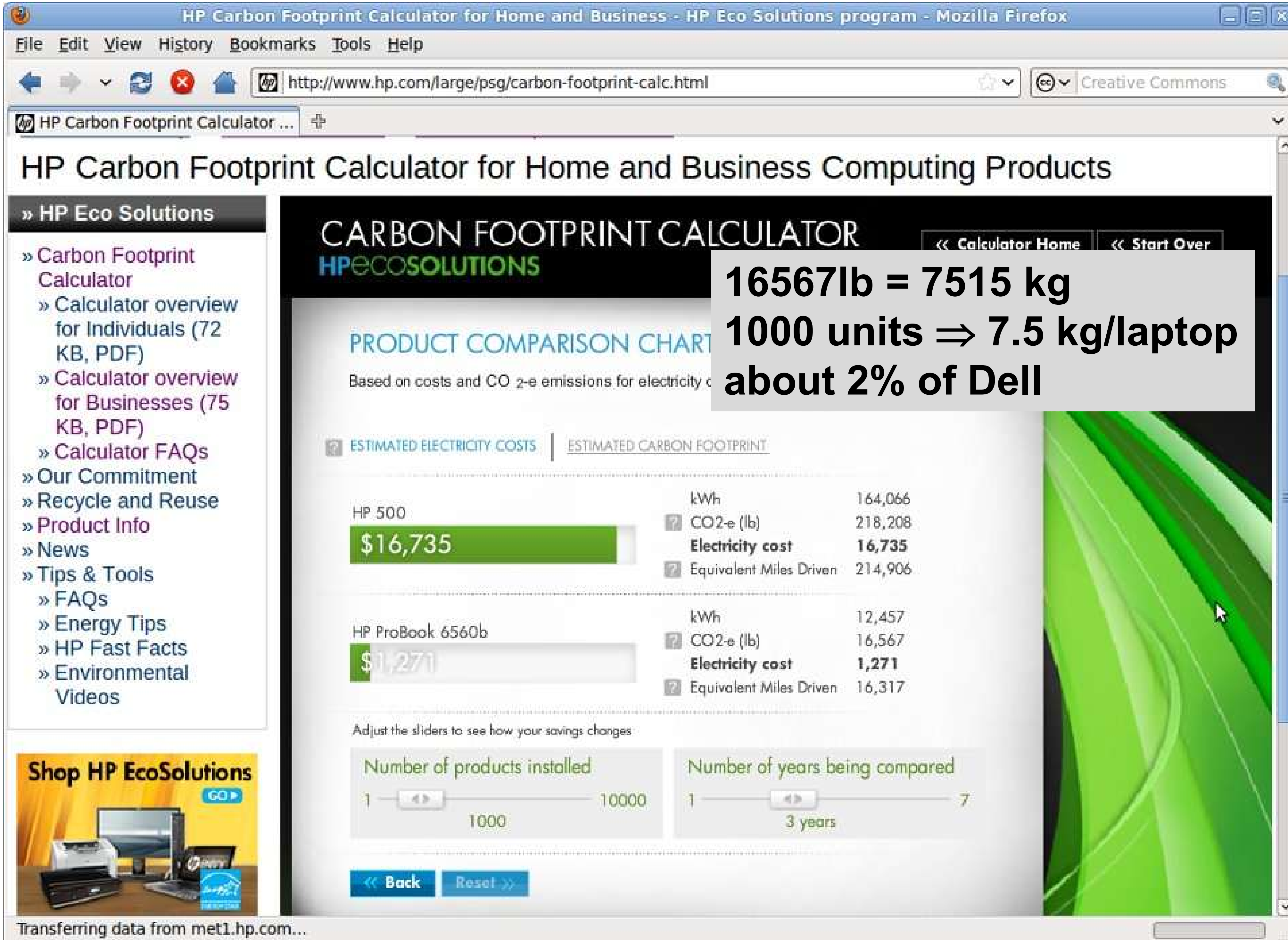
Carbon Footprint of a Typical Business Laptop From Dell

Total greenhouse gas emissions for the Latitude E6400 (350 kg CO_2eq) are comparable to those for 240 liters of orange juice.

Markus Stutz, EMEA Environmental Affairs Manager
May 2010



Manufacturing
Transport to customer
Use phase
Transport to recycling
Recycling 75%
500,0
400,0
300,0
200,0
100,0
0,0
-100,0
US
EU
China



16567lb = 7515 kg
1000 units ⇒ 7.5 kg/laptop
about 2% of Dell

Apple - The Story Behind Apple's Environmental Footprint - Mozilla Firefox

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Apple - The Story Behind Apple's Enviro...

http://www.apple.com/environment/

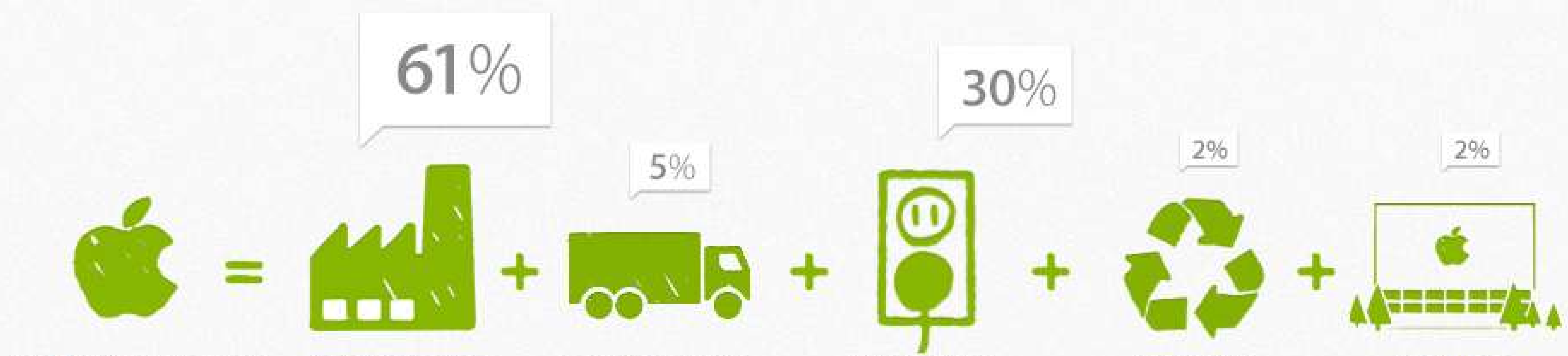
Store | Mac | iPod | iPhone | iPad | iTunes | Support

Apple and the Environment

Overview | Energy Efficiency | Reports | Progress

The story behind Apple's environmental footprint.

Apple reports environmental impact comprehensively. We do this by focusing on our products: what happens when we design them, what happens when we make them, and what happens when you take them home and use them.



2011 Total Footprint Learn more

Manufacturing Learn more

Transportation Learn more

Product Use Learn more

Recycling Learn more

Facilities Learn more

Data Centers and Renewable Energy

Read news about renewable energy and Apple data centers.

Sustainable Energy Supply

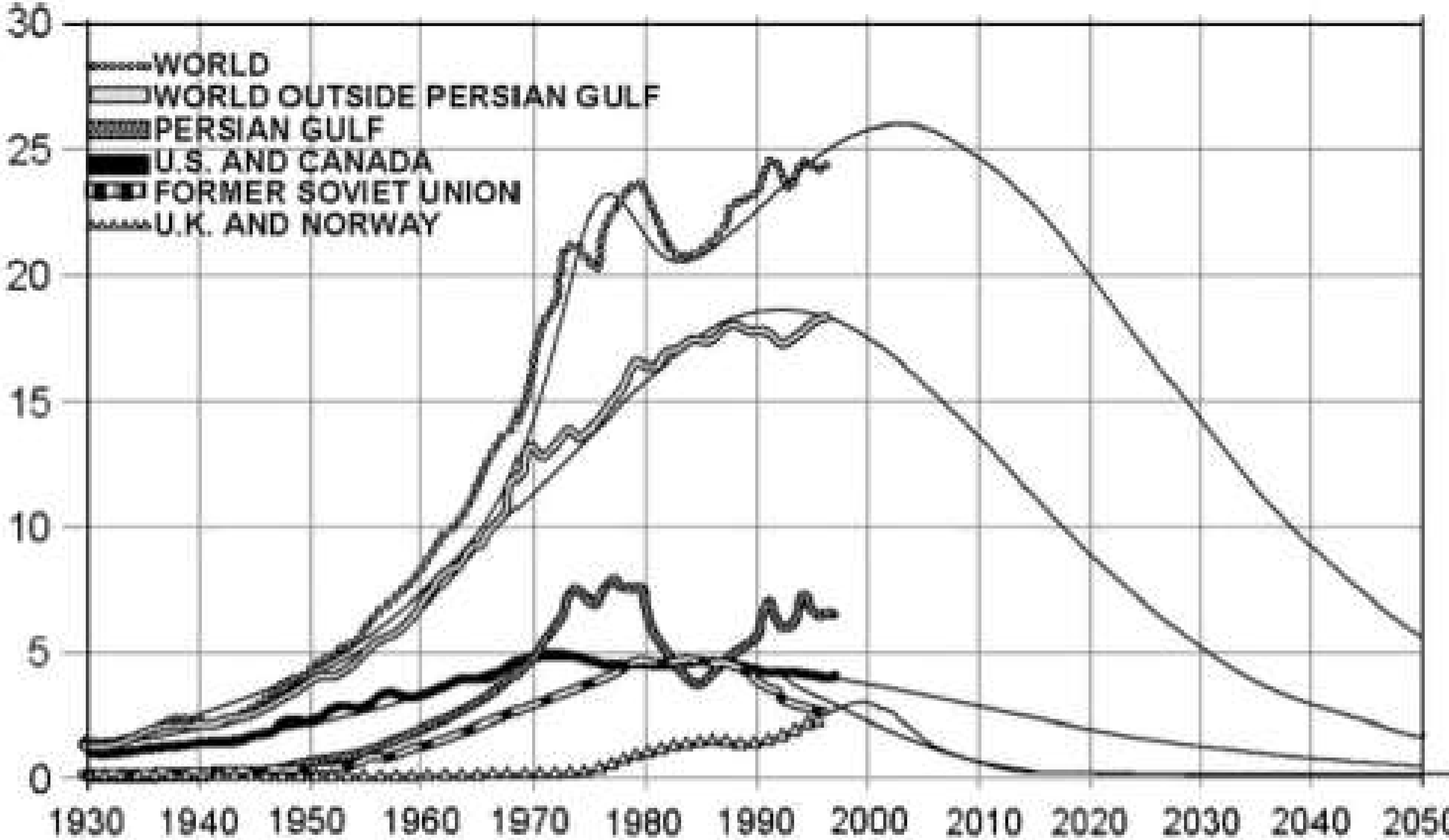
What technologies can provide human energy needs for 1000 years?

Sustainable energy sources?

Keeping the Energy Debate Clean: How Do We Supply the World's Energy Needs?

Proposed solutions include: Sensible energy conservation; Solar thermal collection using parabolic reflectors; Hydrogen used as an energy carrier in combustion engines and for energy storage and transportation.

By Derek Abbott, *Fellow IEEE*


WORLD
WORLD OUTSIDE PERSIAN GULF
PERSIAN GULF
U.S. AND CANADA
FORMER SOVIET UNION
U.K. AND NORWAY
30
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15
10
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1950
1960
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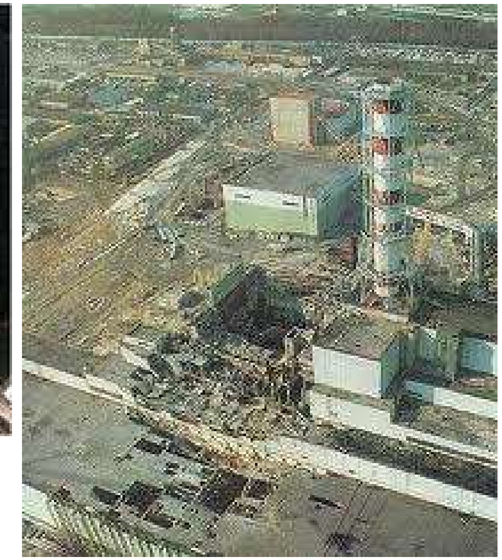
1980
1990
2000
2010
2020
2030
2040
2050

oil supply

Energy-Related Disasters






中油煉油廠爆炸，後勁社區再度呼喊「遷廠」！

中油在後勁 工業污染 環境人權

專題報導 | 2008-07-24

李根政2007/10/26周末夜10:47

中油煉油總廠第六蒸餾工場發生大爆炸，據後勁社區人士表示，爆炸大約發生在今天（10月26日）下午 5點 40分以前， 5點52 分發生大爆炸，社區人士形容有如幻象戰鬥機在起飛時發出的巨大聲響，講電話根本聽不到對方的聲音。

活動看板（請點選日期）
Thursday, July 5
Wednesday, July 25
山林書院（室內＋室外）：高雄營隊

河北滄州煉油廠爆炸 (中國)

2012-06-12 (13:15)

河北滄州煉油廠發生爆炸，暫時未確定傷亡情況。

滄州煉油廠爆炸現場。

肇事的煉油廠是中石化旗下的滄州分公司，煉油廠的聚丙烯車間於上午10時左右爆炸。目擊者表示，爆炸現場冒出巨大火苗，濃煙滾滾。事發時，車間正值工作時間，目前傷亡人數不詳。中新網記者表示，廠房已面目全非，門窗全部脫落，玻璃大部分破碎。

爆炸發生後，當地消防、醫護人員趕往現場救援，現時通往爆炸現場的道路已被封鎖。

煉油廠佔地約180公頃，建於1971年4月，1975年10月投產，是河北省十強企業，連續兩年銷售收入超過100億元，固定資產總額達26.7億元，生產裝置加工能力為年產350萬噸。

即時新聞 Breaking news 》 泰煉油廠起火 將關閉1周

【中央社／曼谷4日專電】 2012.07.04 09:48 pm

泰國國有煉油廠邦乍石油（Bangchak Petroleum）1處煉油廠今天發生爆炸起火，這是1年半來第2次事故。煉油廠將關閉1周，每天生產8萬桶的原油蒸餾設備也將暫停30天。

邦乍石油總裁安努宋（Anusorn Sangnimnuan）表示，預估損失高達1億銖（約新台幣9480萬元），但保險可以理賠，不會影響營收。

Options and Challenges

- power consumption about 15 TW
- power absorbed by Earth about 116 PW
- oil: declining supply?
- nuclear: supply about 6% power now. Uranium at "reasonable cost" for another 80 years. New reactors technologies immature.
- wind: moving mechanic parts need lubrication (oil)
- hydro (dam): damage to ecology
- geothermal: pollute underground water supply

Solar Power

- solar cells (converting optical energy to electric energy): need energy for extracting materials and for manufacturing
- solar panel: reflecting lights to heat liquid and drive a turbine. "low-tech" solution
- hydrogen for transportation, safer than gasoline


hydrogen leak
gasoline leak

Hydrogen

- Hindenburg explosion? It burned, not exploded. 61/97 survived.
- Electrosys $\Rightarrow$ hydrogen $\Rightarrow$ compression $\Rightarrow$ energy consumption? Electrosys can occur at high pressure.
- No infrastructure or demand for hydrogen $\Rightarrow$ hydrogen is widely used in industry.
- Electrosys will deplete water supply $\Rightarrow$ About one trillionth of water is sufficient for 15TW of hydrogen.

Do You Agree?

Solar Trust of America files bankruptcy | Reuters - Mozilla Firefox

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Solar Trust of America files bankruptcy | Re...

http://www.reuters.com/article/2012/04/02/us-solartrust-bankruptcy-idUSBRE8310ZV20120402

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ARTICLE | COMMENTS (4)

Solar Trust of America files bankruptcy

Recommend | 3,295 people recommend this.

Mon Apr 2, 2012 3:52pm EDT

Tweet 87 | Share 19 | Share this | +1 6 | Email

(Reuters) - Solar Trust of America LLC, which holds the development rights for the world's largest solar power project, on Monday filed for bankruptcy protection after its majority owner began insolvency proceedings in Germany.

Login or register | Latest from My Wire

Abound Solar Files for Bankruptcy

US DEPARTMENT OF ENERGY HAD FUNDED THIS ONE, TOO

By Neal Colgrass, Newser Staff
Posted Jul 2, 2012 5:50 PM CDT

STORY | COMMENTS (38) | Go to Grid

(NEWSER) – Another government-supported solar panel company bit the dust today, Reuters reports. Abound Solar filed for Chapter 7 liquidation in Delaware after receiving about $70 million of a $400 million loan from the US Department of Energy, the firm said. The 125-employee company said it also had $300 million in private investment. Like Solyndra and Evergreen Solar, Abound was likely the victim of rock-bottom panel prices forced by competition from China and subsidy cuts in Europe.

Los Angeles Times

Solar panel firm Solyndra to cease operations

The Fremont, Calif., company, which had received a $535-million Energy Department loan guarantee and hosted a tour by President Obama, plans to seek bankruptcy protection.

September 01, 2011 | By Ronald D. White, Los Angeles Times

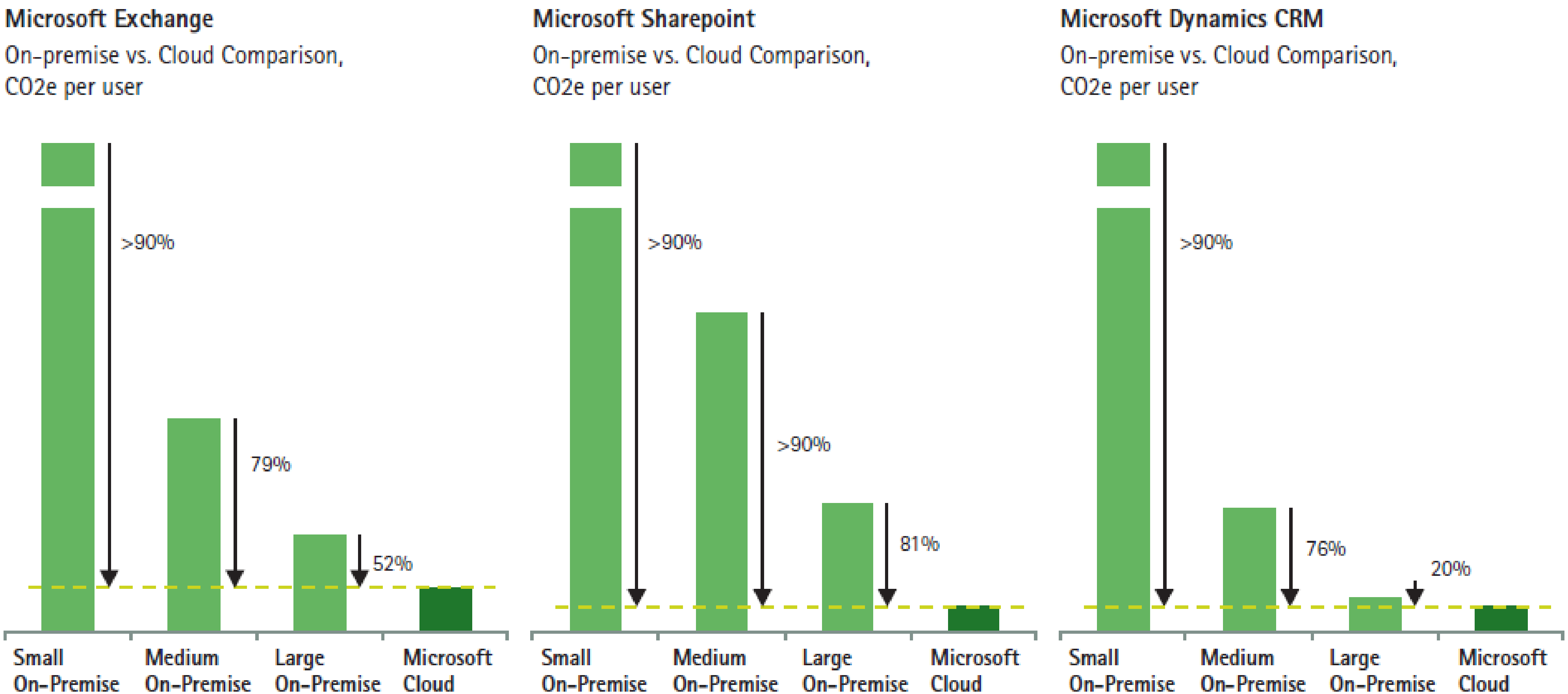
The California solar panel manufacturer that received a high-profile $535-million Energy Department loan guarantee said it was ceasing operations, laying of 1,100 workers and preparing to file for bankruptcy protection.

Solyndra of Fremont, Calif., said it had been rocked by stifling global economic conditions and faced heavy competition from Chinese firms that were undercutting it on costs.

Cloud Computing and Sustainability

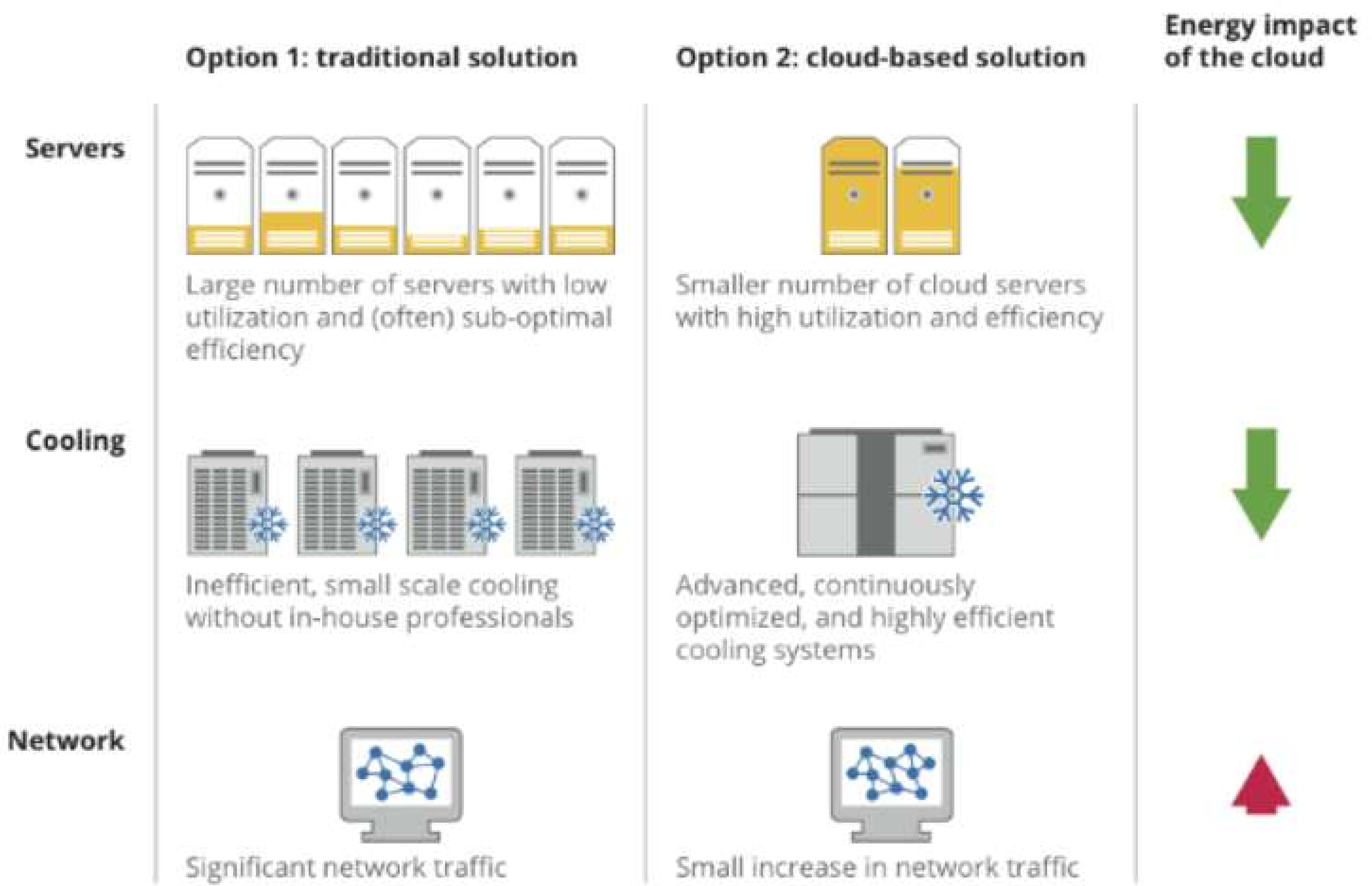

Cloud Computing and Sustainability:
The Environmental Benefits of Moving to the Cloud
accenture
High performance. Delivered.
In collaboration with
WSP

Figure 1: Comparison of Carbon Emissions of Cloud-Based vs. On-Premise Delivery of Three Microsoft Applications



Google Backs Green-Cloud Claims, Touts Apps

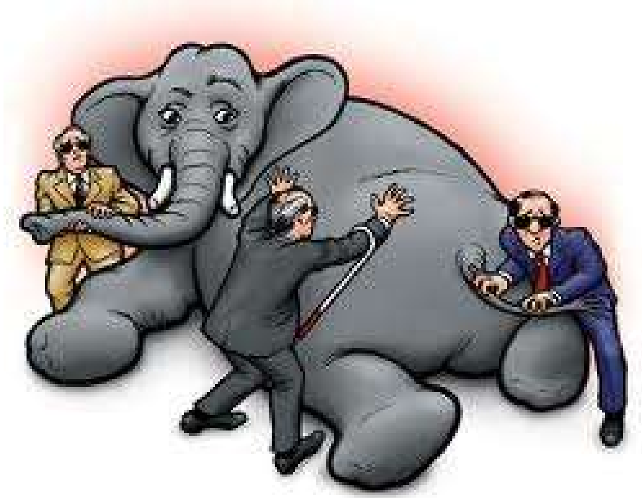
Mike Barton posted in Blog, Featured · June 18, 2012 2:37 pm



Google describes how reducing energy use for servers and server cooling works. *Image:*

Do You Believe Them?

What is Cloud Computing?



瞎子摸象

Video

Data Centers and Cooling

Cloud Computing: Sharing

Rent or buy?

Own, Rent, or Buy a Ticket

Amazon EC2 Pricing - Mozilla Firefox

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Amazon EC2 Pricing

http://aws.amazon.com/ec2/pricing/

On-Demand Instances

On-Demand Instances let you pay for compute capacity by the hour with no long-term commitments. This frees you from the costs and complexities of planning, purchasing, and maintaining hardware and transforms what are commonly large fixed costs into much smaller variable costs.

The pricing below includes the cost to run private and public AMIs on the specified operating system ("Windows Usage" prices apply to Windows Server® 2003 R2, 2008 and 2008 R2). Amazon also provides you with additional instances for Amazon EC2 running Microsoft Windows with SQL Server, Amazon EC2 running SUSE Linux Enterprise Server, Amazon EC2 running Red Hat Enterprise Linux and Amazon EC2 running IBM that are priced differently.

Region: US East (Virginia)

	Linux/UNIX Usage	**Windows Usage**
Standard On-Demand Instances		
Small (Default)	$0.080 per Hour	$0.115 per Hour
Medium	$0.160 per Hour	$0.230 per Hour
Large	$0.320 per Hour	$0.460 per Hour
Extra Large	$0.640 per Hour	$0.920 per Hour
Micro On-Demand Instances		
Micro	$0.020 per Hour	$0.020 per Hour
High-Memory On-Demand Instances		

Amazon EC2 Pricing - Mozilla Firefox

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Amazon EC2 Pricing

http://aws.amazon.com/ec2/pricing/

Reserved Instances

Reserved Instances give you the option to make a low, one-time payment for each instance you want to reserve and in turn receive a significant discount on the hourly charge for that instance. There are three Reserved Instance types (Light, Medium, and Heavy Utilization Reserved Instances) that enable you to balance the amount you pay upfront with your effective hourly price.

The following tables display the Reserved Instance Prices. In addition to Reserved Instances for Linux/UNIX and Windows operating systems specified below, we also offer Reserved Instances for Amazon EC2 running SUSE Linux Enterprise Server and Amazon EC2 running Microsoft SQL Server.Dedicated Reserved Instances are also available.

Linux Windows

Light Utilization Reserved Instances

Region: US East (Virginia)

	1 yr Term		3 yr Term	
	Upfront	**Hourly**	**Upfront**	**Hourly**
Standard Reserved Instances				
Small (Default)	$69	$0.039 per Hour	$106.30	$0.031 per Hour
Medium	$138	$0.078 per Hour	$212.50	$0.063 per Hour
Large	$276	$0.156 per Hour	$425.20	$0.124 per Hour
Extra Large	$552	$0.312 per Hour	$850.40	$0.248 per Hour

Is $0.03/hour cheap?

How much do you pay for your computer?

Let's try to estimate.

How much do you pay per hour?

The Dell Online Store: Build Your System - Mozilla Firefox

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The Dell Online Store: Build Your System

http://premierconfigure.us.dell.com/dellstore/config.aspx?~tgt=cfg&c=us&cs=RC956904&customer_id=RC956904&fb=1&l=en&

Review Your PowerEdge R510 Rack Server

Date & Time: 7/3/2012 7:10:21 PM

PowerEdge R510 Rack Server — Unit Price: $2,051.00

PE R510 Chassis for Up to Four 3.5" Cabled Hard Drives, LED, No Operating System — - $716.00

SYSTEM OPTIONS

PowerEdge R510	PE R510 Chassis for Up to Four 3.5" Cabled Hard Drives, LED	
Processor	Intel® Xeon® E5620 2.4Ghz, 12M Cache,Turbo, HT, 1066MHz Max Mem	edit
Additional Processor	Single Processor Only	edit
Memory	12GB Memory (3x4GB), 1333MHz Dual Rank LVRDIMMs for 1 Processor, Optimized	edit
Operating System	No Operating System	edit
Enterprise Software Licensing	None	edit
Optional Virtualization Offerings	None	edit
Secondary OS	None	edit
OS Media kits	None	edit
Enabled Virtualization	None	edit
OS Partitions	None	edit
Hard Drives	500GB 7.2K RPM SATA 3.5in Cabled Hard Drive	edit
Hard Drive Configuration	No RAID, Embedded SATA Controller for x4 Chassis	edit
Internal Controller	No Controller	edit
External Controller	None	edit
Power Supply	480 Watt Non-Redundant Power Supply	
Power Cords	NEMA 5-15P to C13 Wall Plug, 125 Volt, 15 AMP, 10 Feet (3m), Power Cord	edit

SYSTEMS MANAGEMENT OPTIONS

Embedded Management	Baseboard Management Controller	edit

NETWORKING OPTIONS

PowerEdge R510 Rack Server

Price $2,051.(

Instant Savings $716.(

Price $1,335.0

Discount Details

Preliminary Ship Date: 7/12/2012

Print Summary

Add To Cart

Intel® Xeon® Processor E5620 (12M Cache, 2.40 GHz, 5.86 GT/s Intel® QPI) - Mozilla Firefox

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The Dell Online Store: Build Your System | Intel® Xeon® Processor E5620 (12M C...

http://ark.intel.com/products/47925/Intel-Xeon-Processor-E5620-(12M-Cache-2_40-GHz-5_86-GTs-Intel-QPI)

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Queue (0) Send Feedback English Type Here to Search Products

Intel® Processors ▸ Intel® Xeon® Processor 5000 Sequence ▸ Intel® Xeon® Processor 5600 Series ▸ E5620

Intel® Xeon® Processor E5620 (12M Cache, 2.40 GHz, 5.86 GT/s Intel® QPI)

FICATIONS

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y Specifications

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je Specifications

ced Technologies

ATIBLE PRODUCTS

RING / SSPECS / INGS

Specifications

Essentials	
Status	Launched
Launch Date	Q1'10
Processor Number	E5620
# of Cores	4
# of Threads	8
Clock Speed	2.4 GHz
Max Turbo Frequency	2.66 GHz
Intel® Smart Cache	12 MB

COMPARE PRODUCTS

- Add to Compare
- Compare Now (0)

- Visit the Embedded Design Center >

Electricity Prices by State | Compare Electric Rates by state in Your Area Nation wide - Mozilla Firefox

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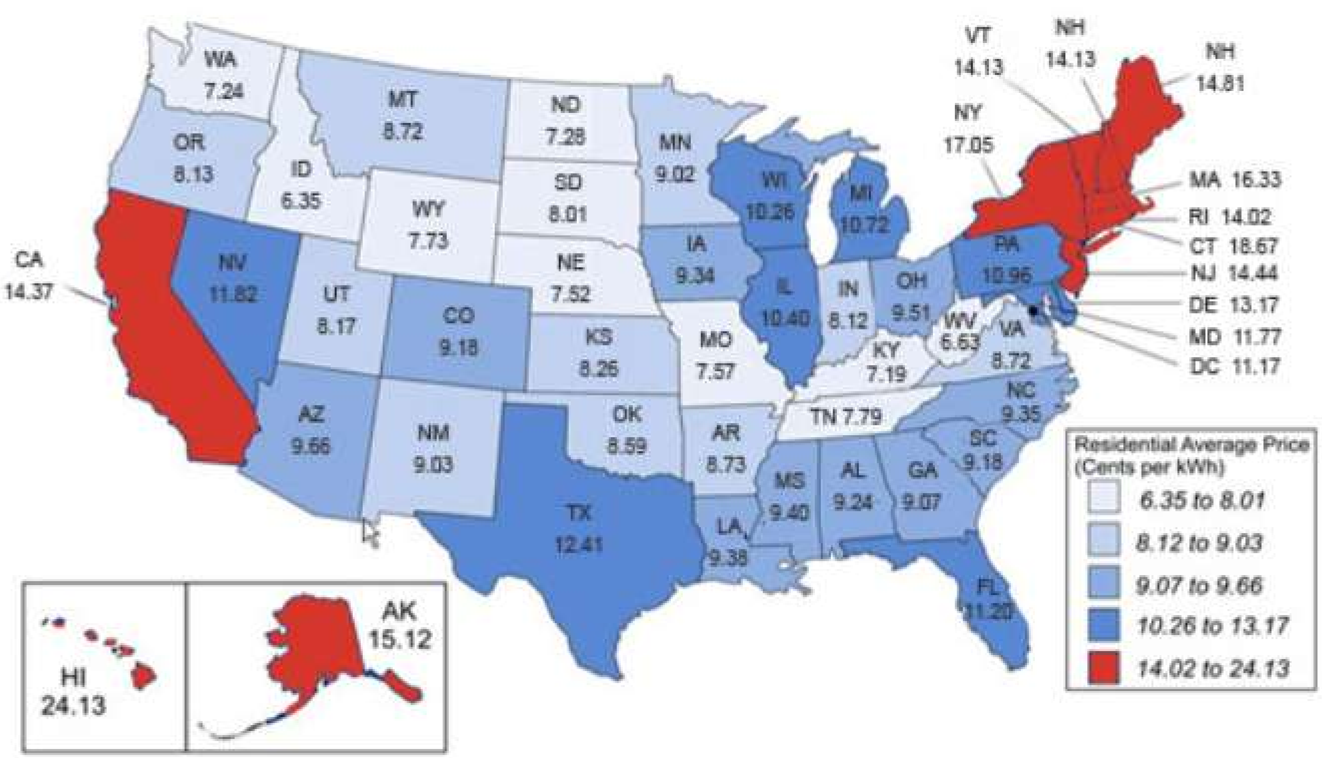
Electricity Prices by State | Compare Electri...

http://www.electricchoice.com/electricity-prices-by-state.php

Google

Electricity Prices by State - National Electric Rate Information

The U.S average residential retail price of electricity was 11.53 cents per kilowatt-hour in 2010



Are You Paying More Than The Average Electric Rate?

Residential Electricity

Enter Your Zip Code here.....

For Home

Commercial Electricity

Enter your zip code here....

For Business

Average Retail Price of Electricity to Ultimate Customers by End-Use Sector, by State, Year-to-Date through August 2010 and 2009

Is $0.03/hour cheap?

Cost Of Ownership

- \$1335 to buy + \$165 network = \$1500
- 480W power supply (overestimation) + 120W network and cooling = 600W
- electricity cost about \$0.12 per kWh = \$0.072h = \$1.728 day = \$630 year
- one system administrator (\$200,000/year) per 1000 server = \$200 per server per year
- life time = 5 years
- total cost = \$1500 + 5 $\times$ (630 + 200) = 5650.
- 5650 / (24 $\times$ 365 $\times$ 5) = \$0.129/hour

Instance Types

Standard Instances

Instances of this family are well suited for most applications.

- Small Instance (Default) 1.7 GB of memory, 1 EC2 Compute Unit (1 virtual core with 1 EC2 Compute Unit), 160 GB of local instance storage, 32-bit or 64-bit platform
- Medium Instance 3.75 GB of memory, 2 EC2 Compute Units (1 virtual core with 2 EC2 Compute Units each), 410 GB of local instance storage, 32-bit or 64-bit platform
- Large Instance 7.5 GB of memory, 4 EC2 Compute Units (2 virtual cores with 2 EC2 Compute Units each), 850 GB of local instance storage, 64-bit platform
- Extra Large Instance 15 GB of memory, 8 EC2 Compute Units (4 virtual cores with 2 EC2 Compute Units each), 1690 GB of local instance storage, 64-bit platform

Micro Instances

Micro instances (t1.micro) provide a small amount of consistent CPU resources and allow you to increase CPU capacity in short bursts when additional cycles are available. They are well suited for lower throughput applications and web sites that require additional compute cycles periodically. You can learn more about how you can use Micro instances and appropriate applications in the Amazon EC2 documentation

.

- Micro Instance 613 MB of memory, up to 2 ECUs (for short periodic bursts), EBS storage only, 32-bit or 64-bit platform learn more about cluster instance concepts by reading the Amazon EC2 documentation. For more information about specific use cases and cluster management options for HPC, please visit the HPC solutions page.

- Cluster Compute Quadruple Extra Large 23 GB memory, 33.5 EC2 Compute Units, 1690 GB of local instance storage, 64-bit platform, 10 Gigabit Ethernet
- Cluster Compute Eight Extra Large 60.5 GB memory, 88 EC2 Compute Units, 3370 GB of local instance storage, 64-bit platform, 10 Gigabit Ethernet

Cluster GPU Instances

Instances of this family provide general-purpose graphics processing units (GPUs) with proportionally high CPU and increased network performance for applications benefitting from highly parallelized processing, including HPC, rendering and media processing applications. While Cluster Compute Instances provide the ability to create clusters of instances connected by a low latency, high throughput network, Cluster GPU Instances provide an additional option for applications that can benefit from the efficiency gains of the parallel computing power of GPUs over what can be achieved with traditional processors. Learn more about use of this instance type for HPC applications.

- Cluster GPU Quadruple Extra Large 22 GB memory, 33.5 EC2 Compute Units, 2 x NVIDIA Tesla "Fermi" M2050 GPUs, 1690 GB of local instance storage, 64-bit platform, 10 Gigabit Ethernet

EC2 Compute Unit (ECU) – One EC2 Compute Unit (ECU) provides the equivalent CPU capacity of a 1.0-1.2 GHz 2007 Opteron or 2007 Xeon processor.

See Amazon EC2 Pricing for details on costs for each instance type.

See Amazon EC2 Instance Types for a more detailed description of the differences between the available instance types, as well as a complete description of an EC2 Compute Unit.

↑ Top

How many instances can this machine provide?

instances?

- 4 cores at 2.4 GHz
- 12 GB memory
- one instance = 1 GHz 2007 Xeon processor
- first-order approximation = 8 instances
- \$0.129/hour $\Rightarrow$ \$0.016/hour-instance < \$0.03
- Therefore, the cloud vendor can make money. For on-demand instance (\$0.08/hour), if the utilization is above 20%.

Why is a cloud vendor like an airliner or a hotel?

All of them want to improve utilization (i.e. occupancy).

The Real Cost of a CPU Hour

Edward Walker, *University of Texas at Austin*

IT organizations can now outsource computer hardware by leasing CPU time through cloud computing services. A proposed modeling tool can quantitatively compare the cost of leasing CPU time from these online services to that of purchasing and using a server cluster of equivalent capability.

IEEE Computer April 2009

Cloud Computing for Business

- Many businesses are seasonal or have high fluctuation of demands.
- Most businesses do not have expertise in managing IT.
- Renting reduces the up-front investment and avoid cost of idle computers.

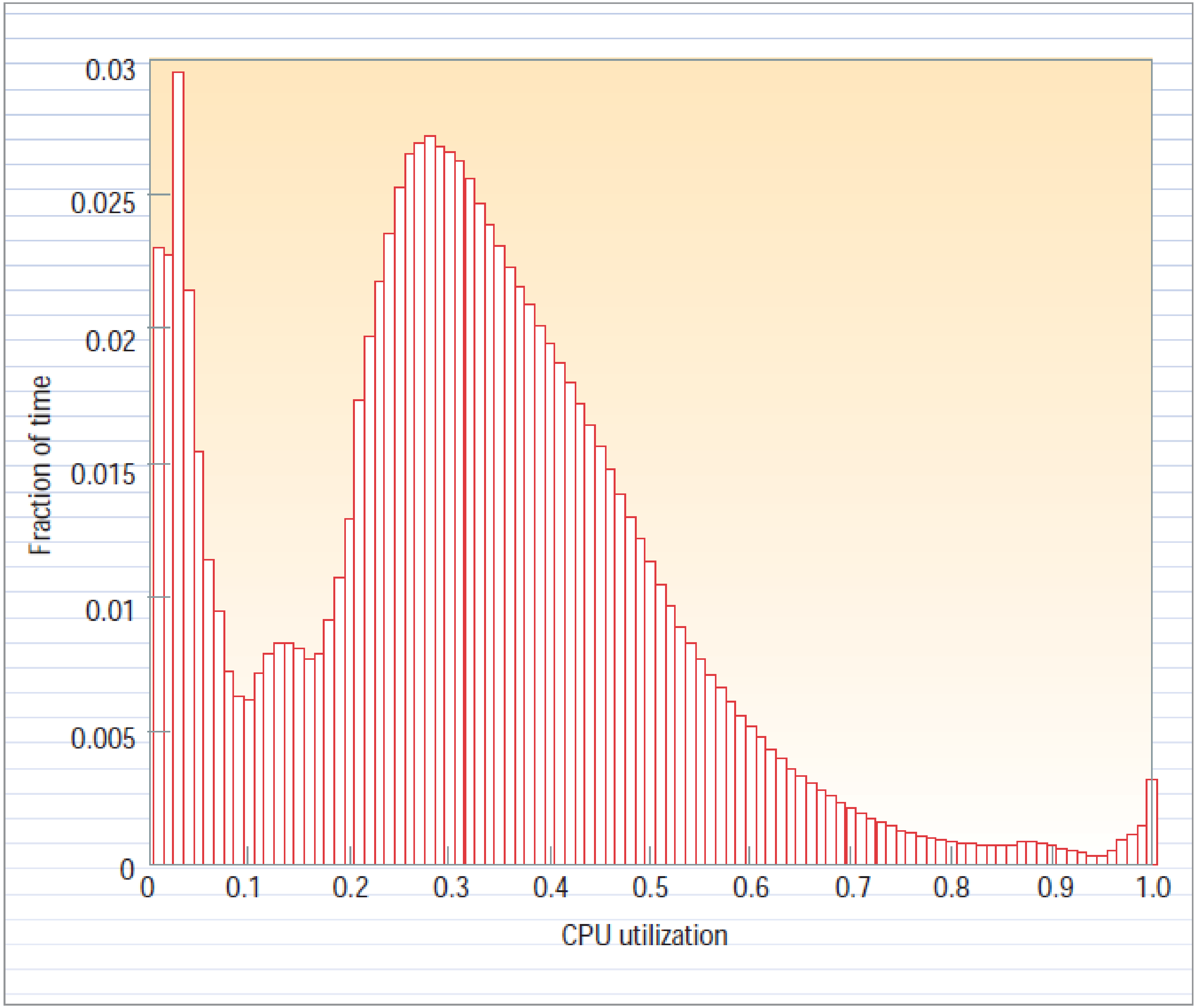


Figure 1. Average CPU utilization of more than 5,000 servers during a six-month period. Servers are rarely completely idle and seldom operate near their maximum utilization, instead operating most of the time at between 10 and 50 percent of their maximum utilization levels.

Why is the utilization low?

Servers are usually under-utilized to provide short latency.

Problems of Datacenter Power

- A typical datacenter contains thousands of machines. Each consumes several $M/month on power for the server and cooling.

$$\text{PUE (power utilization efficiency)} = \frac{\text{power consumption}}{\text{power for computing}}$$

- Server utilization is not very high and the energy efficiency (power / load) is low at low utilization.
- Energy-proportional computing is hard because of physical properties. For example, a disk consumes most power keeping the platters spinning, not reading or writing data.

Cooling in Datacenter

- Cool air comes (pushed) from the bottom.
- Hot air pulls from the top and then sent to radiators. Air flow is hard to control.
- If you can save 5% power, you can save a lot of money.
- How to save power?
- One of them is virtualization.

  One physical machine runs several virtual machines so that fewer physical machines are needed.

Google uncloaks once-secret server | Business Tech - CNET News - Mozilla Firefox

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http://news.cnet.com/8301-1001_3-10209580-92.html

Google uncloaks once-secret server ...

April 1, 2009 2:26 PM PDT

Google uncloaks once-secret server

by Stephen Shankland   Font size Print E-mail Share 121 comments

Tweet 212 Share 938

Google for the first time showed off its server design. (Click to enlarge)
(Credit: Stephen Shankland/CNET)

Most Popular

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- New bacteria redefines 'life as we know it'
- Google elevates PDF reading in Chrome 8
- Ask Maggie: Kindle vs. Nook, waiting for the iPad 2
- Get a loaded HP laptop for $399.99

CNET River

jetscott: So, remind me why Albert Haynesworth's benched again? #redskinscouldusethehelp

declanm: Here in Honolulu's airport, #TSA isn't using millimeter wave naked body scanner (has it cordoned off, in fact). Result: fast security lines.

jetscott: Right before our eyes...

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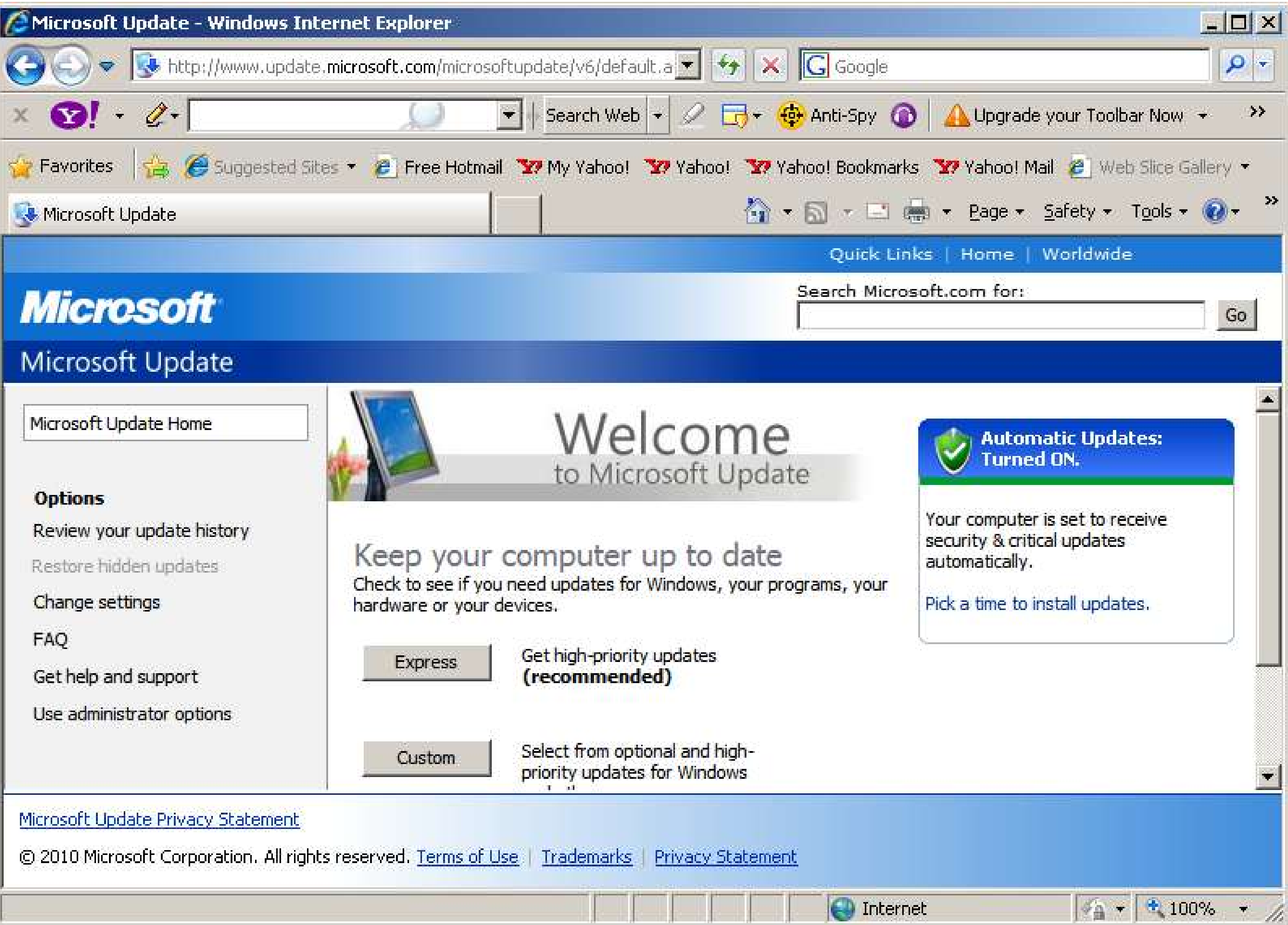
Done

Additional Advantages of Cloud

- no need to worry about buying, installing, upgrading, repairing, recycling ...
- sharing data (among your own computers and among people) + backup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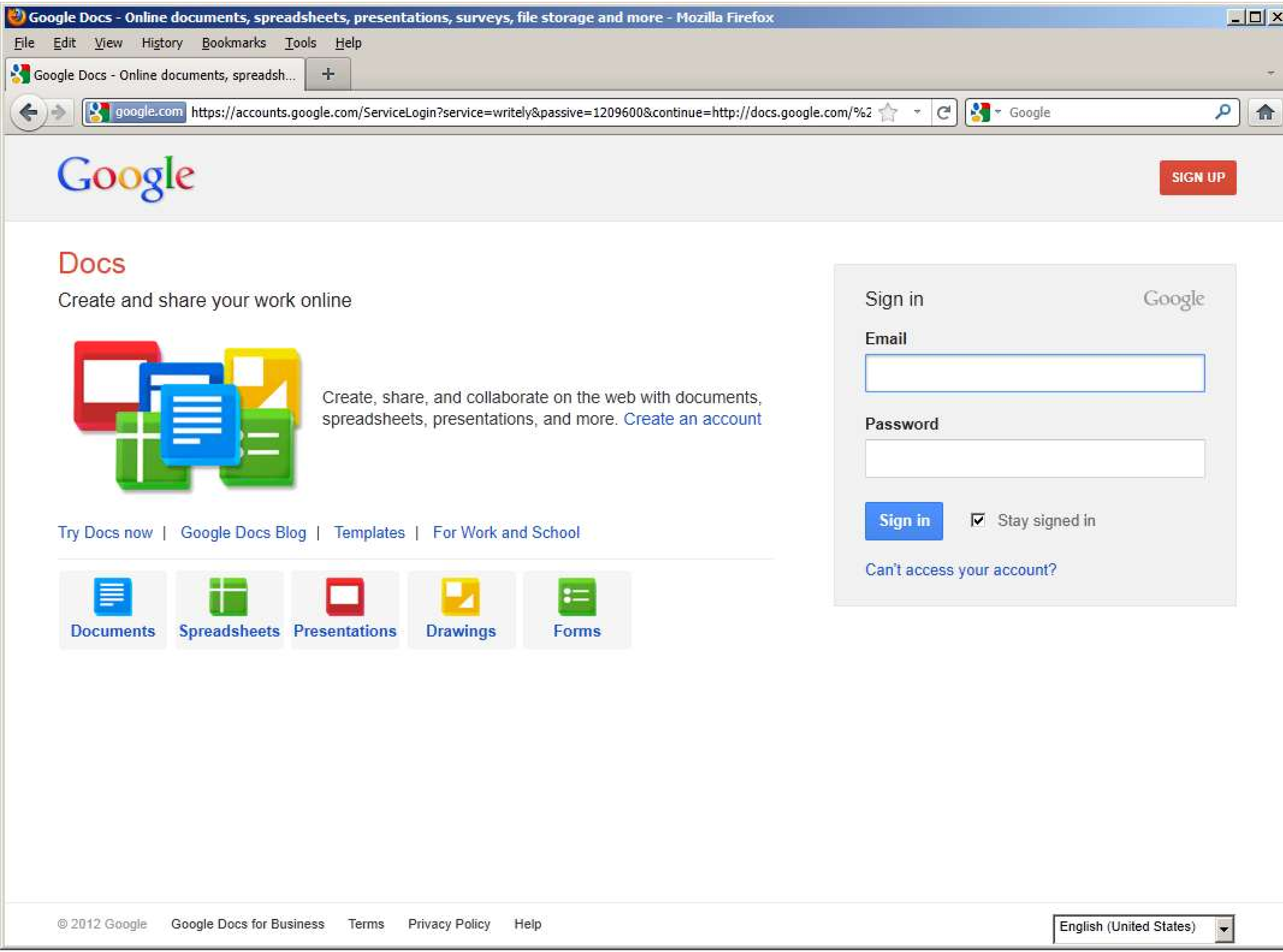
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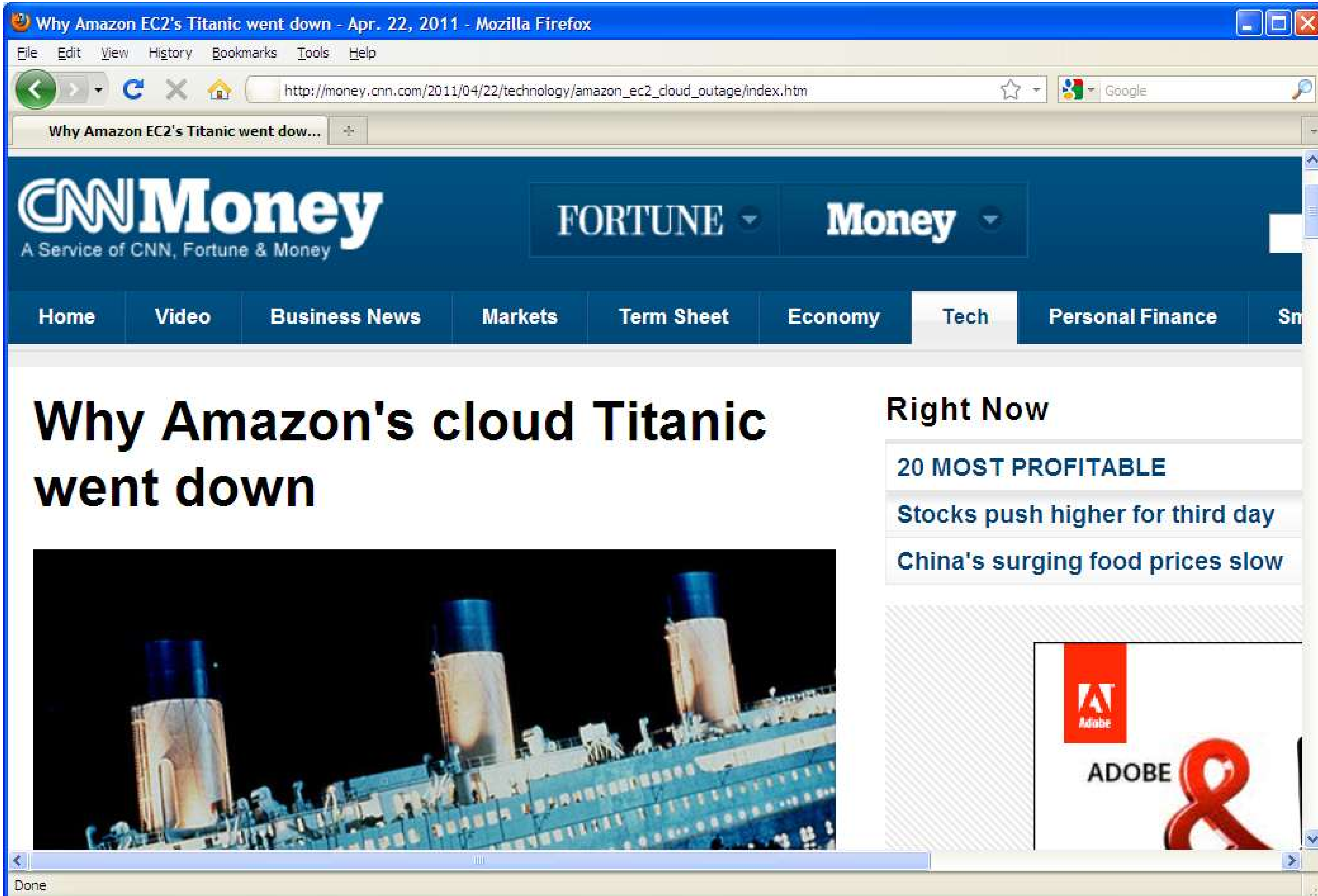
Why Cloud Computing Will Never Be Free

The competition among cloud providers may drive prices downward, but at what cost?

Dave Durkee, ENKI

The last time the IT industry delivered outsourced shared-resource computing to the e
was with timesharing in the 1980s, when it evolved to a high art, delivering the reliabi
performance, and service the enterprise demanded. Today, cloud computing is poised t
the needs of the same market, based on a revolution of new technologies, significant u
computing capacity in corporate data centers, and the development of a highly capabl
communications infrastructure. The economies of scale of delivering computing from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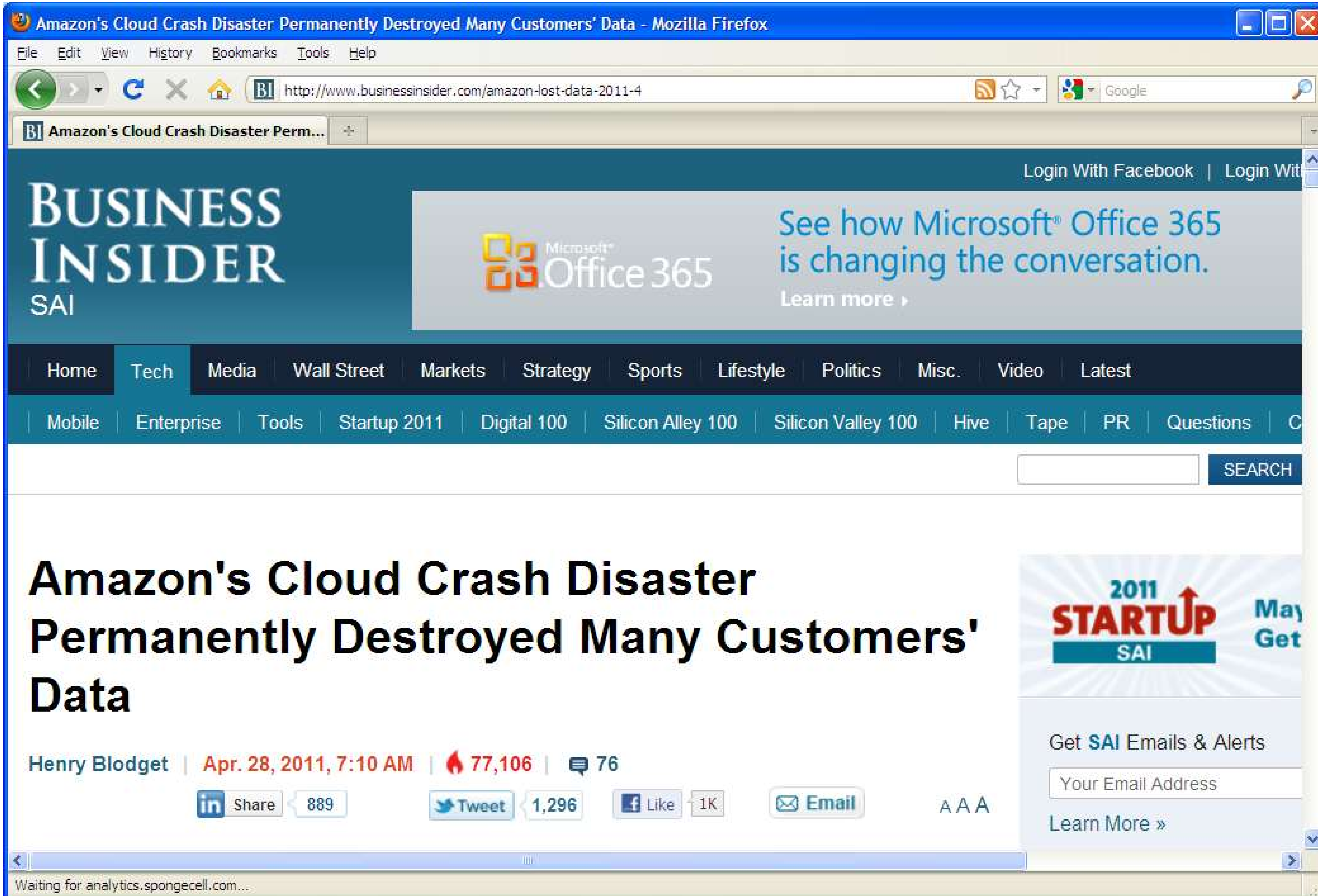
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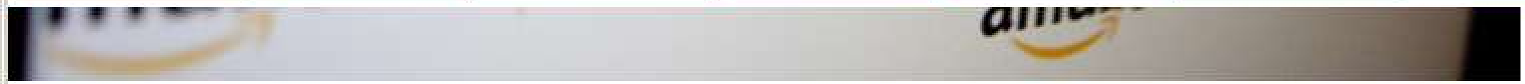

Amazon.com Inc. signage is displayed on a computer monitor in Washington, D.C.Photographer: Andrew Harrer/Bloomberg

Bloomberg News

Amazon Says Data Center Power Back After Storm Outage

By Danielle Kucera on July 02, 2012 | 0 Comments

Companies Mentioned

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$229.53 USD 0.21 0.09%

NFLX
NETFLIX INC
$72.04 USD 4.19 5.82%

Company Lookup

Amazon.com Inc. (AMZN) (AMZN) said severe East Coast thunderstorms led to power outages on June 29 at its Internet-based computing services, which are used by hundreds of thousands of businesses to store data and run websites.

The storms impacted power to several data centers in northern Virginia beginning on Friday night, the Seattle-based company said in an e-mailed statement. In one location, backup power didn't operate correctly, affecting certain users. The company didn't identify the customers and said power was fully restored by the next

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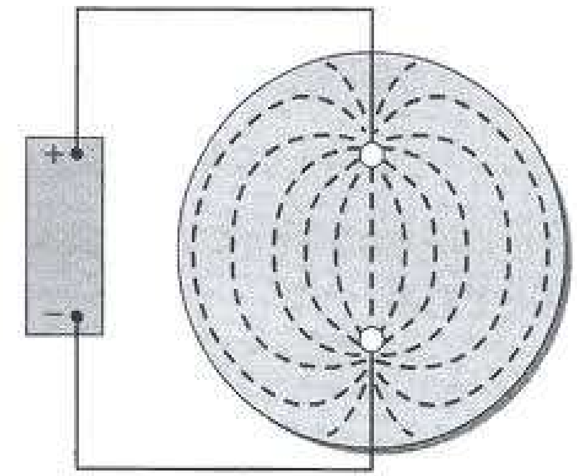
Summary

- Cloud computing may reduce carbon emission by sharing at higher utilization (direct impacts).
- Some studies provide estimates but lack details.
- The indirect impacts (does cloud encourage more use and thus more energy consumption?) are difficult to quantify.

Reducing Computing Energy

How to Reduce Energy?

Energy for Computing



- mechanical
  - fans
  - air conditioners
  - hard disks
- electronic / optical
  - electric energy = charge $\times$ voltage difference

    $E = C \times V$, $1\ J = 1C \times 1V$
  - model a CMOS transistor as a capacitor

    $Q = CV \Rightarrow E = CV^2$
  - power is energy consumption divided by time

    $P = dE/dt = CV^2f$, f is the clock speed

How to Save Energy

$Q = CV \Rightarrow E = CV^2$
$P = dE/dt = CV^2f$

- reduce waste: standby or sleep mode
- new technologies: lower V, smaller C
- reduce power: reduce f
- use less energy for the same operation: shrink transistors (Moore’s Law). However, as transistors are smaller, more transistors are put into the same chip using a higher clock rate $\Rightarrow$ more power, even though more work is done

Voltage and Frequency Scaling

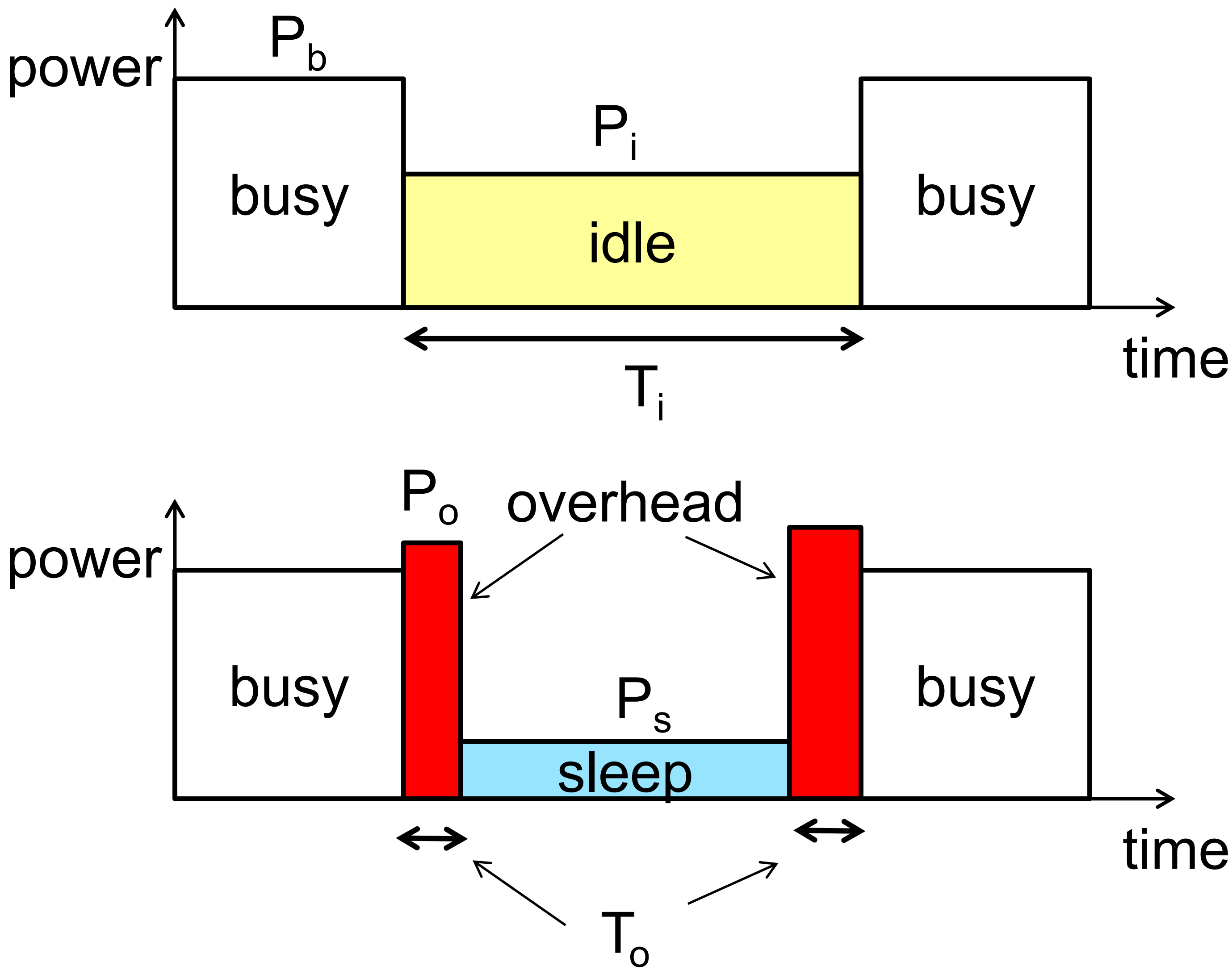
- slow down, $P = CV^2f\alpha$, not all capacitors switch every cycle, α is the switching factor
- lower frequency $\Rightarrow$ lower power, but execution takes longer
- reduce voltage, $V \propto f$ (first-order approximation), lower voltage at lower frequency
- $f_1 = 0.5f_2$, $V_1 = 0.5V_2 \Rightarrow P_1 = 0.125P_2$, $t_1 = 2\ t_2$, $E_1 = 0.25\ E_2$
- Slowing the clock rate to half $\Rightarrow$ the power is reduced to one eighth (1/8) $\Rightarrow$ execution time doubles $\Rightarrow$ energy reduced to one fourth (1/4).
- This is an approximation because leakage is not considered.

Low-Power Mode

- It is rare that a component needs to run at the peak performance continuously.
- If the component does not need the peak performance, it can enter a low-power (standby or sleep) mode.
- time and energy overhead for entering and exiting (“wake up”) the low-power mode

  $\Rightarrow$ should not enter the sleep mode too often
- Timeout is the most widely used approach, based on the assumption: “If it is idle for a while, it is likely to remain idle.”

Decision to Sleep



Break-Even Time

- Do not sleep: $\mathrm{Energy} = \mathrm{P_i T_i}$
- Sleep: $\mathrm{Energy} = \mathrm{P_o T_o + P_s(T_i - T_o)}$, assume $\mathrm{T_i > T_o}$
- Break-even if

$$\mathrm{P_i T_i = P_o T_o + P_s(T_i - T_o)}$$

- Assume $\mathrm{P_i > P_s}$ (otherwise, why to sleep?)

$$\mathrm{T_i(P_i - P_s) = P_o T_o - P_s T_o}$$

$$\mathrm{T_i = max(\frac{P_o T_o - P_s T_o}{P_i - P_s}, T_o)}$$ (break-even time)

- If $\mathrm{T_i}$ is longer than the break-even time, sleep.

What are the assumptions?

Predict T_i

- When a request arrives, the request must be served as soon as possible. Future requests are unpredictable.
- Many researchers (NTHU, Stanford, USC, UCLA...) in late 1990s tried to predict T_i and decide whether a component should sleep.
- Predicting T_i is hard. (Predicting future is hard in general.)
- Can you schedule requests so that you know when they arrive?

Optimal Decisions and Timeout

- If you can predict future, the component should sleep if $T_i > \frac{P_o T_o - P_s T_o}{P_i - P_s}$.
- How much can you approach the optimal decision if you do not know the future?
- Timeout: if a component is idle for a while, it is likely to remain idle $\Rightarrow$ wait for τ, if the component is still idle, sleep.
- The component wastes energy during τ. If actual idle time is long, timeout is good.
- How to decide τ?

τ = break-even time

- Use the perfect prediction for comparison.
- Set τ to the break-even time. How much energy will this timeout method consume?
- What is the best case for the timeout method?
  - When there is no idle time. Both consume power P_b.
  - When the idle time is long. Both consume power P_s.
- What is the worst case for the timeout method? When $T_i = \frac{P_o T_o - P_s T_o}{P_i - P_s} + \delta$.
  - Optimal solution can save a little energy.
  - Timeout solution just puts the component to sleep and

2-Competitive

- Since the idle time is slightly longer than the break-even time, the timeout solution will waste energy $P_o T_o$ without saving any energy.
- By definition, break-even time means the saved energy equals to the energy overhead.
- Since this timeout method saves no energy and also consumes the overhead energy, the timeout method consumes twice amount of energy compared with the perfect solution.
- Thus, the timeout solution is 2-competitive.

n-Competitive

- For a minimization problem $\mathbb{P}$, the optimal solution has cost $\mathbb{C}$.
- An algorithm has cost $k\mathbb{C}$; k is at least one.
- If for any possible $\mathbb{P}$, $k \leq n$, we say this algorithm is n-competitive.

What Are the Implications?

2-Competitive Timeout

- For an unpredictable sequence of requests, you can achieve 2-competitive by using a simple timeout method with τ = break-even time.
- Thus, any solution that is based on timeout has to beat this simple method.
- What can you do?
  - Do not use timeout
  - Change the assumptions

Can You Do Better?

- If you can prefetech data or defer write, a new request does not have to be served immediately $\Rightarrow$ You can make the idle time longer.
- Prefetch consumes energy to read and to store data [1]. Fetched data may not be used.
- Deferring write may degrade reliability.
- Power cycles may also affect reliability.
- Use multiple components (such as a disk array or multiple cores) to share loads.

[1] Nathaniel Pettis, Le Cai, and Yung-Hsiang Lu, "Statistically Optimal Dynamic Power Management for Streaming Data", IEEE Transactions on Computers, 55 (7), July 2006, pages 800-814.

Summary

- Putting a component into sleep state may save energy if the component can sleep long enough.
- The minimum idle time to save energy is called the break-even time of this component.
- A simple timeout is 2-competitive. If you want to do better, you need to change the assumptions.

Don't Sleep. Slow Down.

Reduce Power Consumption

- Dynamic power of CMOS circuit: $P = CV^2f\alpha$
- How to reduce power?
  - reduce C: using smaller transistors
  - reduce V: using lower voltage (however, leakage current will increase).
  - reduce f: lower clock rate degrades performance
  - reduce α: clock gating and power gating
- Reducing power and reducing energy are not always consistent.
- Best way to reduce power or energy $\Rightarrow$ turn off everything (probably not desirable).

Scaling for Real-Time Tasks

- Real-time task: a task must complete before a deadline. Missing the deadline can have undesirable (or disastrous) consequences.
- Finishing before the deadline is not better.
- If a task should complete before time t, should a multi-speed processor
  - compute as soon as possible and then sleep?
  - use two or more speeds and voltages?
  - use one speed and finish the task just in time?

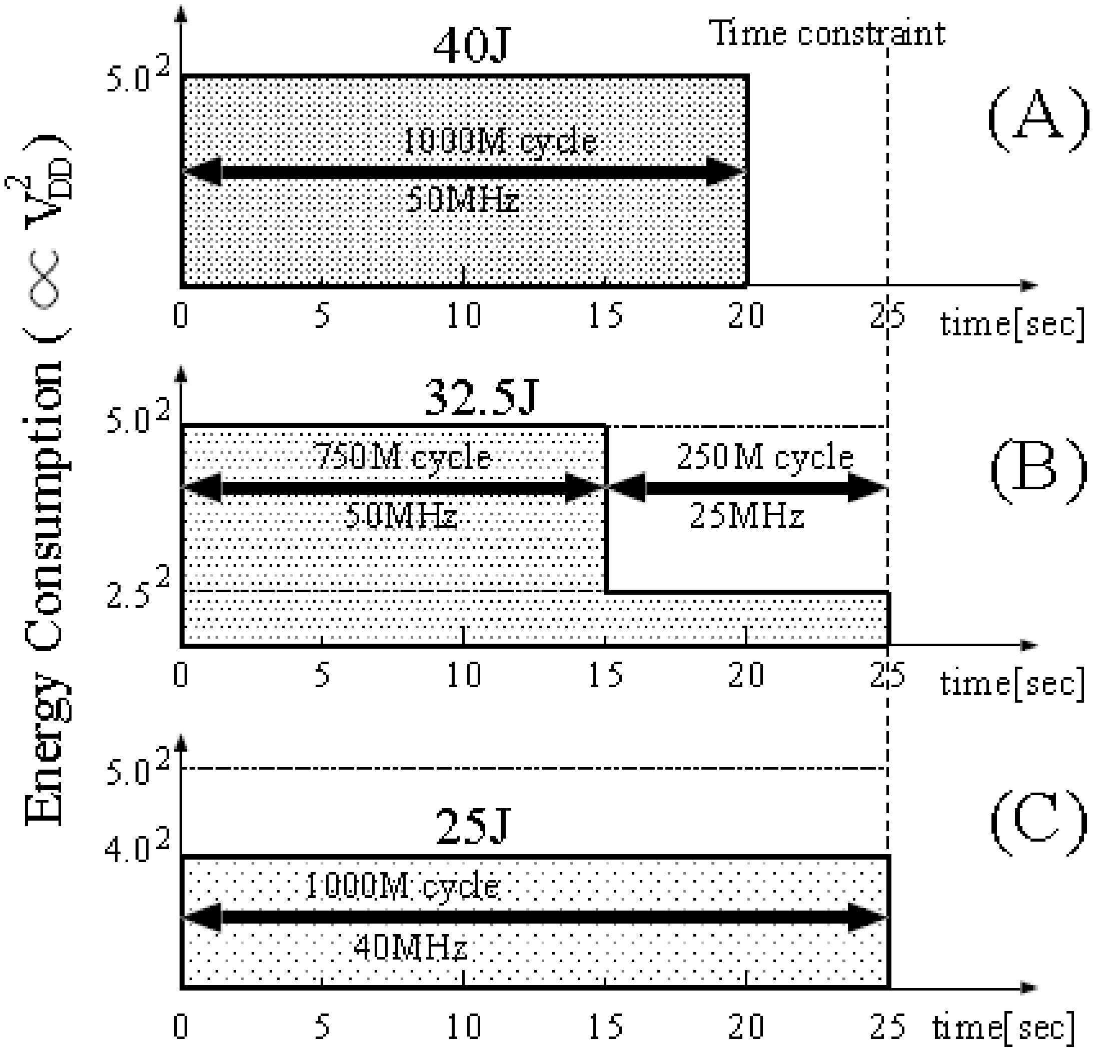


Figure 1: An example of power-delay optimization

Using one speed, the slowest, is the most energy-efficient.

Ishihara and Yasuura, "Voltage Scheduling Problem for Dynamically Variable Voltage Processor", International Symposium on Low Power Electronics and Design 1998.

Voltage and Frequency Scaling

- Many papers have been published on finding the optimal (or heuristic) solutions for real-time systems.
  - hard deadlines
  - soft deadlines
  - on-time deadlines
  - multiple processors
  - multiple tasks
  - periodic tasks
  - sporadic tasks
  - ...

Why Are Processors Multicores?

1 core at f vs. 2 core at 0.5f

- one core $P_1 = CV^2 f\alpha$
- two cores $P_2 = 2\ C(V\ /2)^2 f/2\alpha = P_1/4$
- same performance (if you can fully parallelize the tasks)
- $E_2 = E_1/4$

- Therefore, multiple cores may achieve the same performance at lower energy consumption.

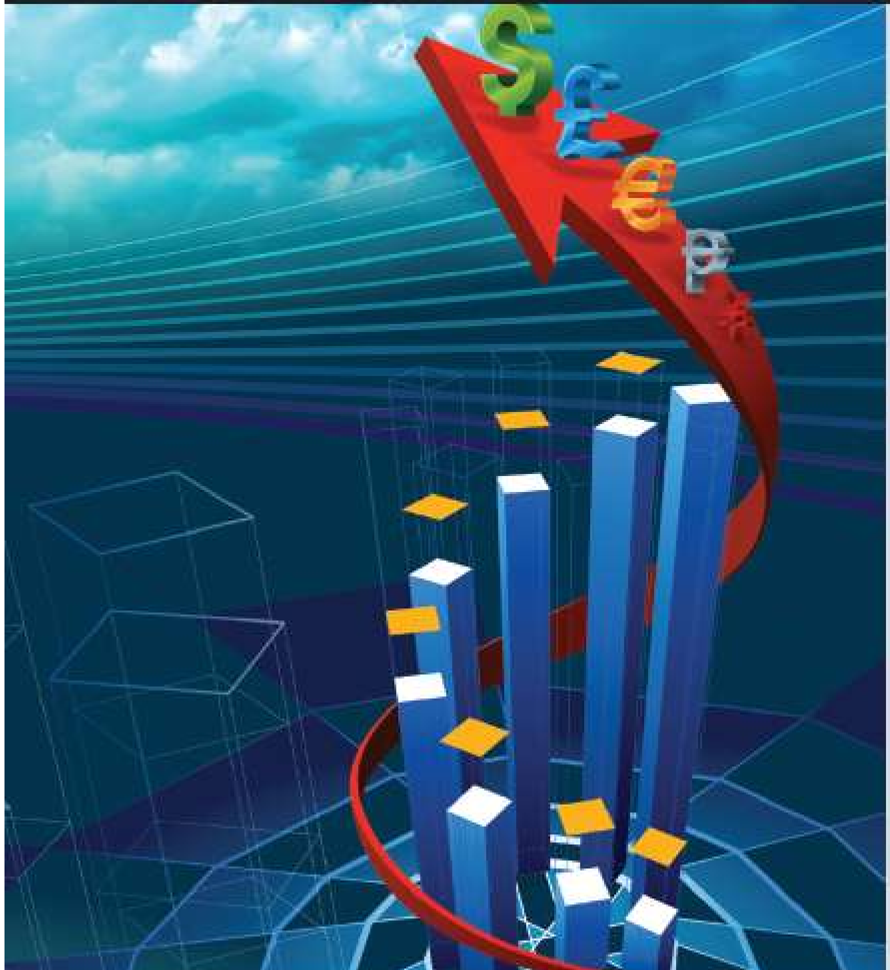
Can You Do Better?

Asynchronous Systems

Ivan Sutherland (Turing Award 1998)

Why do you make everyone run at the same speed?

COVER FEATURE



CLOUD COMPUTING FOR MOBILE USERS: CAN OFFLOADING COMPUTATION SAVE ENERGY?

Karthik Kumar and Yung-Hsiang Lu, *Purdue University*

IEEE Computer April 2010

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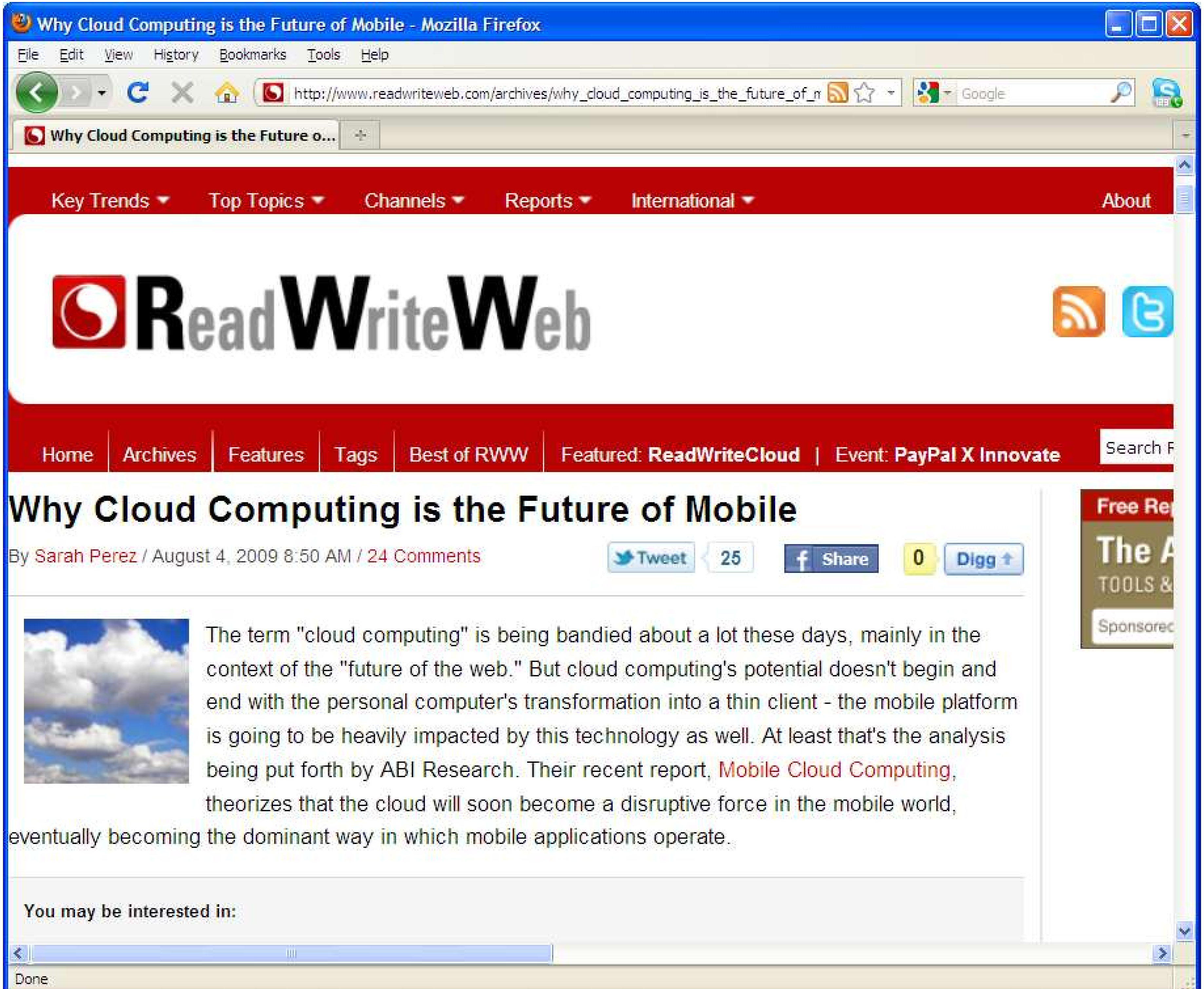
Wanted: Long-Lived Smartphone Batteries

By Jack Loo, computerworld.com.sg- Aug 23, 2008 4:10 pm

While smartphones are armed with an array of features like Wi-Fi, touch screens and integrated GPS, their battery life needs to be improved for users to get the most out of their devices, says research firm Canalys.

Recent consumer research conducted by Canalys, in several European countries, reinforces the importance of balancing features against power consumption. In a survey of more than 4,000 mobile phone users in March, battery life came out as the aspect of their phone with which they were least satisfied.

Another survey of 3,000 consumers in June showed that having better battery life than current mobile phones and notebooks would make two-thirds of respondents "more", or "much more", likely to purchase



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Why Cloud Computing is the Future of Mobile

By Sarah Perez / August 4, 2009 8:50 AM / 24 Comments

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The term "cloud computing" is being bandied about a lot these days, mainly in the context of the "future of the web." But cloud computing's potential doesn't begin and end with the personal computer's transformation into a thin client - the mobile platform is going to be heavily impacted by this technology as well. At least that's the analysis being put forth by ABI Research. Their recent report, Mobile Cloud Computing, theorizes that the cloud will soon become a disruptive force in the mobile world, eventually becoming the dominant way in which mobile applications operate.

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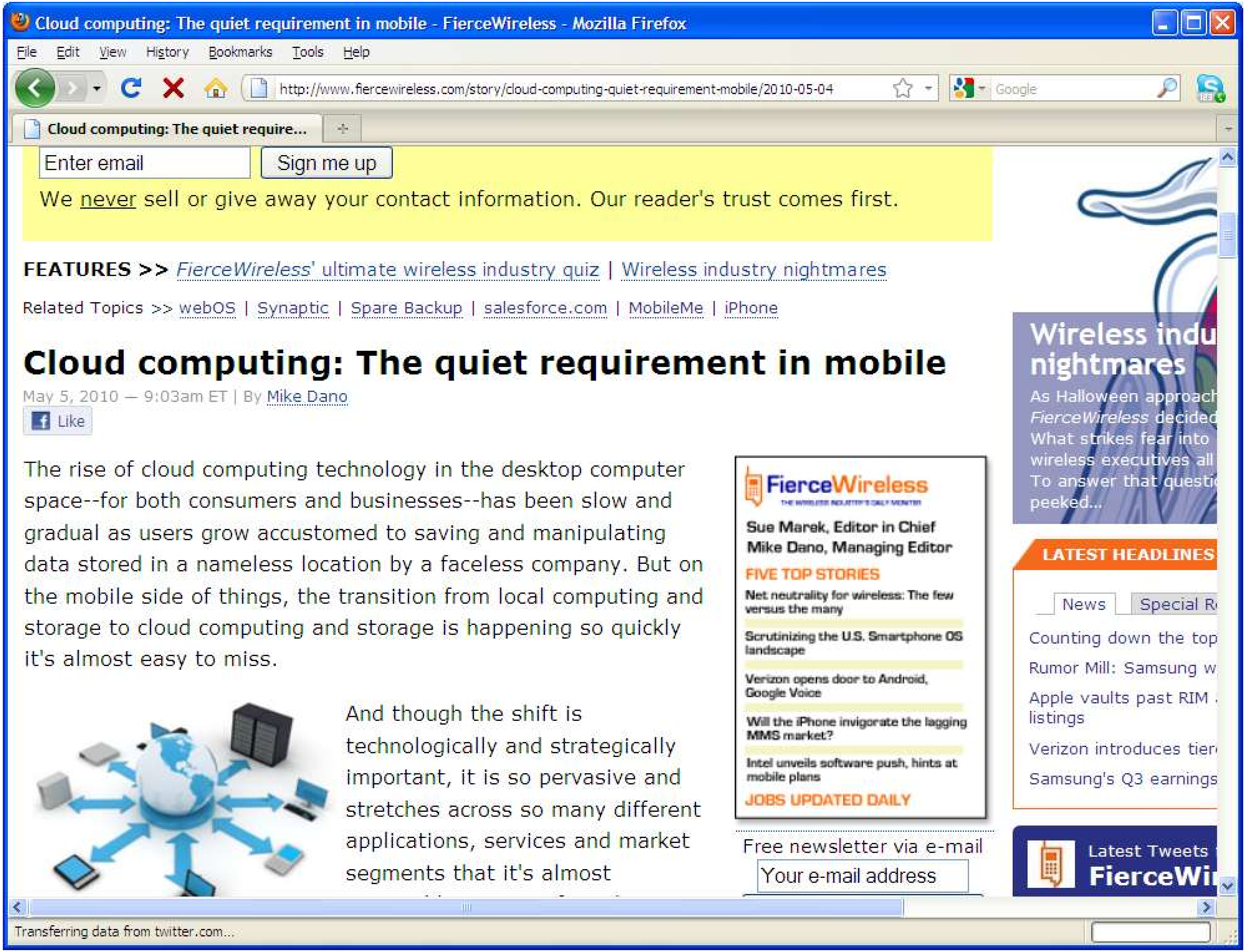

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Cloud computing: The quiet requirement in mobile

May 5, 2010 — 9:03am ET | By Mike Dano

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The rise of cloud computing technology in the desktop computer space--for both consumers and businesses--has been slow and gradual as users grow accustomed to saving and manipulating data stored in a nameless location by a faceless company. But on the mobile side of things, the transition from local computing and storage to cloud computing and storage is happening so quickly it's almost easy to miss.

And though the shift is technologically and strategically important, it is so pervasive and stretches across so many different applications, services and market segments that it's almost

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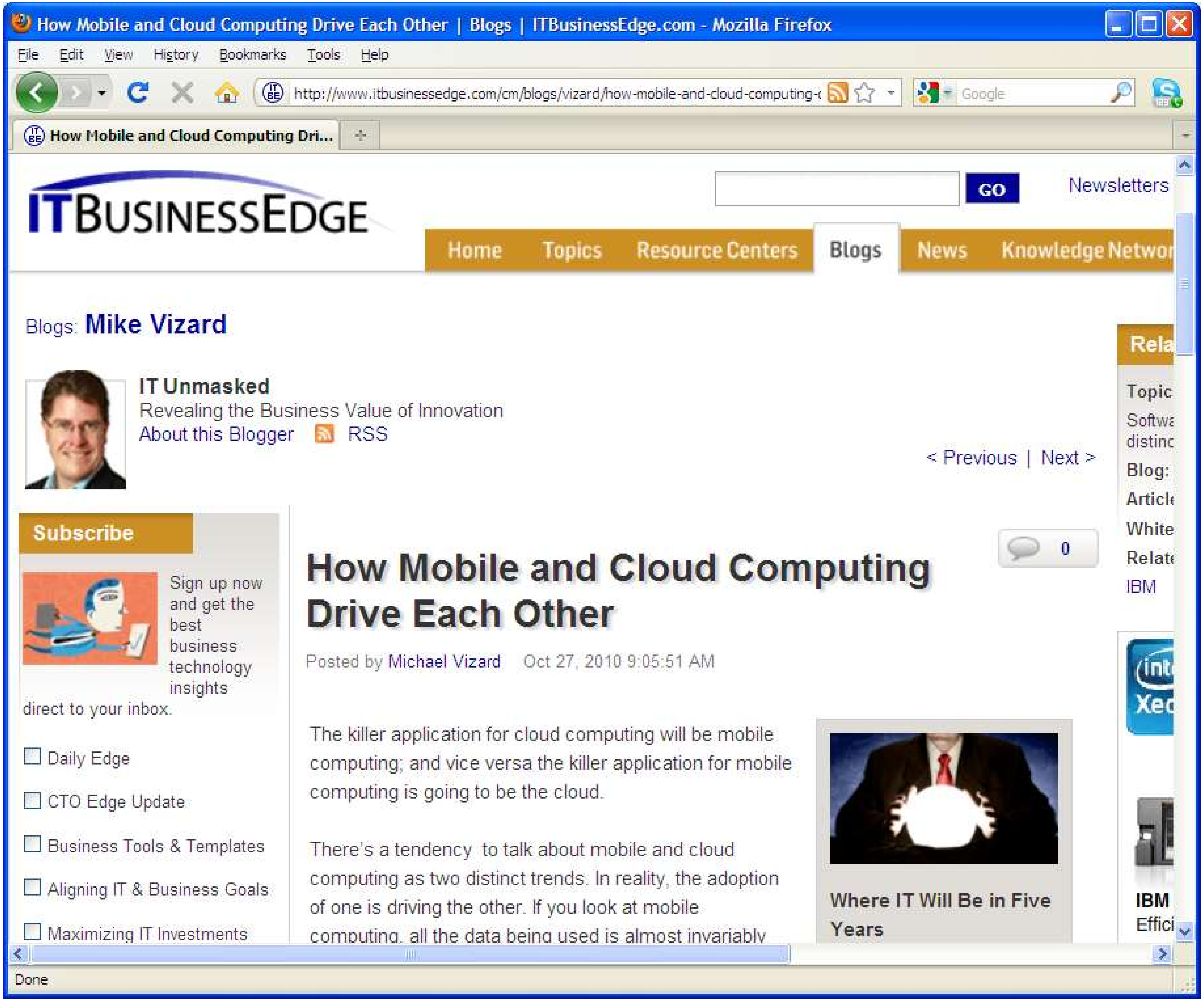

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How Mobile and Cloud Computing Drive Each Other

Posted by Michael Vizard Oct 27, 2010 9:05:51 AM

The killer application for cloud computing will be mobile computing; and vice versa the killer application for mobile computing is going to be the cloud.

There's a tendency to talk about mobile and cloud computing as two distinct trends. In reality, the adoption of one is driving the other. If you look at mobile computing, all the data being used is almost invariably

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For Google, the Cloud Is Its Mobile Future
By Om Malik | Aug. 12, 2010, 11:15am PDT | 8 Comments
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If there was any doubt that mobile and the cloud will eventually converge, Google is putting it to rest. At an event in San Francisco today, the company showed off two applications that leverage Google's back-end infrastructure and its Android OS to bring a powerful new mobile user experience. The two apps are Voice Actions and Chrome2Phone.
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Google Nexus 7 Tablet Review: Solid, but Not Revolutionary

Google Nexus 7 Review, by Melissa J. Perenson July 3, 2012

The Google Nexus 7 tablet resets expectations of what an inexpensive tablet can and should be. Starting at $199, the Nexus 7 clearly guns for Amazon's same-

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Pros

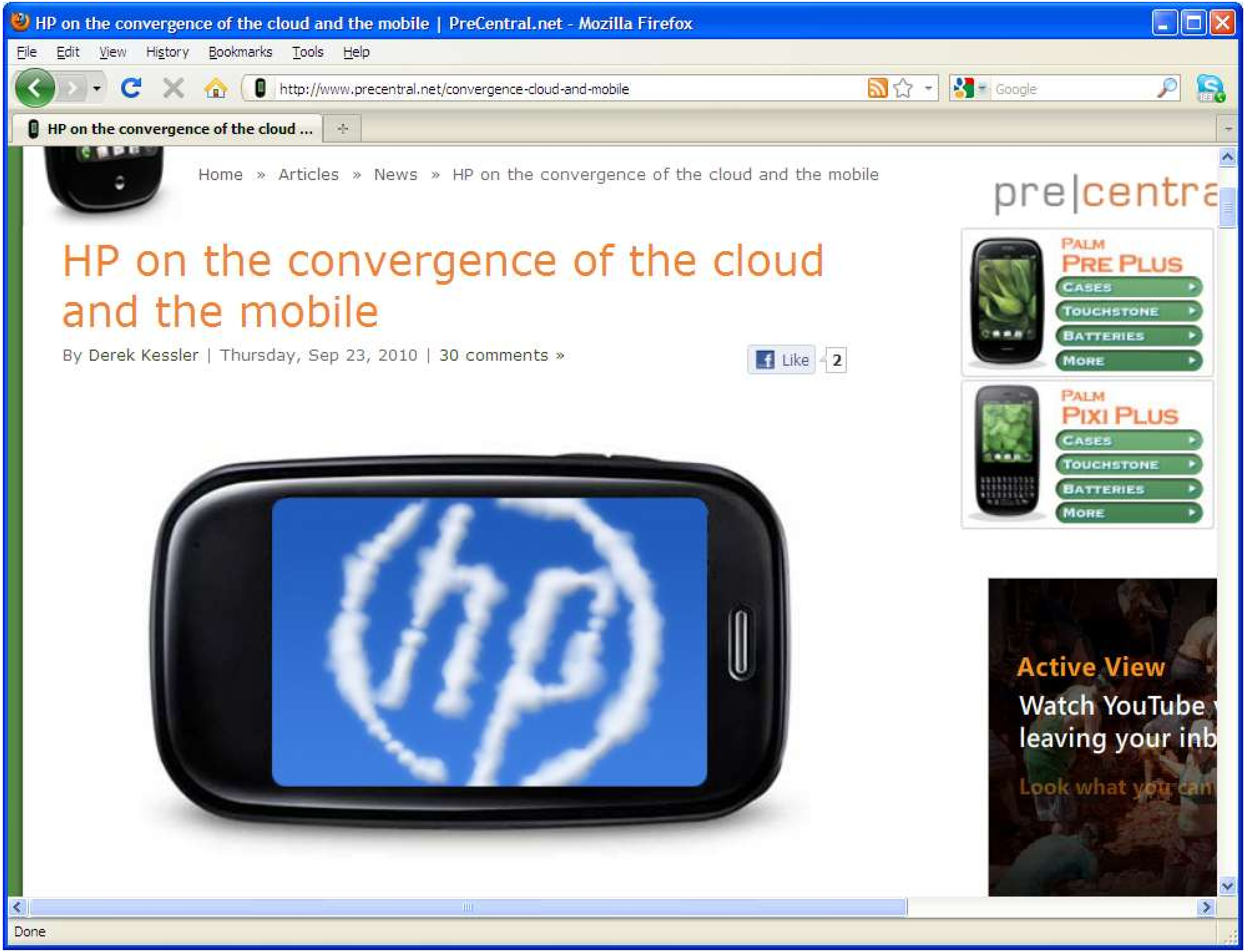
- Solid design
- Optically bonded display minimizes glare

Cons

- Lacks a MicroSD card slot
- 8GB model has just 5.62GB of user-accessible space

Bottom Line

The best 7-inch Android tablet you can buy today, the Nexus 7 delivers solid performance and usability at a value price; but it also has at-times funky text rendering and its lack of a MicroSD card slot makes the 16GB model the better option.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AWS Supports Mobile Cloud Computing

May 11, 2011

By Matthew Dublin

Amazon Web Services has expanded support for the AWS software development kits for mobile device operating systems Android and Apple's iOS for and the iPhone and iPad. Developers can now create applications that will enable users to access Amazon EC2, Amazon CloudWatch, Amazon Simple Email Service, Elastic Load Balancing, and Auto Scaling, all from their mobile devices.

AWS already supports mobile device software development for Amazon S3, Amazon SimpleDB, Amazon Simple Queue Service, and Amazon SNS

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2. **GenomeWeb Daily News**
Nanosphere Nets $32M in St

3. **ProteoMonitor**
Cellzome Teaming with Pfizer the Epigenetics of Stem Cell

4. **In Sequence**
Early Users Weigh in on Pac on Strobe Sequencing, Hybri with Illumina

5. **GenomeWeb Daily News**
People In The News

Why Mobile + Cloud?

Mobile	**Cloud**
+ convenience	– immobile
+ interaction with users	– no user interface
+ sensors	– no physical interface
– speed	+ speed
– storage	+ storage
– battery energy	+ grid powered
– low data rate (at best Mbps)	+ high data rate (Gbps)
– lose system and data	+ backed up

Mobile systems will never match servers' capabilities.

Offloading to Save Energy

Energy savings on a mobile system:

$$\underbrace{P_c \frac{C}{M}}_{\text{energy computing on mobile system}} - \underbrace{\left(P_i \frac{C}{S} + P_n \frac{D}{B}\right)}_{\text{mobile's energy when computing on server}}$$

P_c	power to compute	C	processor cycles
M	mobile's speed	P_i	power for waiting
S	server's speed	P_n	power for network
D	data to exchange	B	network data rate

Energy Savings

Assume

- $P_c = P_i = P_n$ (simplification, they are very close)
- $S = x\,M$ (i.e. server is x times faster, $x > 1$).

$$P_c \times \frac{C}{M} - P_i \times \frac{C}{S} - P_n \times \frac{D}{B}$$

$$\Rightarrow P\left(\frac{C}{M}\left(1 - \frac{1}{x}\right) - \frac{D}{B}\right)$$

Suppose *P*, *C*, and *M* are given. How to save energy?

- increase x or *B* (or both)
- reduce *D*

$$P\left(\frac{C}{M}\left(1-\frac{1}{x}\right)-\frac{D}{B}\right)$$

To save energy

- Increasing x (i.e., server speed) has limited effects.
- Reduce D
  - It may be really small (only some "pointers") already because most data are already stored in the cloud.
  - Require "intelligent synchronization": better understanding of data formats (for non-text data) and opportunistic (when B is high or energy is abundant, such as AC powered)
- B is increasing in newer wireless networks.

Mobile Netw Appl
DOI 10.1007/s11036-012-0368-0

A Survey of Computation Offloading for Mobile Systems

Karthik Kumar · Jibang Liu · Yung-Hsiang Lu · Bharat Bhargava

Mobile Networks and Applications, April 2012

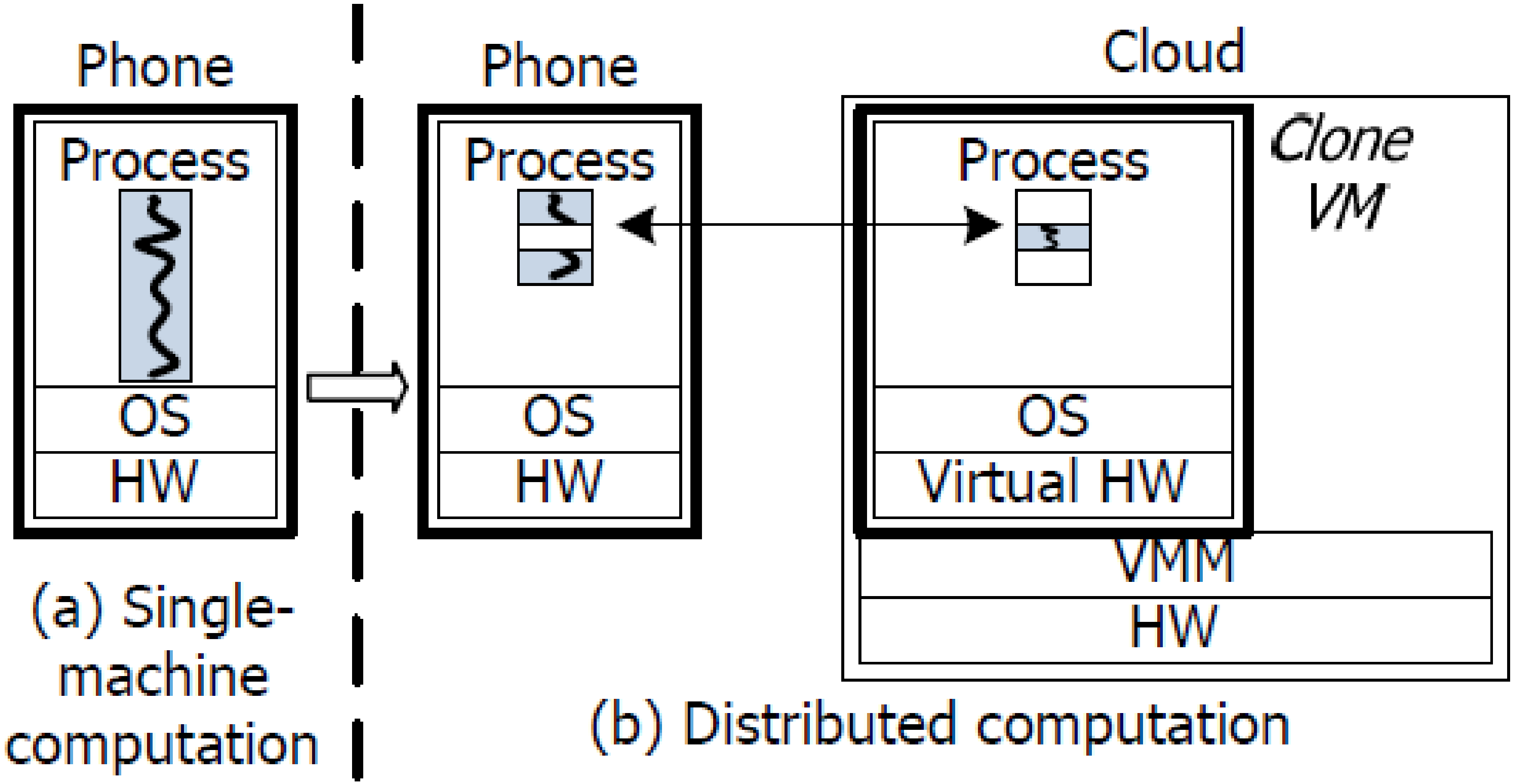


Figure 2: Our system model. Our system transforms a single-machine execution (smartphone computation) into a distributed execution (smartphone and cloud computation) (semi)-automatically.

Byung-Gon Chun, Sunghwan Ihm, Petros Maniatis, Mayur Naik, Ashwin Patti. CloneCloud: Elastic Execution between Mobile Device and Cloud. European Conference on Computer 2011.

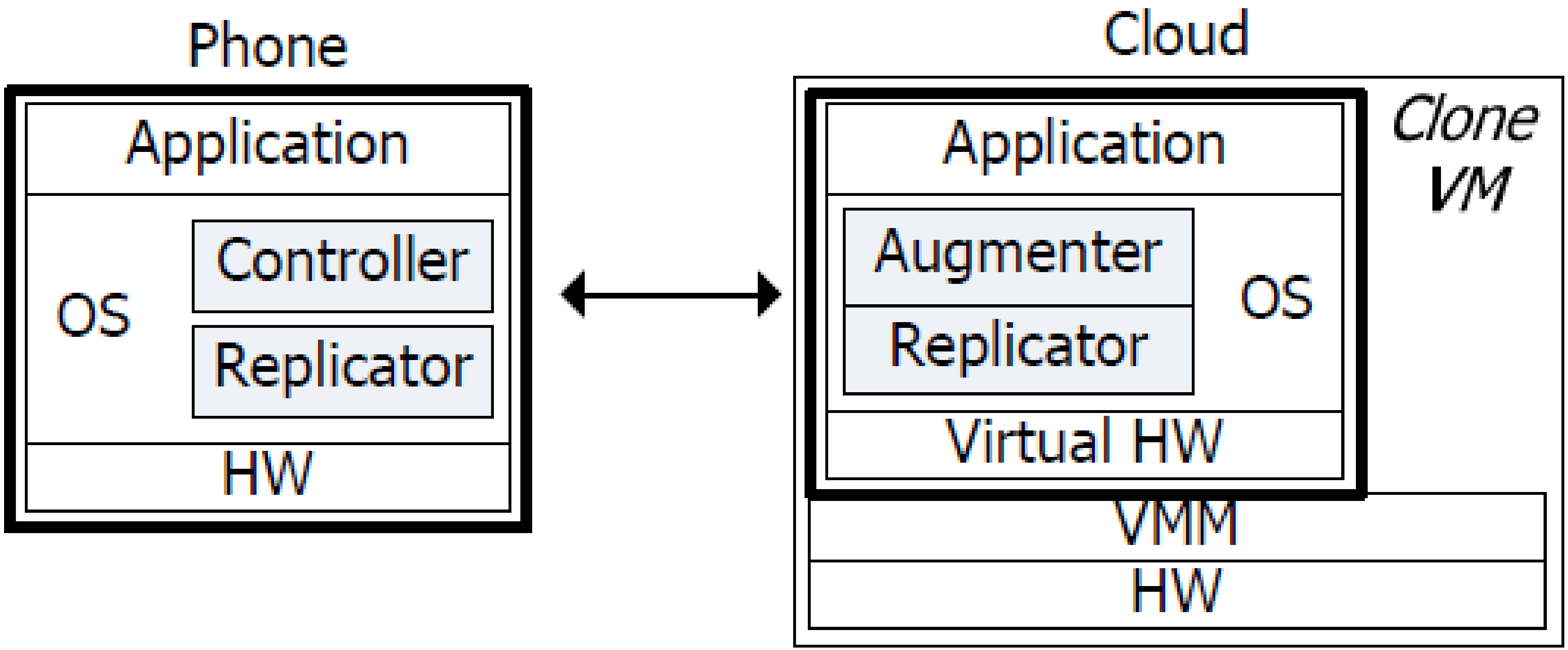
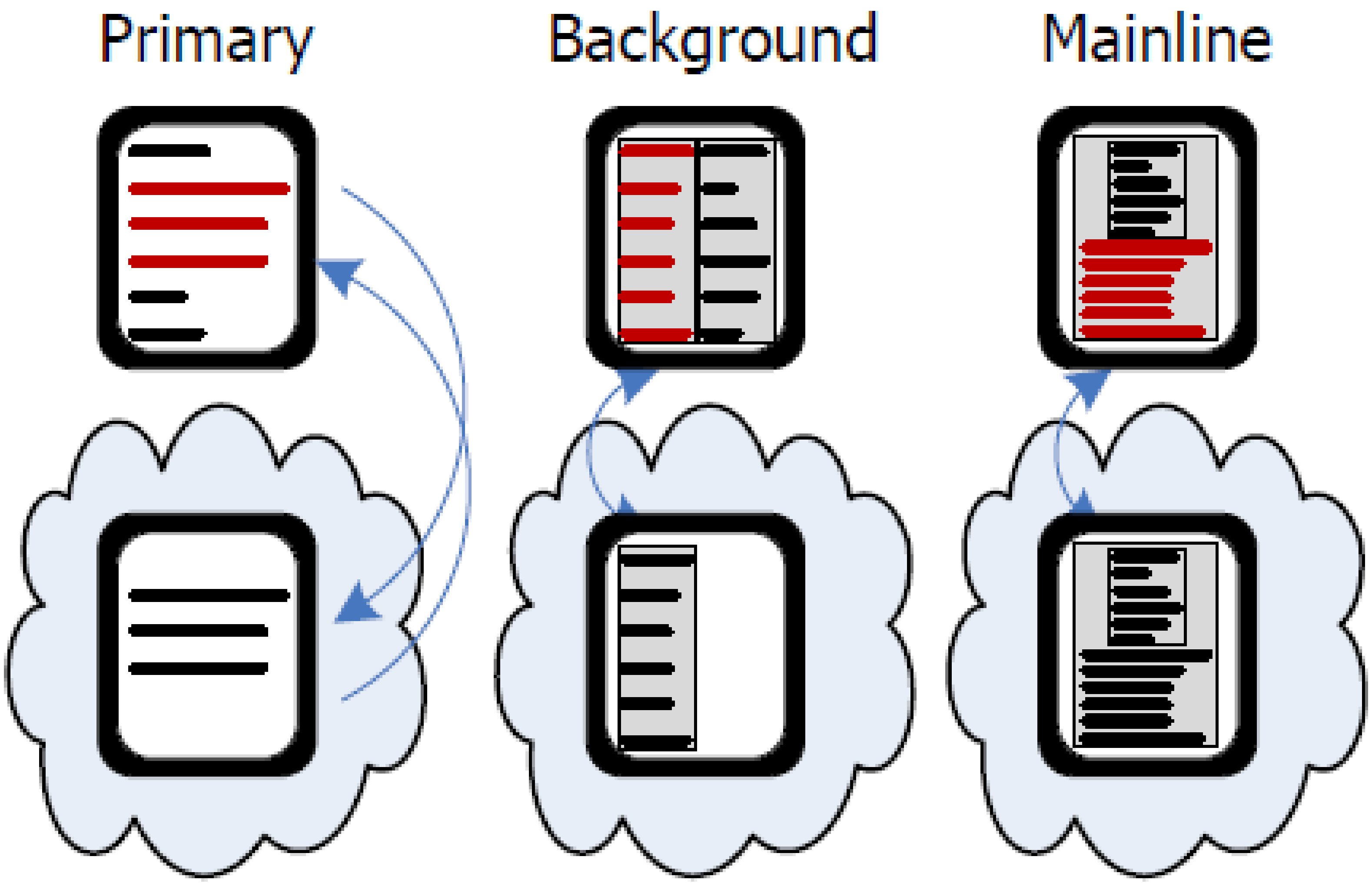


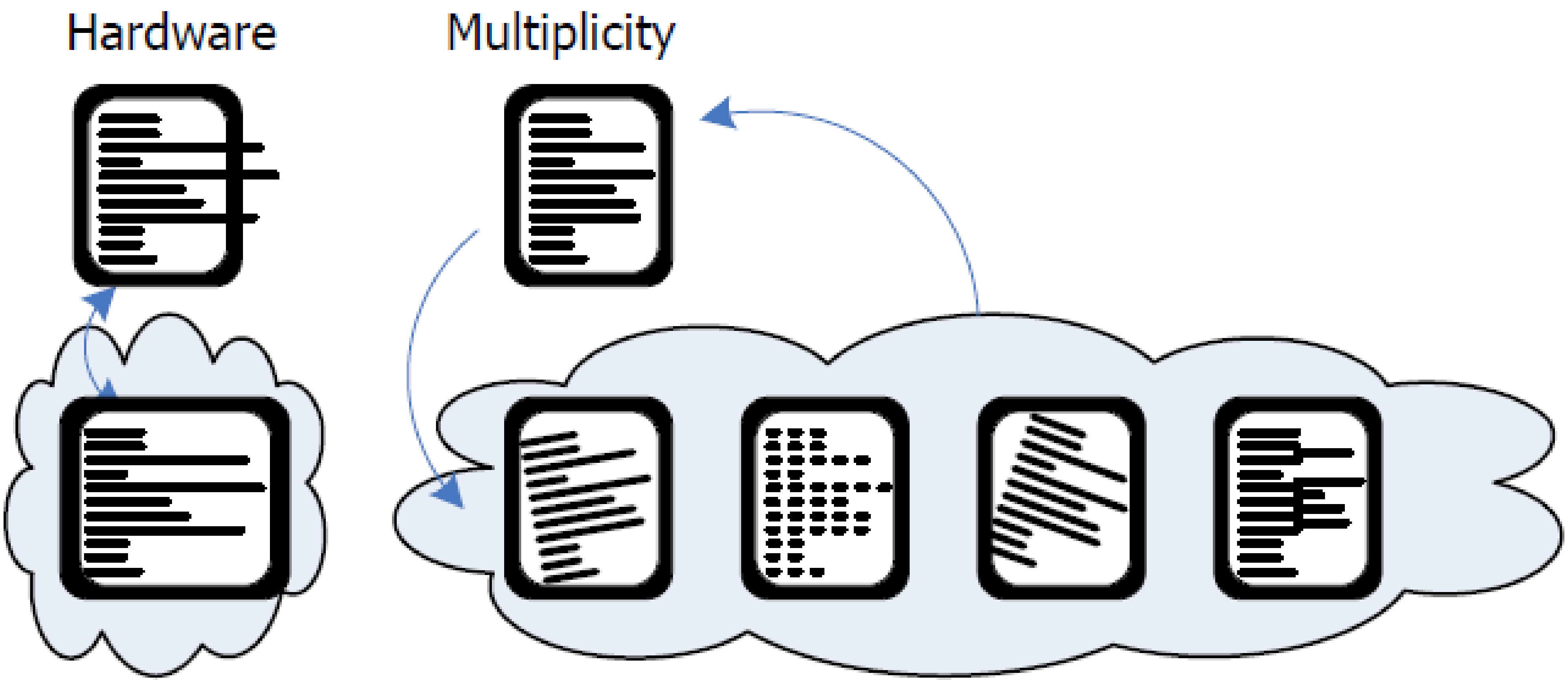
Figure 3: Clone execution architecture for smartphones.

Five Types of Augmentation

- primary: heavy computation (such as recognition) executed at server (similar to client-server model)
- background: no user interaction (such as scanning for virus, analyzing photos)
- mainline: user interaction (such as debugging)
- hardware: limited hardware of the phone (with "capability inflation")
- multiplicity: parallel execution on a server, explore different options

Augmented Execution




Hardware
Multiplicity

Four Steps for Cloning

1. create a clone in the cloud (or personal desktop)
2. synchronize states periodically or on-demand
3. augmented applications executing in the clone
   - whole system replication or incremental checkpointing
   - automatic or semiautomatic partition
4. integrate results from the clone

Design Decisions

- What should be considered for augmentation? automatic selection or manual annotation?
- When to synchronize? keeping the states consistent without consuming too much energy. depending on the types of augmented applications
  - background: once a few hours
  - primary and mainline: more frequently
  - dependent on the available wireless network

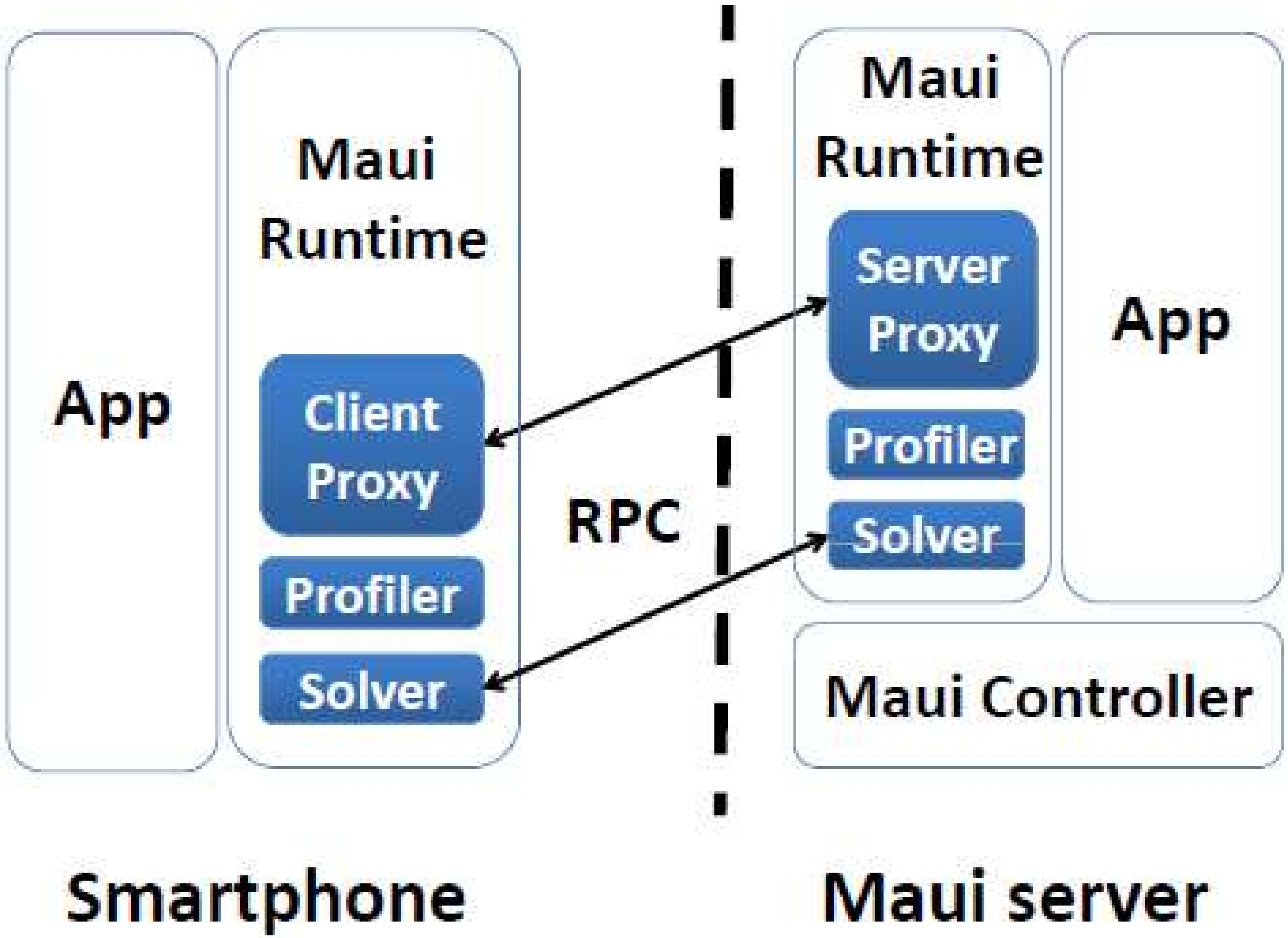


Figure 3: High-level view of MAUI's architecture.

Eduardo Cuervo, Aruna Balasubramanian, Dae-ki Cho, Alec Wolman, Stefan Saroiu, Ranveer Chandra, and Paramvir Bahl, MAUI: Making Smartphones Last Longer with Code Offload, in ACM MobiSys 2010

MAUI

- programming environment for smartphones
- developers annotate the methods that can be offloaded. offload unit: method
- If a server is available, at run-time decide whether to offload. If disconnected, execute on the phone.
- Monitor network (bandwidth and latency).
- Profilers collect information to determine whether the next invocation should be offloaded.
- MAUI determines the amount of data to transfer for offloading and the amount of computation.

Determine Offloadable Code

- Programmers mark what is *remoteable*
- Unoffloadable:
  - user interface
  - IO
  - reading sensors
  - communication with another computer (i.e. not the phone, nor the offload server), such as a web server
- Server obtains code
  - from the phone directly
  - download from another server based on a signature sent by the phone

```
//original interface
public interface IEnemy {
  [Remoteable] bool SelectEnemy(int x, int y);
  [Remoteable] void ShowHistory();
  void UpdateGUI();
}

//remote service interface
public interface IEnemyService {
  MAUIMessage<AppState, bool> SelectEnemy (AppState state, int x, int y);
  MAUIMessage<AppState, MauiVoid> ShowHistory(AppState state);
}
```

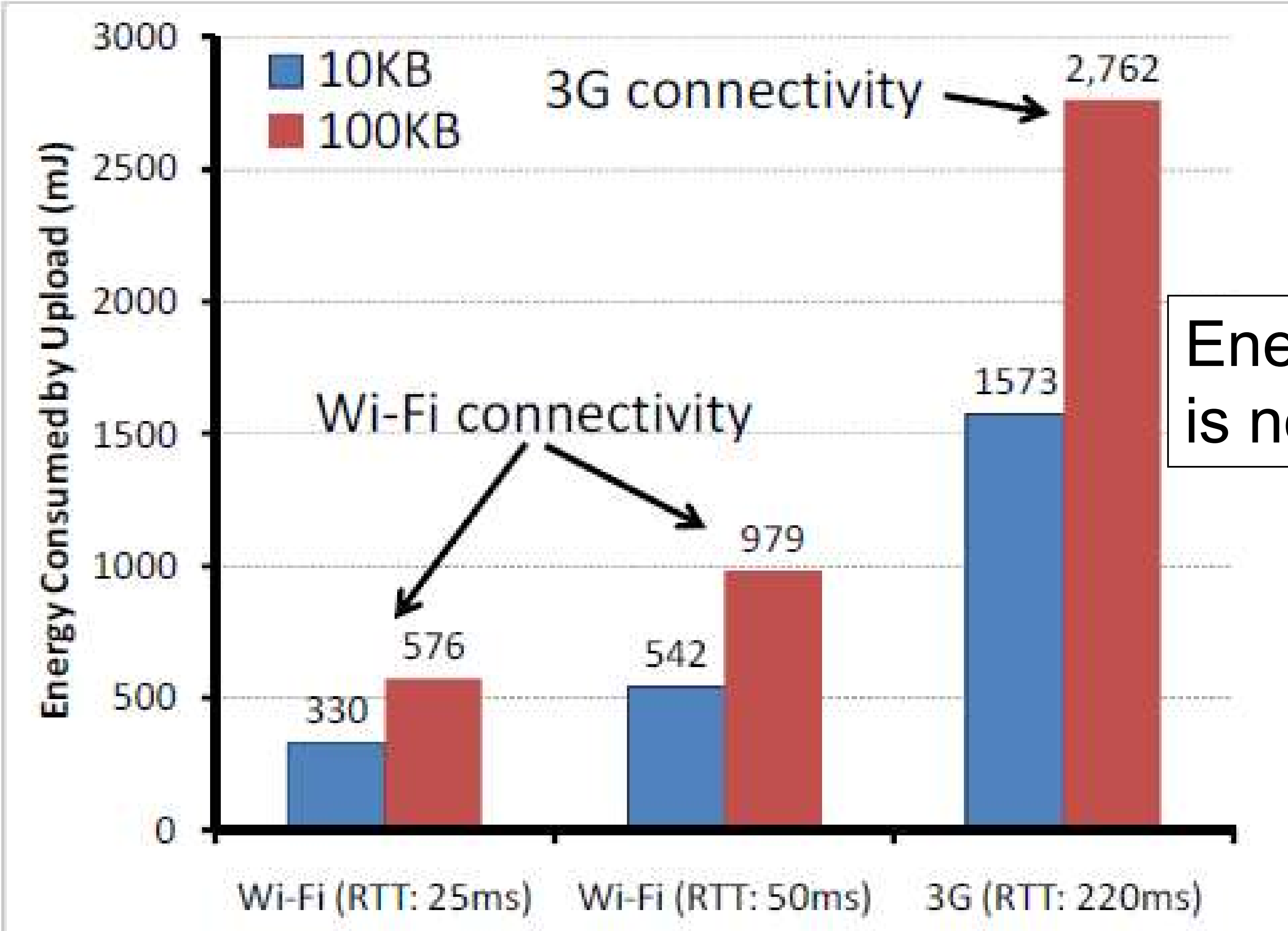
annotations

Additional return values and argument

Figure 4: Local and remote interfaces.

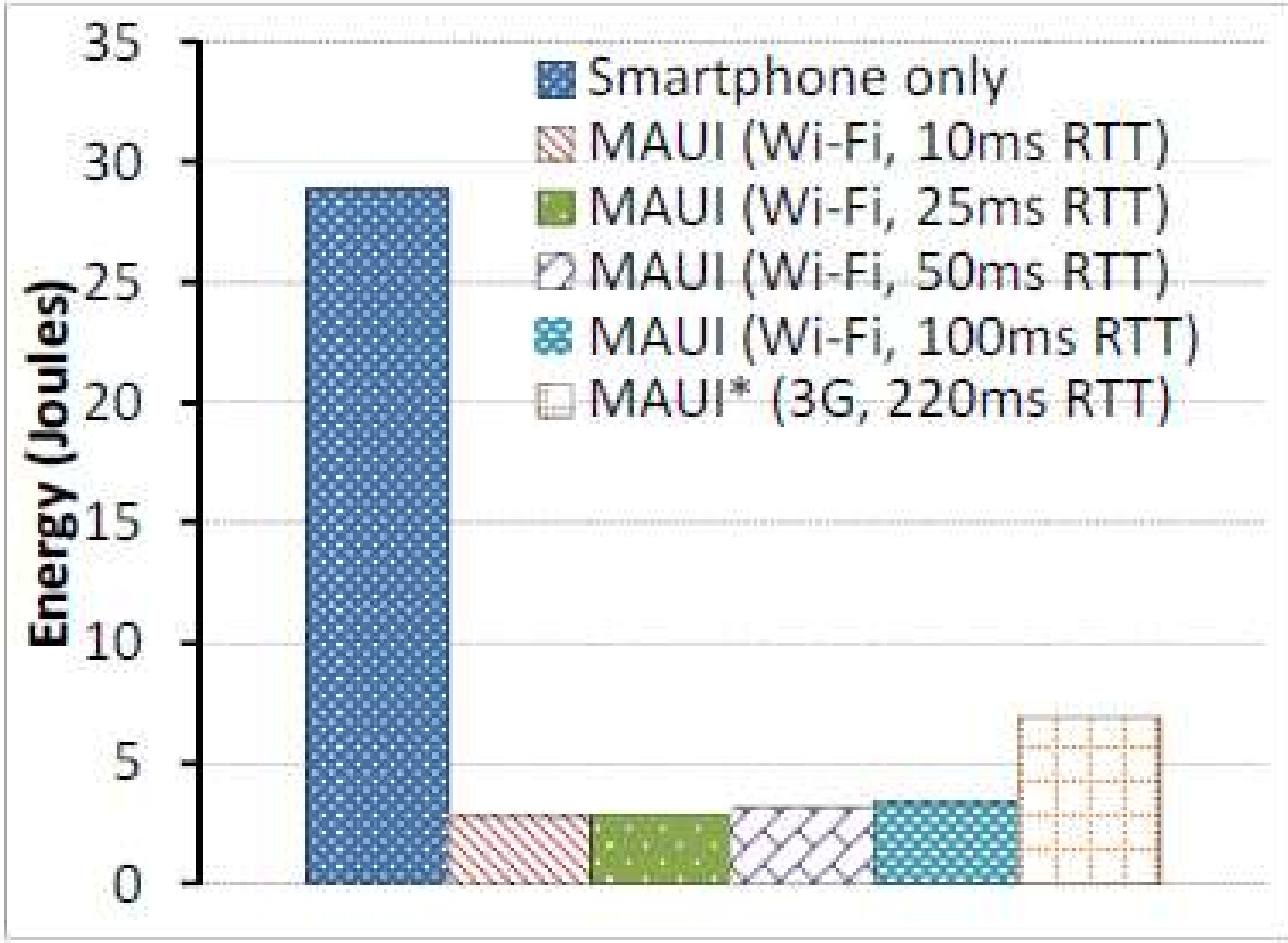
Profiler

- energy profile = hardware measurement + model
- estimate CPU time based on past invocations
- dynamic voltage scaling not a major problem in predicting execution time

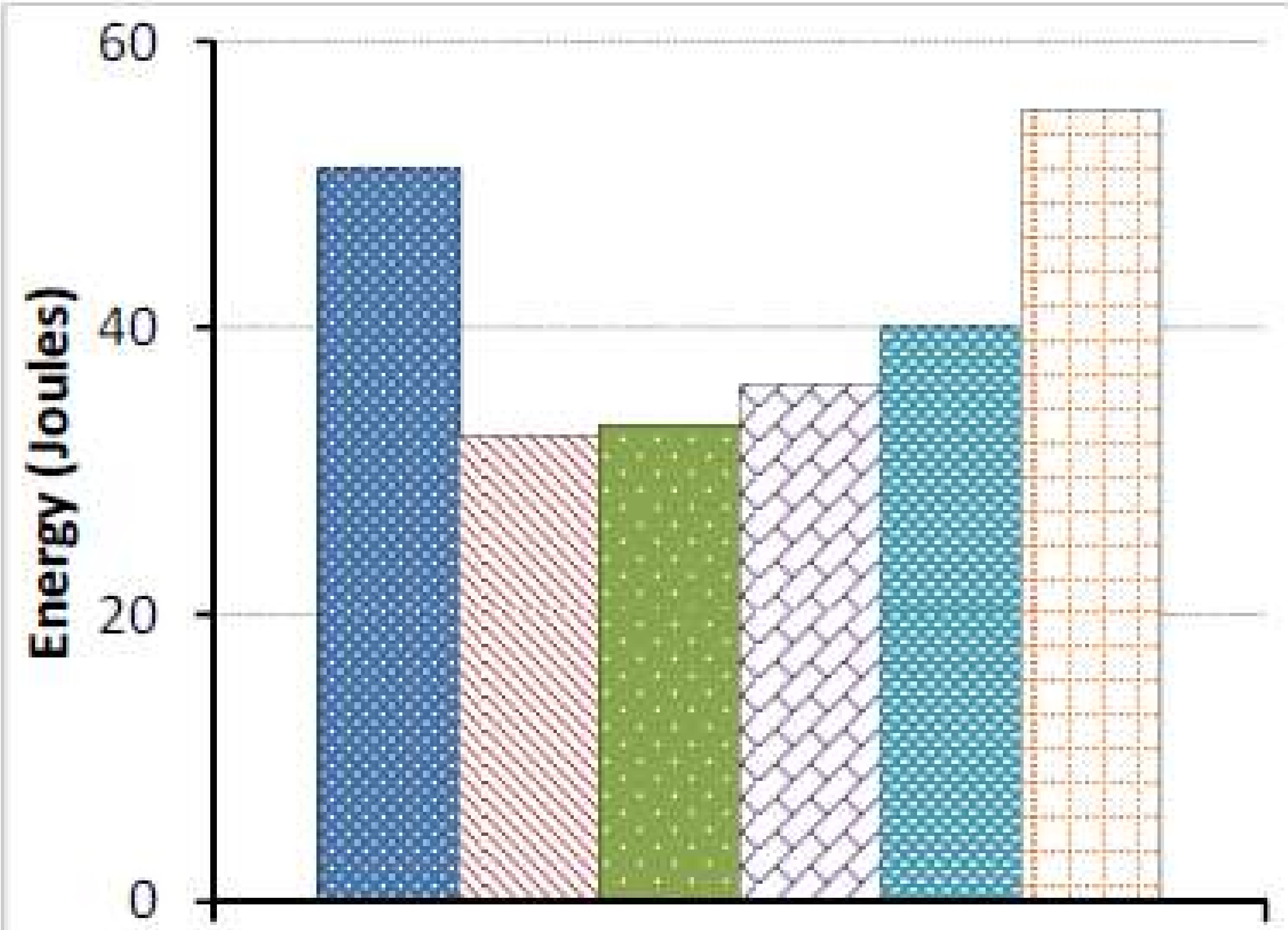


Energy for 100KB is not 10 times

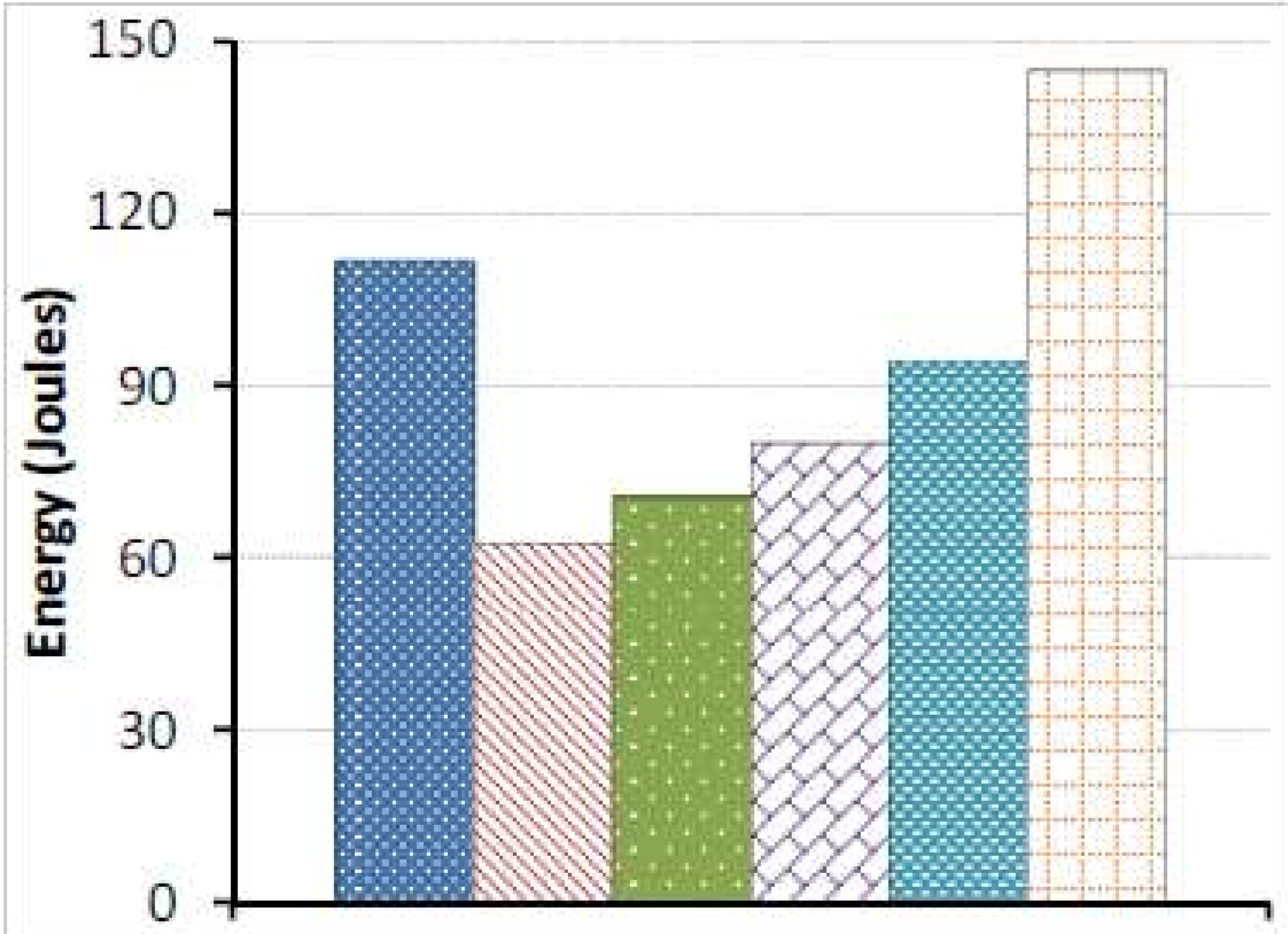
Figure 1: The Energy Consumption of Wi-Fi Connectivity vs. 3G Connectivity *We performed 10 KB and 100 KB uploads from a smartphone to a remote server. We used Wi-Fi with RTTs of 25 ms and 50 ms (corresponding to the first two sets of bars) and 3G with an RTT of 220 ms (corresponding to the last bar).*



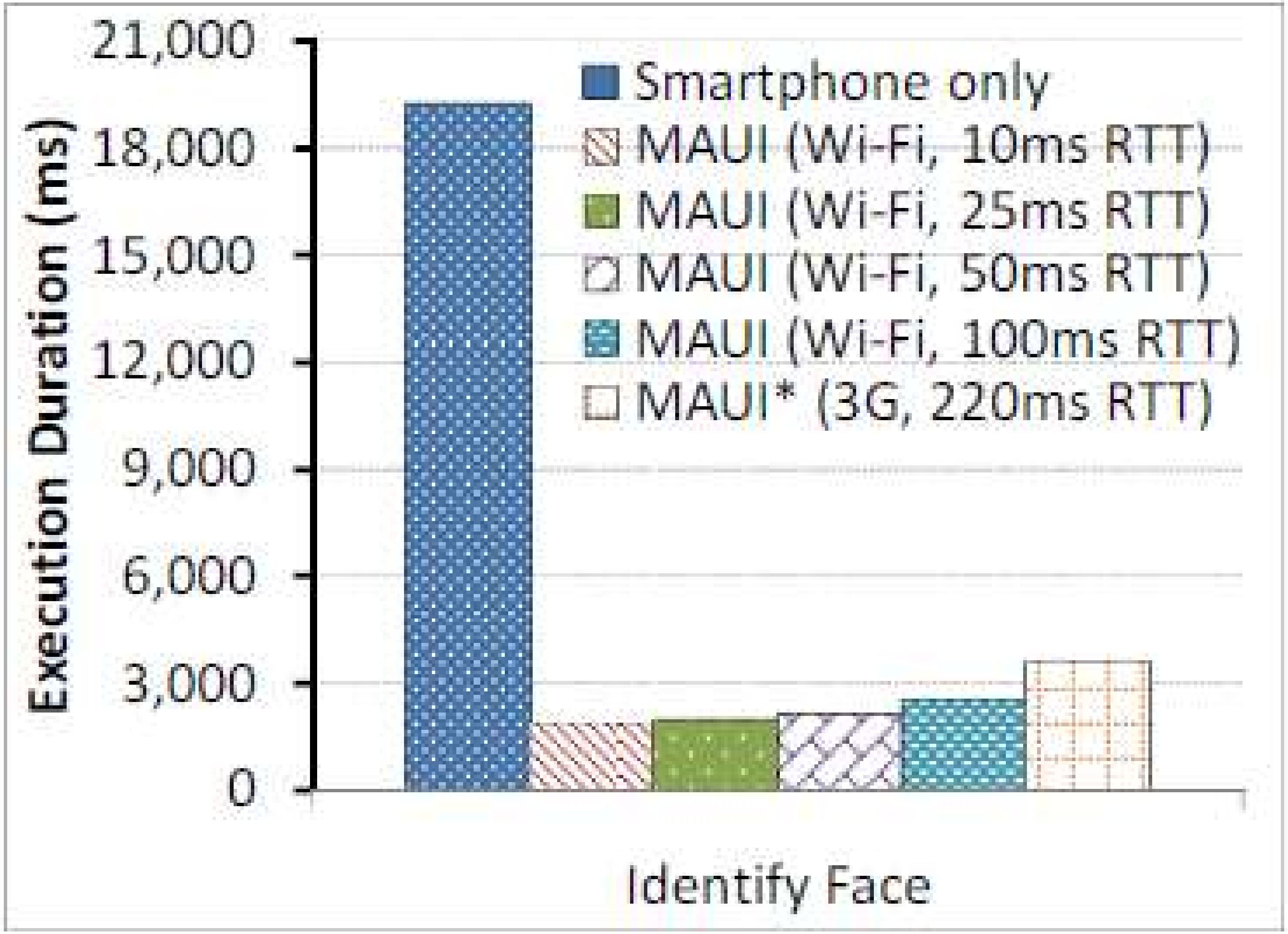
ONE RUN FACE RECOGNITION



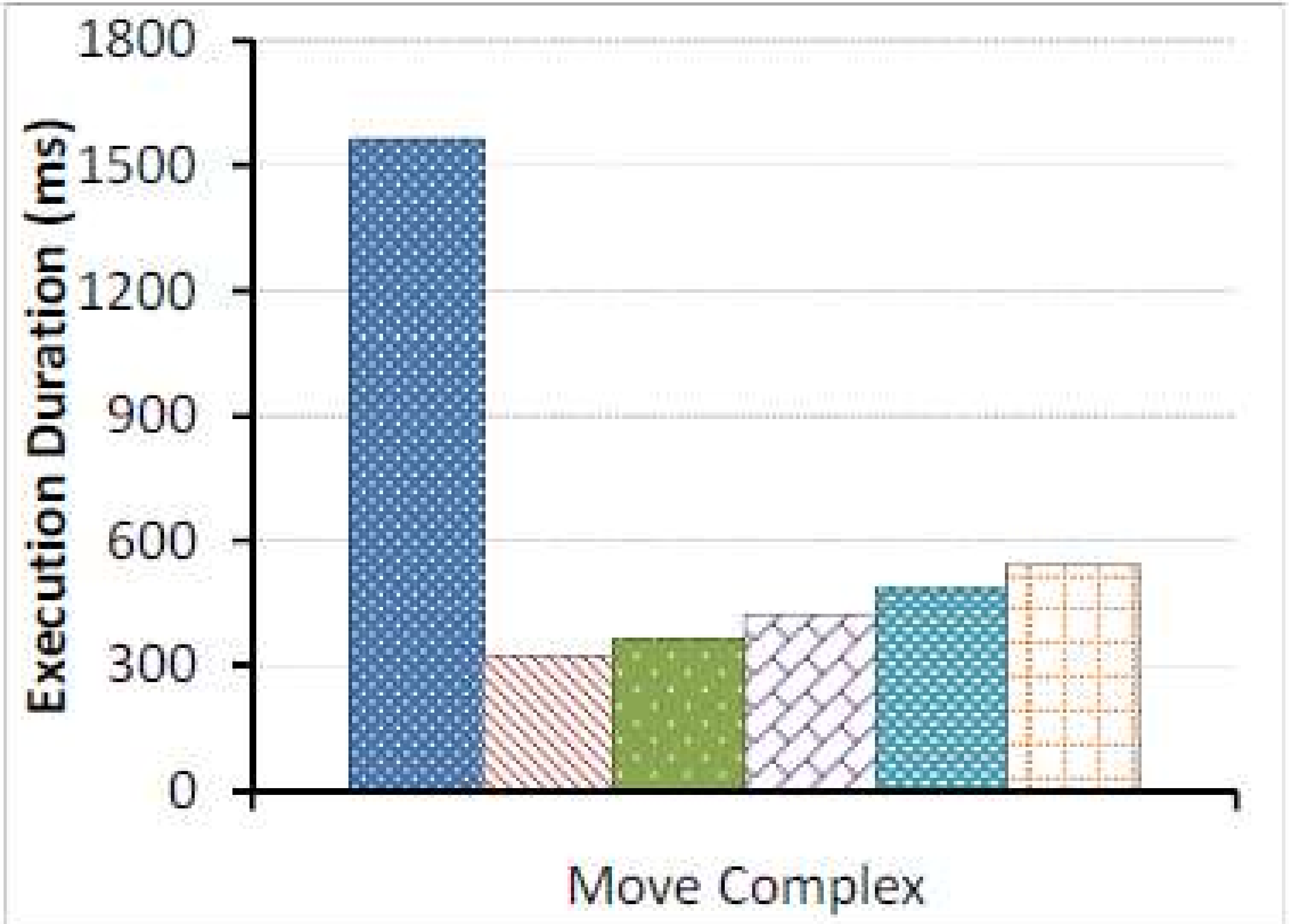
400 FRAMES of VIDEO GAME



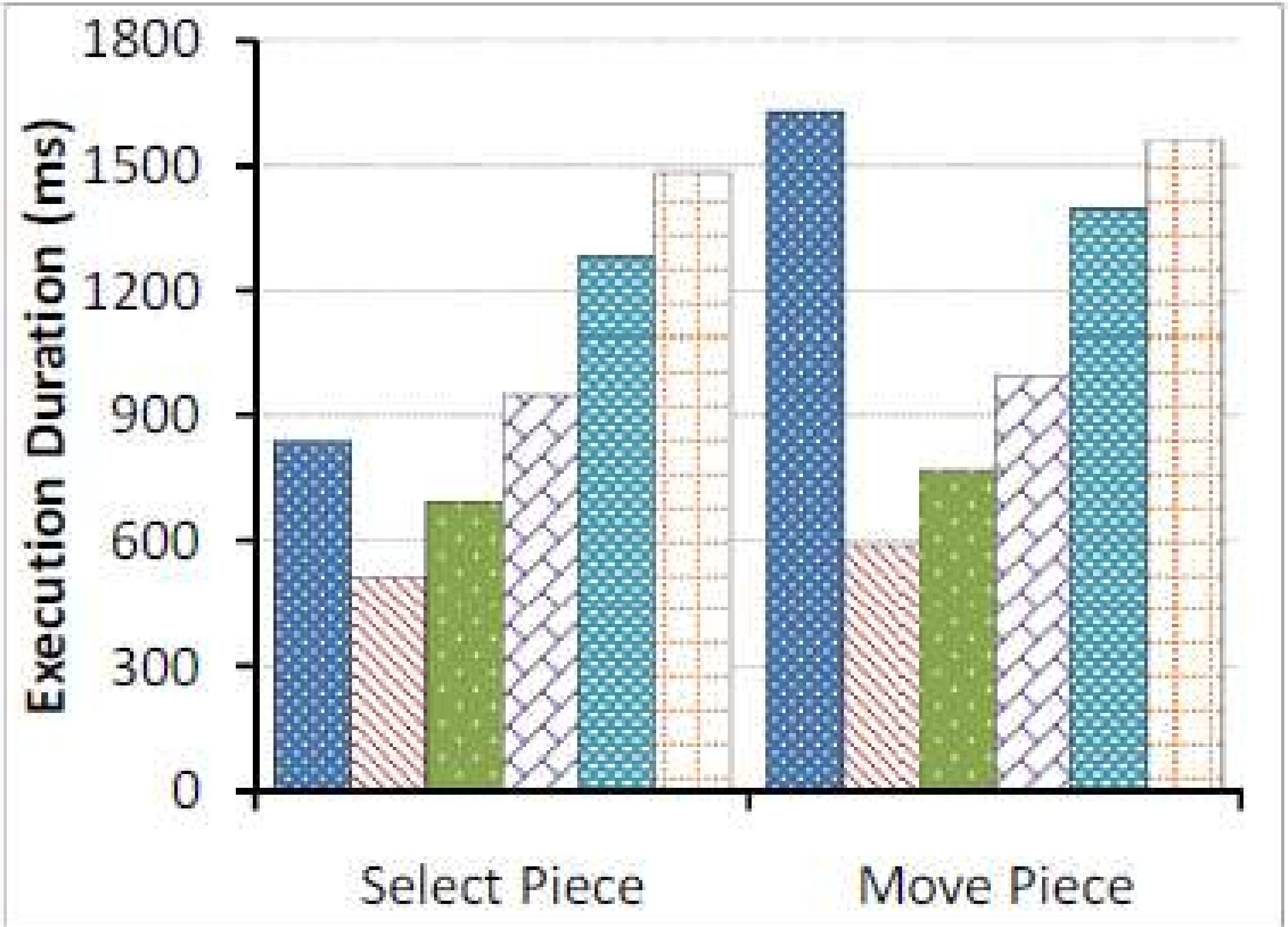
30 MOVE CHESS GAME



ONE RUN FACE RECOGNITION



400 FRAMES of VIDEO GAME



30 MOVE CHESS GAME

Environmental Impacts?

- Your smartphone may last 2 hours longer by offloading. What are the environmental impacts?

GREEN IT

IEEE Computer, November 2011.

End-to-End Energy Management

Yung-Hsiang Lu, *Purdue University*
Qinru Qiu, *Syracuse University*
Ali R. Butt and Kirk W. Cameron, *Virginia Tech*

To improve energy efficiency, we must consider the end-to-end energy use of a task involving multiple computer systems.

Do you agree?

Conclusion

- Sustainable energy supplies are one of the most important challenges.
- Electronics have great impacts to our environment.
- ICT consumes about 3-4% electricity directly. The indirect impacts are significant but difficult to measure.
- Saving electronic energy is a important topic for researchers and designers.
- Many solutions have been proposed.
- Much more work needs to be done.