How electronics can help energy management

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http://cmp.imag.fr

CEBE IAB meeting, 17 September 2013, Tallinn, Estonia

Agenda

- Introduction
- SC and energy issues
  - Electronic Equipment
  - Automotive
  - Lighting
  - PV
- The future: nanoelectronics
  - 3D
  - Ultra low-power electronics
  - Self-powering ICs with PV/OPV
- Final conclusions

Introduction

Energy / climate issues very important

Electronics in general, SOC, SIP, much needed

How SC industry can address energy issues: generation, conversion, use, storage?

[Sources: IEA "Energy efficiency policy recommendations", 2008,
R.P. de VRIES/NXP keynote at ISSCC 2009 (RPdV),
Ch. BELADY/Microsoft keynote at ICCD 2008, and SEMITHERM 2010
A. SHAKOURI/UC Santa Cruz]

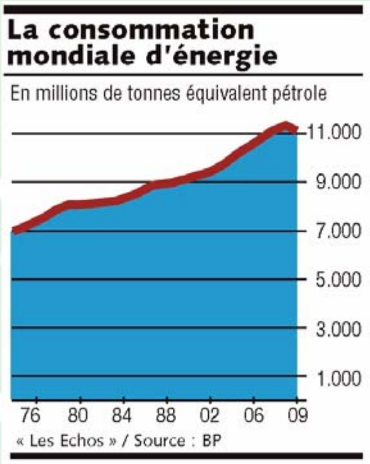
Some facts

Worldwide oil consumption 2008

USA	19.4	Million barrels/day
China	8.3	
Japan	4.8	
India	2.9	
Russia	2.8	
Germany	2.5	
Brazil	2.4	
South Korea	2.3	
Canada	2.3	
Saudi Arabia	2.2	
France	1.9	
......		
Worldwide	84	

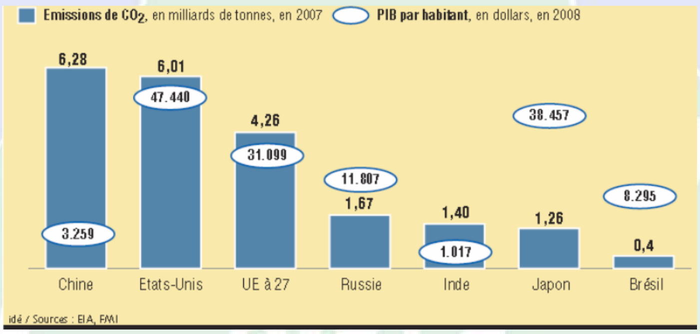
Minus.... 0.6% over 2007....

but .... in 2009, thanks to the economic situation... first decline on energy demand since 1982



Les Echos, 10 June 2010

CO_2 vs GNP



Gt/year $/year in 2008

In France, over the XX^th century:

- population: x 1.5
- GNP: x 10
- electric power consumption: x 1,500

Recommendations

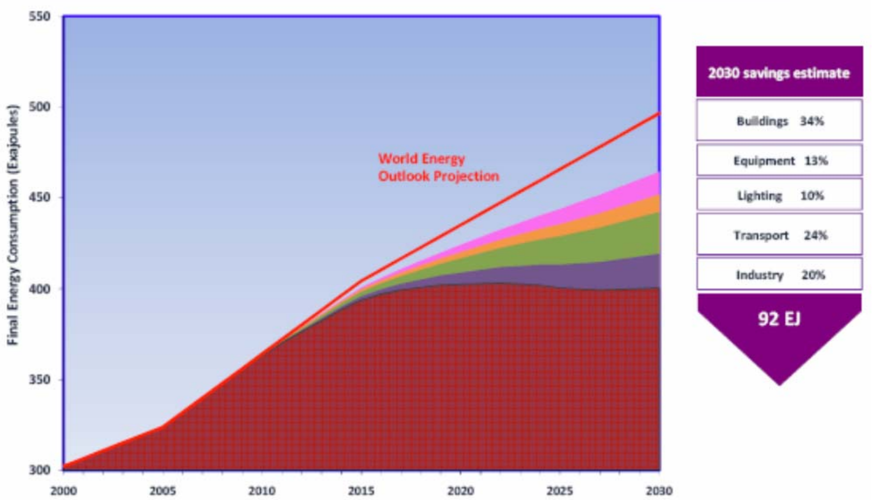
- Lord Nicholas STERN
  today: 435 ppm CO_2
  +2.5 ppm/year
  2100: ➔ 750 ppm
  +5°C....
  beyond +2°C: unpredictable climate consequences
  ➔
  - 20 $GtCO_2$/year instead of 40 $GtCO_2$/year in 2050
  - absolute targets instead of percentages, that are based on 1990 emissions
  - growth targets:
    if +2.5% for US, Europe, Japan
    +7% for China, India
    +5% Brazil, Indonesia

    ➔all divide by 4 the CO_2 emitted by 1% of growth

- IEA

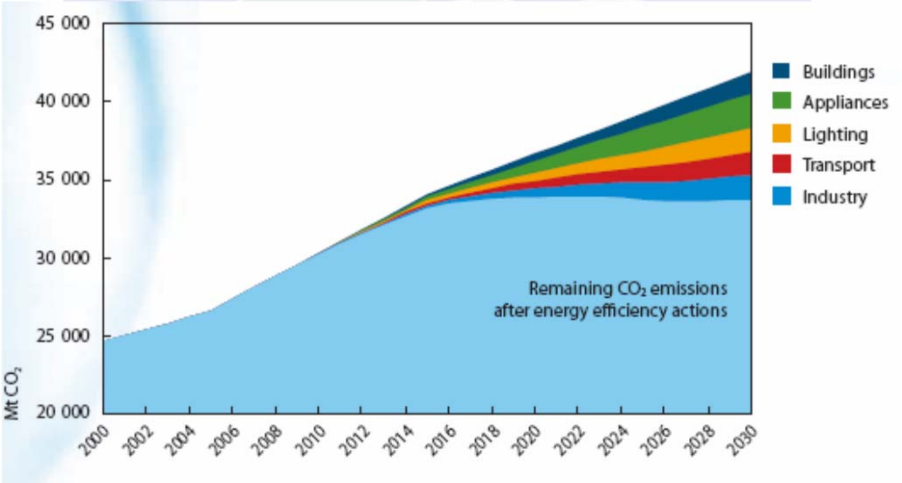
  IEA to G8 policy recommendations: save 20% of total energy by 2030.

  ➔ reduce global CO_2 emissions by 20% per year by 2030 (≃ 8 $GtCO_2$/year)



IEA Energy Efficiency Policy Recommendations, 2006-2008.
Impact on World Final Energy Consumption

Mt/year



IEA CO_2 savings potential from energy efficiency recommendations

Buildings	**:**	**1.4 $GtCO_2$/year**
Equipment	**:**	**2.2 $GtCO_2$/year**
Lighting	**:**	**1.2 $GtCO_2$/year**
Transport	**:**	**1.4 $GtCO_2$/year**
Industry	**:**	**1.6 $GtCO_2$/year**

Sequestration CO_2?

Projects....

France: 50 Mt sequestered in 2050 (~ 500 Mt emission / year...)

World: 9 Gt sequestered in 2050 (10 Mt sequestered/year, 30 Gt emission/year...)

plus energy to capture, transport, sequester: +10% to 40%

Total investment over 40 years: $6 trillions....

Electronic equipment

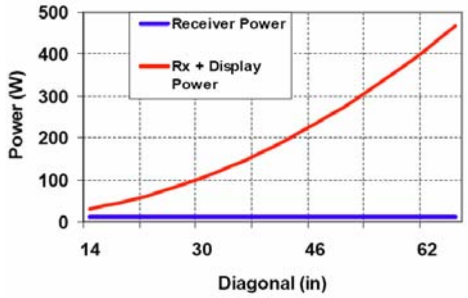
standby mode in home appliances:
5% to 10% of total home power consumption
EU regulation 2008:

- ≤ 2 W 2010
- ≤ 1 W 2013

(except internet boxes (telephone))
➔50 TWh presently in EU, down 75% in 2020

operational mode: TV displays consume 120 W in 32", 460 W in 66"....

3 M homes move to home cinema: 1 power plant.....



TV power vs. screen size [RPdV]

actually:

- power consumption frequently not displayed in shops...
- picked up by chance: 470 W for 46'' 635 W for 58" (major brand....), some even do not post the power...
- plasma consumes much more than LCD, while plasma is recommended for very large screens...
- old cathodic display: around 100 W....
- objective in 2020: 1 W per inch (40 W for 40'')

hopes:

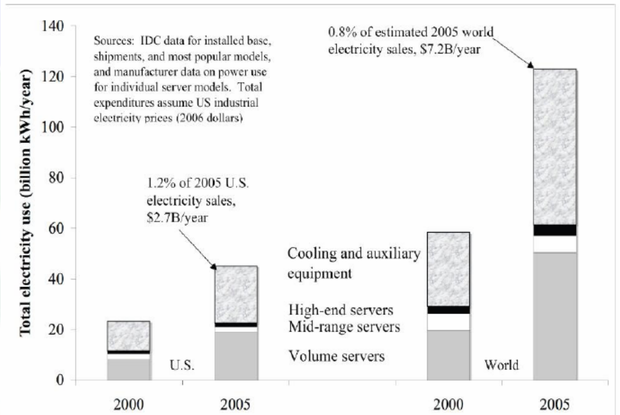
- LED backlighting for laptops (52% in 2009 to 100% in 2012)
- LED TV growing fast
- MEMS-based devices to replace LCD, plasma, OLED? TMOS (Time-Multiplexed Optical Shutter), DMS (Digital Micro Shutter), iMoD (interferometric MoDulator)? For small sizes only probably

high-tech equipment: (TV, computers, set-top boxes, etc.):

2% of worldwide CO_2 (but savings on the 98% because of new life styles, e.g. virtual meetings, e-commerce, etc.)

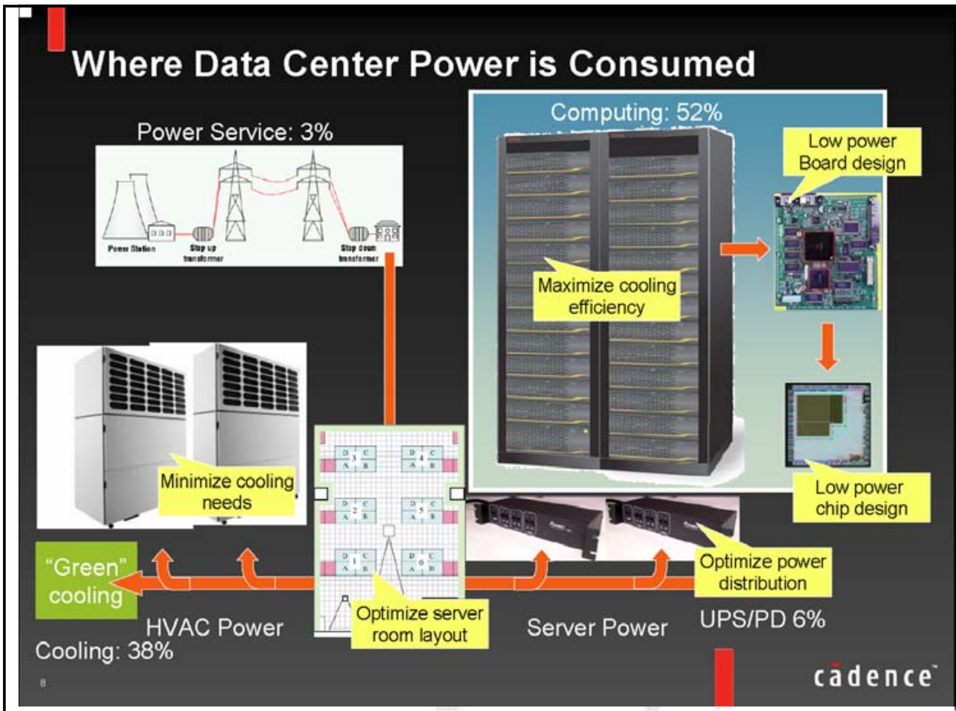
data centers: 1.2% of total consumption in USA in 2005

Figure ES-1: Total electricity use for servers in the U.S. and the world in 2000 and 2005, including the associated cooling and auxiliary equipment



expected to be 2.5% of total power consumption in USA (30 power plants) in 2010, 10% in 2020
at this time: CO_2 from US DCs = CO_2 from US planes

in Europe: 40 B kWh, 80 B in 2012

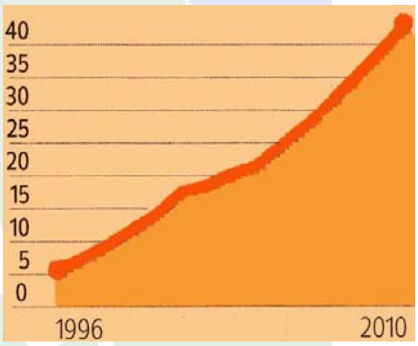


Ted VUCUREVICH

Why so much power needed?

Demand:

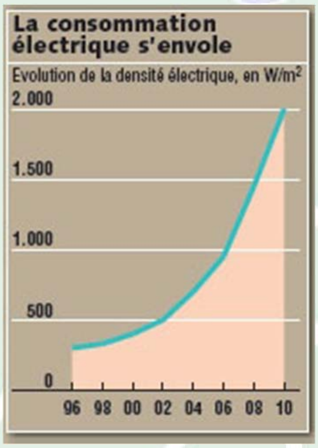
Total number of servers worldwide (millions)



Google: 1M? 260 MW

Second Life: 4,000 in 2007

Cooling: W/m² in data centers



Les Echos, 12 April 2010

data center: 100,000 servers, 11 times the size of a football field, every W in the die translates into $3 to $4 in support cost (100,000 servers ➔ $300 K to $400 K for 1 W...)

Servers come in containers (~ 2,000 servers), ~ 100 containers in a data center, 3 pipes: power, water, data

Generation 3 Microsoft (Chicago DC): 17 times the size of a football field

Cost of a DC: 500 M$


What are Containers?
Use either standard ISO shipping container or similar size
40',20',10' x 8 x 8'6"
Many New Applications emerging…
Homes
Museums
Hotels
Bars
Pools
Cities
29 ©Microsoft 2008
C. Belady ICCD, Lake Tahoe August 14, 2008
Microsoft


CBlox Computing
IBM
Introducing
ICE Cube
Rackable Systems
The world's most efficient modular data ce
hp
Verari
Sun
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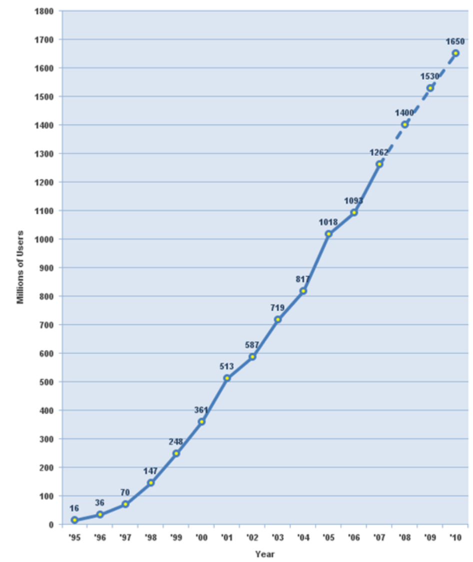
Microsoft

perf/W is going up (16X in 10 years), but demand goes up....

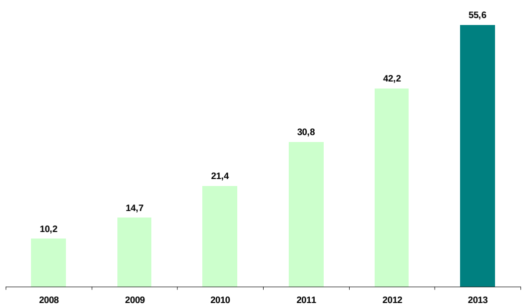
Internet Users in the world

Growth 1995-2010



Source: www.internetworldstats.com - January, 2008

Internet traffic in the world



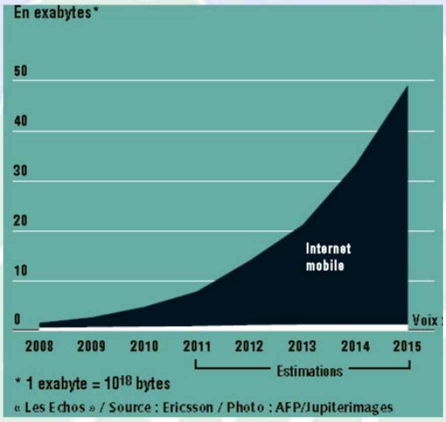
facebook : 800 millions members....
40 billions picts

YouTube

YouTube alone uses as much bandwidth today as the entire Internet did in 2000

200 Tbytes of traffic daily = 10 x entire US Library of Congress holdings

Mobile internet



Les Echos, 4 June 2010

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cloud computing (rental of hardware resources (plus possibly software)): will it help?
possibly: less (too) big server farms
conversion from CAPEX to OPEX for users

smart grid: need of electronic equipment for control, communications and security between the grid and downstream electronic products. Electronic products designed such that they can be turned on/off, up/down.

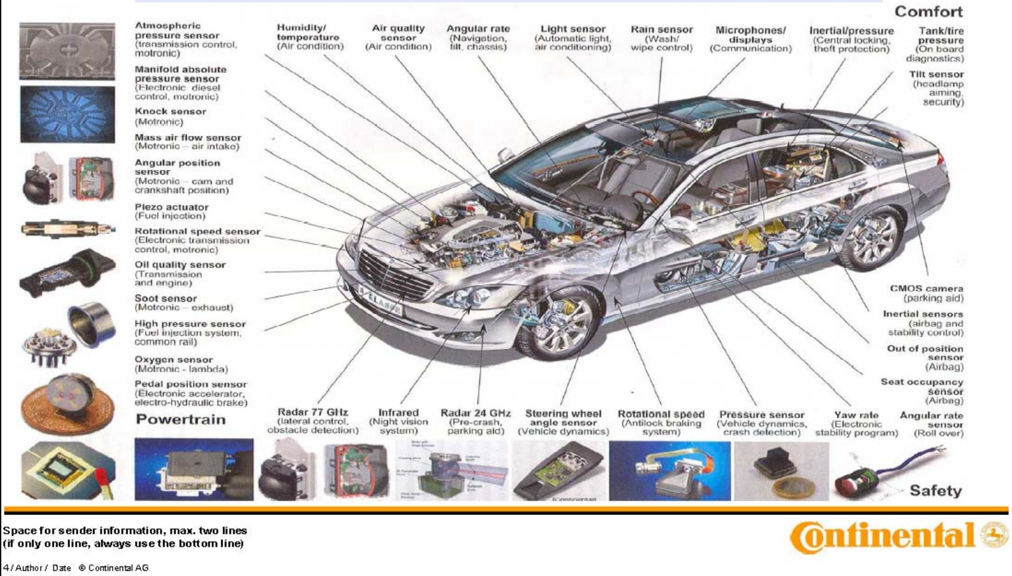
Automotive

- 60% of world oil consumed in transport
- road vehicles: 80% of total transport energy consumption
- 35% decrease in oil consumption per car over the last 30 years

  50% more reduction by 2030

  and 50% more for light-duty vehicles
- How?: electronic control of engine + electronics / sensors for safety and control

  $ value of electronics: +3% per annum, to increase rapidly: 22% in 2000, 35% in 2010, 45% in 2015



- Electric cars will help on oil consumption on the roads, but they need an electrical source... (if all cars in France: +25% to +50% electrical consumption....)
  total process may be not very efficient
  $ value of batteries: ~ 30%, $ value of electronics... 70%
  power stations to recharge... ???

- Various types of hybrid cars can save oil consumption with stop-start, use of electrical power for acceleration, regenerative braking, electrical transmission,... Many DC-DC converters needed, DC-AC needed, etc.

- Conventional cars: replacement of wiring by electrical networks save weight, hence consumption, replacement of the lighting by LEDs,....

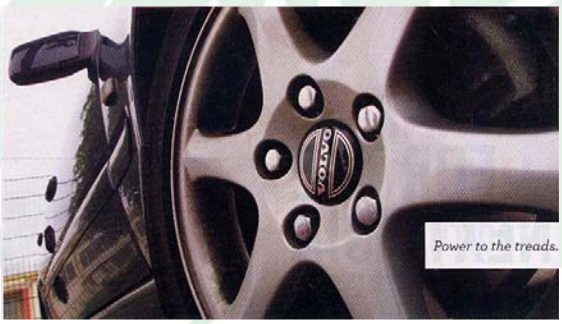
- A promising technology for electric (EV) / hybrid (HEV) cars: wheel motors?

  electric cars still destroy 60% of energy because of mechanical parts.

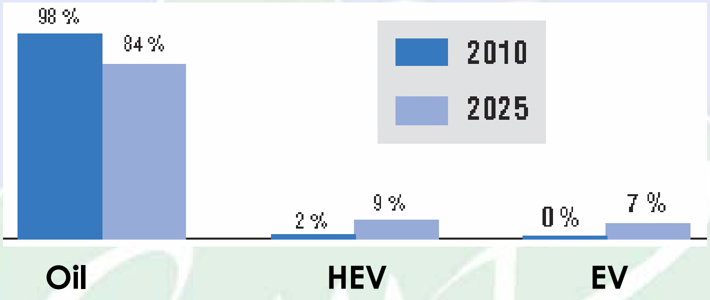
  wheel motors use electromagnets and pulses of electricity

  200 cars, buses, trucks already in test

  MICHELIN: plus suspension and brake

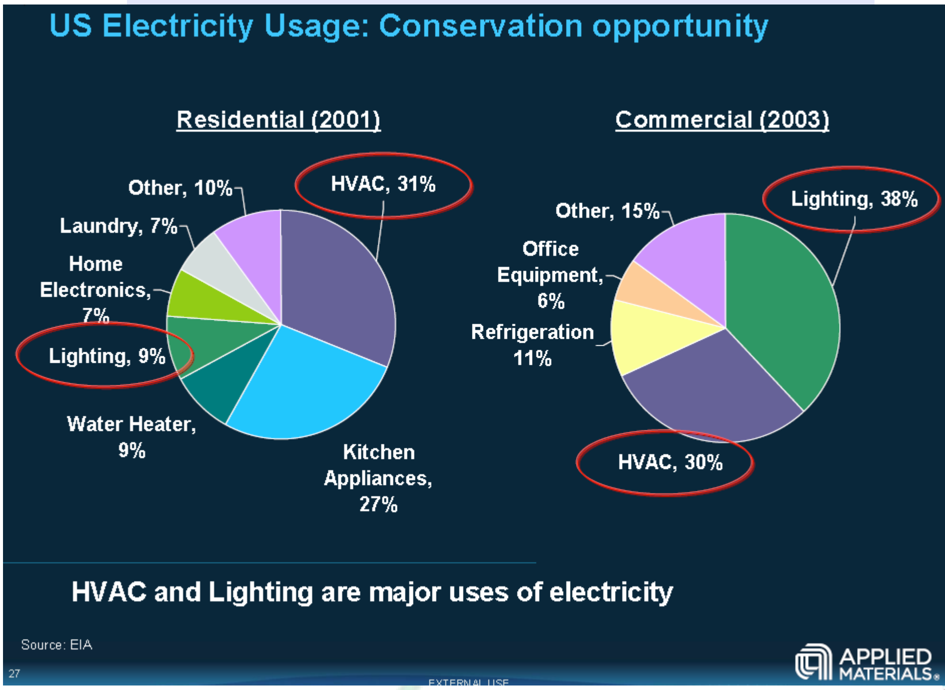


Market



Bosch says 97% vs. 3% in 2020. 97% are the main target to work on CO_2

Lighting, buildings.....



Lighting

- 20% of total electricity produced... replacement of incandescent lamps by fluorescent or tube lights can save 80%. In EU:

  + 100W : 1 Sept. 09

  + 75W : 1 Sept. 10

  + 60W : 1 Sept. 11

  + all others : 1 Sept. 12

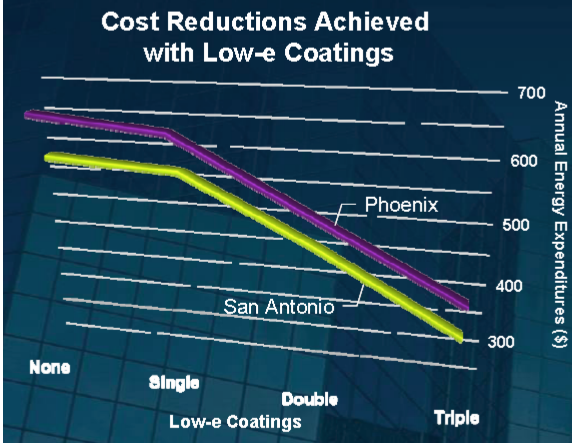
- Move from discrete power components to integrated solutions for the drive electronics

- In addition: occupancy detection....

Buildings

- Heating, ventilation, air-conditioning, lighting,....
- Metering allows the shaving of peaks (hence of the total capacity), by powering off some devices. Many sensors required. 15% to 20% energy savings expected.
- Metering allows power providers to get information (but traffic on internet....)
- Coatings on glasses

Reducing HVAC Energy: Architectural Coated Glass



2000 ft2 house with 300 ft2 of windows

Annual Energy Loss (U.S.) Due to Today's Windows: ~ 4.5Q BTUs* (6% total energy usage, cost >$40B)

APPLIED MATERIALS

Increasing Adoption of Coated Glass

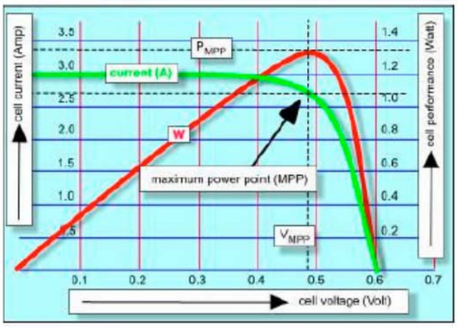
Savings from 2007 Global Output ~ 36,000 Bbl/day†

† Equivalent to 12 oil wells or 18Mt CO_2

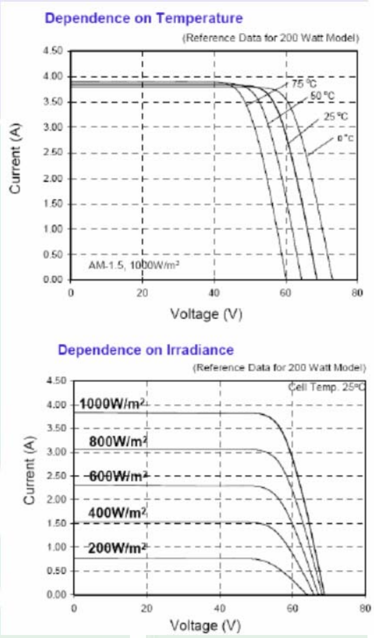
APPLIED MATERIALS

PV (the earth receives nearly 100K times more energy than required worldwide)

- Several PV technologies
  - crystalline (high conversion efficiency, high cost)
  - thin film (lower, lower)
- Very important: power output maximized when cell operated at an optimum voltage, dependent on temperature and irradiance...
- Installed capacity: +20% to +40% per annum, to increase with the increasing competitiveness of PV (price of PV generation vs. grid price)



Optimum Load for Single Photovoltaic Cell
(National Semiconductor)



Temperature and Irradiance Dependence of a PV Module
(National Semiconductor)

➔ electronic control! (local)

Not something new.... issue is competitiveness

Solar/PV and the 1970s Energy Crisis

- "I will soon submit legislation to Congress calling for the creation of this Nation's first solar bank, which will help us achieve the crucial goal of 20 percent of our energy coming from solar power by the year 2000." – Jimmy Carter, 1979

White House West Wing - 1984

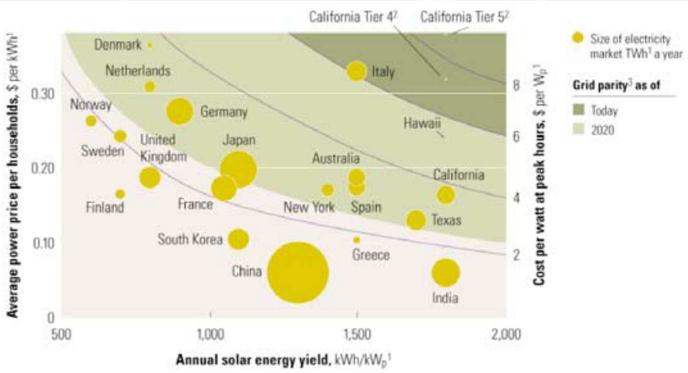
White House West Wing - 1992

- "The administration has significantly reoriented the country's approach to energy matters in the past 2 years." – Ronald Reagan, 1983

EXTERNAL USE

APPLIED MATERIALS

Moving competitiveness of PV (with price of PV decreasing)



[1] kWh = kilowatt hour; kW_p = kilowatt peak; TWh = terawatt hour; W_p = watt peak; the annual solar yield is the amount of electricity generated by a south-facing 1 kW peak-rated module in 1 year, or the equivalent number of hours that the module operates at peak rating.

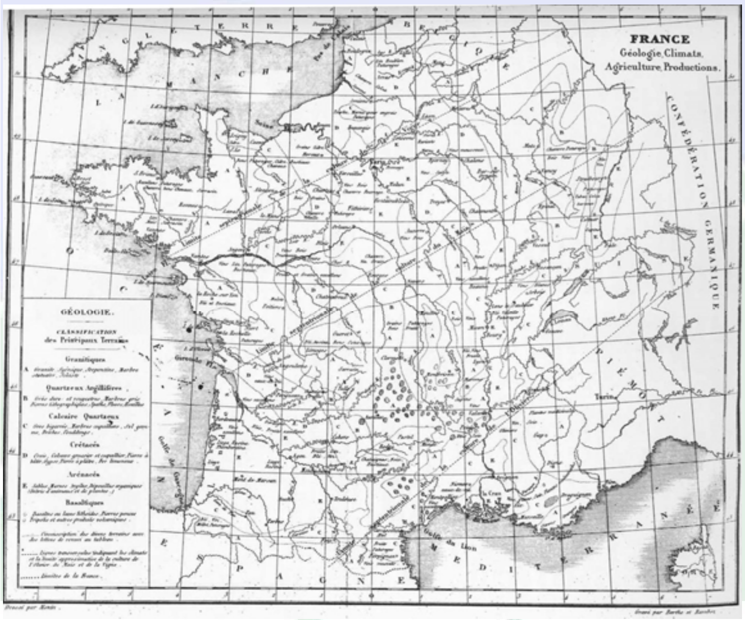
[2] Tier 4 and 5 are names of regulated forms of electricity generation and usage.

[3] Unsubsidized cost to end users of solar energy equals cost of conventional electricity.

Source: CIA country files; European Photovoltaic Policy Group; Eurostat; Pacific Gas & Electric (PG&E); Public Policy Institute of New York State; McKinsey Global Institute analysis

to compare to ....

Moving limits of wine culture with global warming

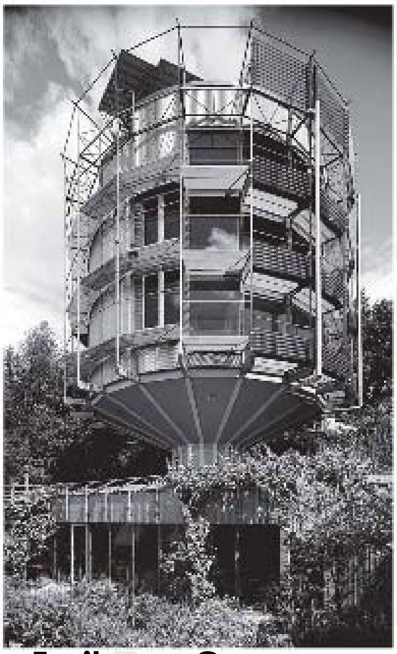


Concrete examples: zero energy building

ZEB building in Dijon, France

1,600 sensors, 550 sqm PV

Rotating solar building



Freiburg, Germany

Turning Torso Tower in Malmö: part of the city where the energy was supposed to be produced locally, from renewable sources.

Project: Portland (OR)

no energy, no water consumed

no waste produced

EV + PV: go blue, not green....

Blue Car (BOLLORE)

self-service rentals in Paris

Blue Earth (SAMSUNG)

mobile communication: 1.6 billon people no access to reliable power grid

HEV

PRIUS V3: solar roof in 2010 (to power A/C, not the battery)

Going further blue....

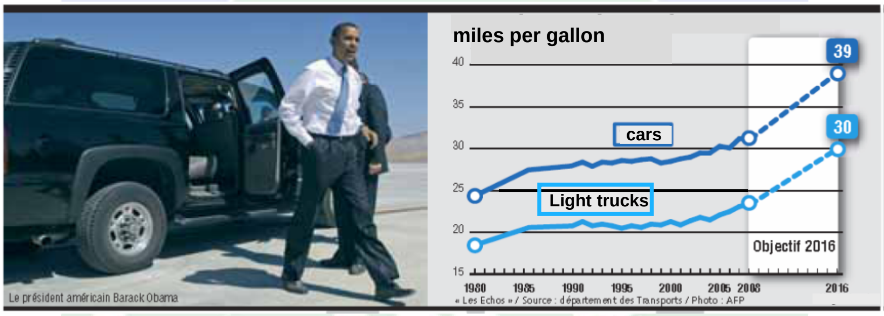
PUMA

Personal Urban Mobility and Accessibility

- SEGWAY and GM, 2012-2014
- 2 sqm, 150 kg
- today: 15 euros for 100 km
  tomorrow: 25 euros for 10,000 km .... (???)

Other GM personal EV project

Concrete plans in the USA



[Les Echos, 20 May 2009]

Old plans in the USA....

- 1835: Thomas DAVENPORT, small locomotive
- 1891: William MORRISON

- 1900: 28% of 4,192 cars produced in the USA were EVs
- 1905 ca: first Thomas EDISON EVs, but batteries problems

- 1910 ca: new batteries

Old plans in the USA....

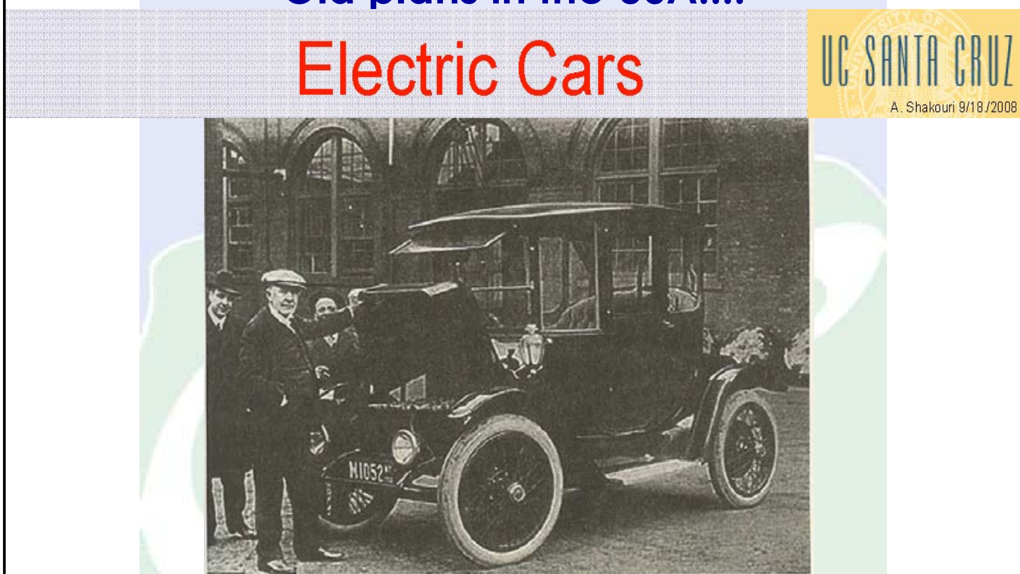


Figure 3.3
Thomas Edison believed that electric cars, such as the one that he is seen here inspecting in 1913, will prevail over the unclean gasoline-powered cars. From the Smithsonian Institution's photo set Edison After 40 at http://americanhistory.si.edu/edison/ed_d22.htm.

Vaclav Smil, Energy at the Crossroads, 2005

Direct Current (DC) Electricity

UC SANTA CRUZ

A. Shakouri 9/18./2008

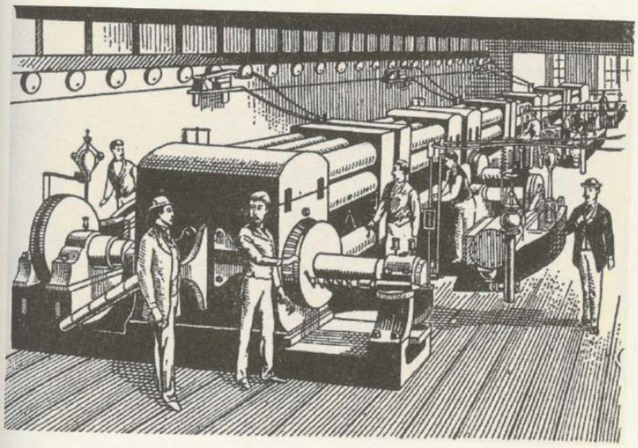
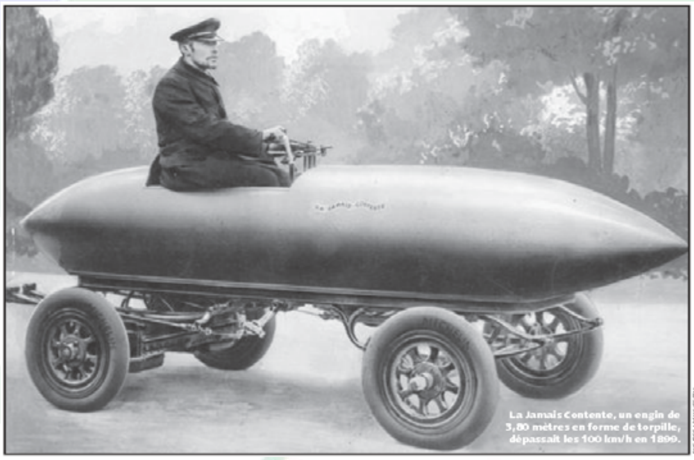


Figure 3.1
Six jumbo dynamos of Thomas Edison's first American electricity-generating station located at 255–257 Pearl Street in New York and commissioned on September 4, 1882. The station's direct current was initially supplied to only 85 customers and it energized just 400 light bulbs. Image reproduced from *Scientific American* (August 26, 1882).

Vaclav Smil, Energy at the Crossroads, 2005

In Europe....

1842: Andrew DAVIDSON, Edinburgh
1895: Charles JANTAUD, Paris-Bordeaux race, 50 km autonomy
1899: Camille JENATZY: the Jamais Contente, 100 km/h



La Jamais Contente, un engin de 3,80 mètres en forme de torpille, dépassait les 100 km/h en 1899.

Further electric cars dead projects

Industries & Technologies, October 2009

New electric cars projects

LUMENEO Smera | **MITSUBISHI** iMiEV | **RENAULT** ZOE | **HYUNDAI** i10 Electric

Adapted from Electronique International, 15 October 2009

2010

- GM Chevrolet Volt
- Ford Transit Connect
- Renault Twizy

2011

- Nissan Leaf

Even the Trabant.....

130km/h, autonomy 160km,
A/C by PV on the roof, 2012

Light Trucks

MODEC (20 trucks operated by DERET in 2009)

Busses

GRUAU, 2010

Light Truck Projects

Bright's IDEA prototype, 40 miles on battery plus 40 miles per gallon, 50,000 trucks, 2014

How about CO_2 for electric cars...?
Zero emission....?
NO!

CO_2 emissions moved to plants, to generate the energy for the batteries....

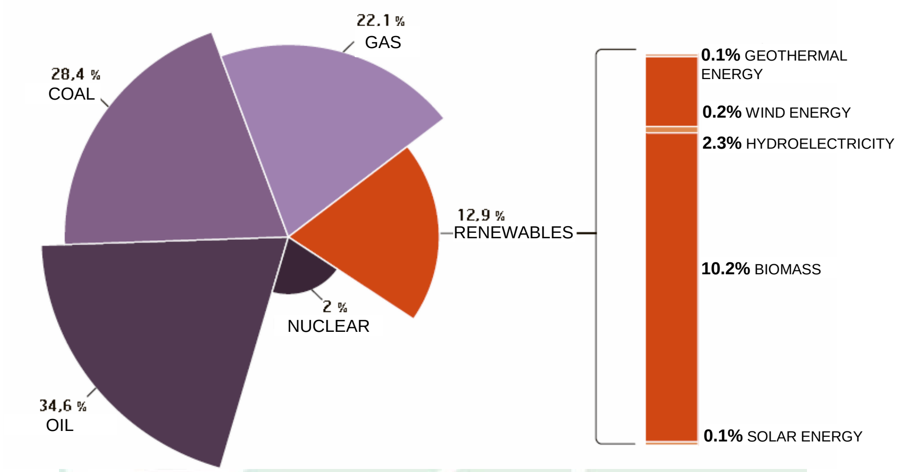
Some examples (small car, averages, next slide). On the average: 100 g CO_2 per km (vs. 120 g on the average). Can be very different depending on energy generation (nuclear, coal)

In France 12 g CO_2/km versus 125 g, because of nuclear generation (but not true in the winter or during peak hours because of coal generation)

Also:
- recycling the batteries (2 years lifetime)
- infrastructures for recharging the batteries
- cost of the cars
- large quantities of rare metals required for the manufacturing (chinese monopoly...)

Industries & Technologies, October 2009

Worldwide energy resources



[Les Echos, May 2011]

Notable HEV, low CO_2 emission....

Porsche 918!

25 kms EV autonomy
70 g/km CO_2 emission
718 hp: 218 hp EV + 500 oil
3 l/100 km (78 m/gallon)

or Jaguar C-X75
99 g CO_2/km

EV safety issues

- battery
- high voltage

Safety – A Closer Look I

infineon

- The energy content of Li-Ion batterys for electric cars is three orders of magnitude higher than those for laptops

sueddeutsche.de

Suche

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Home > Digital | Wikileaks | Software | Soziale Netzwerke | Cebit | iPad | IFA | Ressortarchiv

Gefahrenquelle

Sony startet weltweiten Rückruf von Notebook-Akkus

Sony wird weltweit Notebook-Akkus zurückrufen, die es an Laptop-Bauer geliefert hatte. Zuvor hatten nach Dell, Apple und Toshiba auch noch Lenovo und IBM gut 500.000 Akkus der Japaner zurückgerufen.

Aufgrund von Fehlern bei der Herstellung der in den Akku-Packs verbauten Lithium-Ionen-Zellen besteht die Gefahr, dass sich diese überhitzen. Einer Pressemitteilung zufolge verhandelt Sony seine Pläne gerade mit der US Consumer Product Safety Commission und will sich außerdem mit anderen Behörden abstimmen, sofern dies erforderlich ist. Seine OEM-Kunden für die Akkus will Sony ebenfalls über die Details informieren und die Anzahl der betroffenen Teile sowie den Zeitplan für den Austausch mit ihnen klären. Details des weltweiten Rückrufs wollen die Japaner "in Kürze" mitteilen.

[Georg PELZ]

Safety – A Closer Look II

- Electric vehicles are run at high voltages (300V+) to minimize resistive losses
- The safety of drivers/passengers, rescue forces and car mechanics needs to be maintained at any time

[Georg PELZ]

The best option....?

EV powered by fuel cell, not by a battery

Fuel cell: 1839 by William GROVE
H_2 + O_2 + electrolyte (polymer membrane)
electric power to electric motor
waste .... water

Renault-Nissan: fuel cell Scenic presented in 2009, 350 km

GM Chevrolet Equinox, 160 km/h, 420 kms
HONDA FCX Clarity, 460 kms
HYUNDAI FCEV, 580 kms
DAIMLER
TOYOTA
FAM F-City H2 car

issues: H_2 storage (hydrures, Mg, Li)
recharge stations (200 ww today)
maintenance

Today and tomorrow

E-REV (Extended Range EV)

EV plus thermal engine to charge the batteries

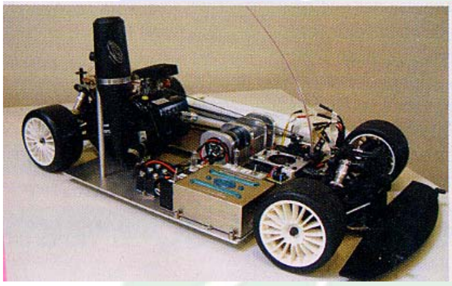
Chevrolet Volt

Opel Ampera

500 km

40g Co_2/km

Notable research and alternate options



battery rechargeable by changing the electrolytes in minutes, by FhG

pneumatic energy, 80 kg of compressed air, rechargeable in minutes, by MDI

SSFC (semi-solid flow cell) harvesting electrons from a liquid electrolyte through a reactor synthetic fuel stored in a tank, pumped at a “gas” station Cambridge Crude, USA

The worst....?

China projects: coal liquefaction to serve as diesel.... (cf. WW2) = very huge CO_2 emission + huge H_2O quantity required.

Depends on crude oil cost....

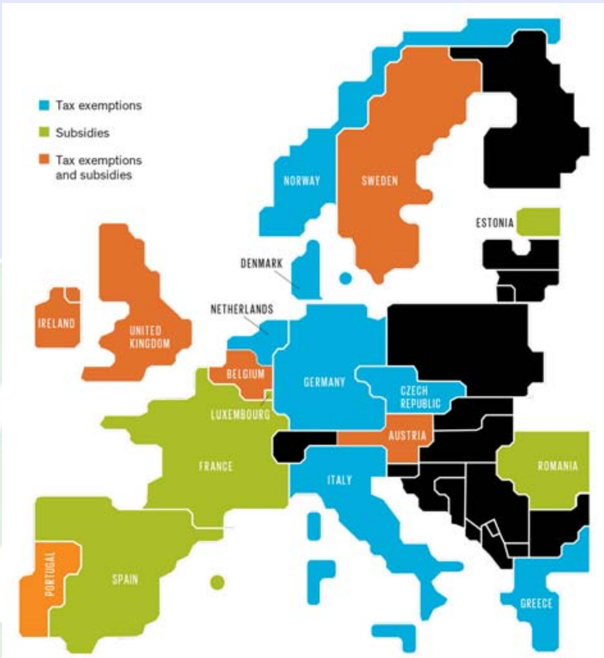
And... SO_2 in addition to CO_2: SO_2 blocks solar rays...

The best....?

China projects: gigantic PV power generation to power batteries...

The worst or the best....?

Incentives in various countries to buy EVs: cash rebates, tax credits, import duties withdrawn, use of carpool lanes with no passenger,....



SPECTRUM, July 2013

Canada: Ontario & Quebec govts

US: Federal govt

+ California, Colorado

+ Virginia: to shift automotive transportation from petroleum over to coal….

PV everywhere

Powering ads during the night, the grid during the day

Les Echos, 14/15 May 2010

PV everywhere

PV-powered keyboard by Logitech

Les Echos, 7 January 2011

PV large plans

Olmedilla de Alarcón (Spain): 60 MW, 2008, 130 ha

Lieberose PV farm (Germany): 53 MW, inaugurated August 2009, 560,000 panels, 210 football fields

Lieberose (under construction)

Toul (France): 140 ha, 143 MW, 2012

San Luis Obispo, California (USA):

250 MW (2012) + 550 MW (2013, 285 ha)

California asks that Pacific Gas & Electric provide 20% of electricity from renewables by 2010

Ouarzazate (Morocco): 500 MW, 2015

Large PV city plants

Bordeaux: 92,000 sqm, 12 MW, over parkings

Perpignan: 70,000 sqm, 9 MW, over a market +150,000 sqm in 2012

Renault in France: 60 MW over parkings and manufacturing plants

NYC: 45 to 70 MW over private buildings in 2015

CA: CA's Million Solar Roofs Initiative, 1GW installed, 3GWs in 2016

Zero energy supermarkets
Casino, France

2 M sqm on roofs and parkings

Zero energy offices

Grenoble: Bonne Energie

Ordos, China: 2 GW....

65 sqkm..... in a desert, for 3 M inhabitants

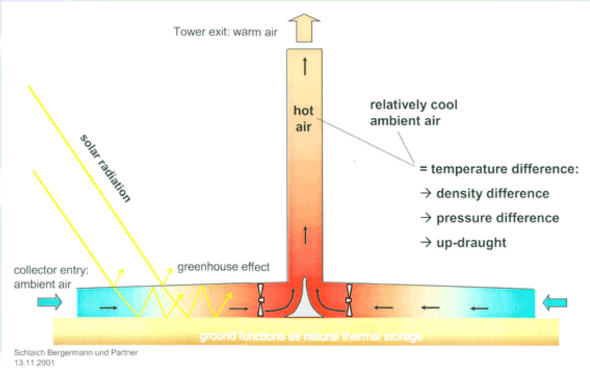
plus 2.6 GW PV, plus 6.9 GW wind energy.... for actually 1.4 M inhabitants... Transportation???

Solar Power Towers

Sevilla, Spain
- PS 10: 115 m high, 11 MW, 624 mirrors, 120 sqm each
- PS 20: 20 MW

Manzanares, Spain

- pilot plant 82-89 of a “Solar Chimney”
- larger projects on-going



Abu Dhabi, 100 MW, 2012

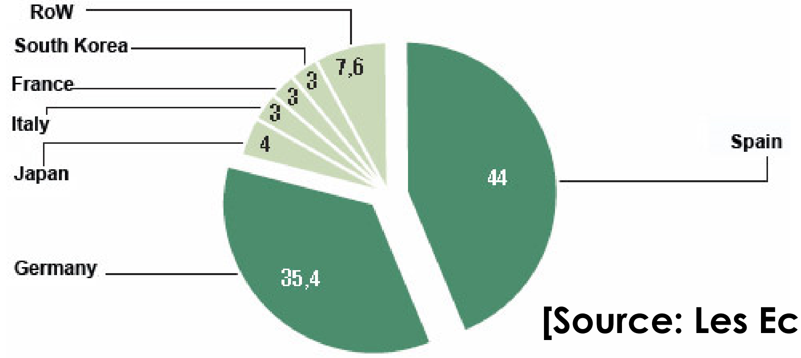
DESERTEC Project (idea..., in Sahara)

- to power Europe
- 15% of power needs in 2050
- very high cost
- transportation issue
- political aspects

Malaysia: Bosch solar cell manufacturing plant in Penang

PV market

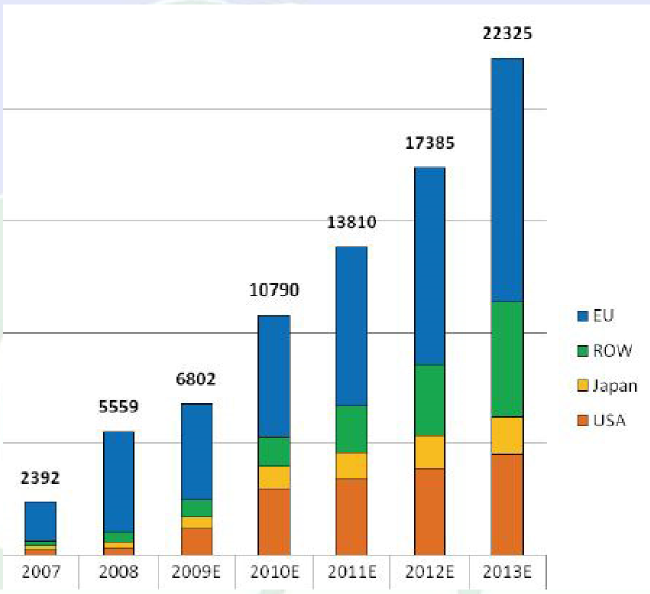
- 2008 PV market in various countries, in %



[Source: Les Echos]

- Investments for PV manufacturing > investments for SC manufacturing in 2010
- $ 800 M in 2008 SC for alternative energy systems (solar, wind, fuel cells), expected to rise to $ 2 B in 2012

PV worldwide market: 6802 MW peak in 2009



CO_2 savings: an excuse for disputable projects

- 60 t trucks; “2 trucks instead of 3”....

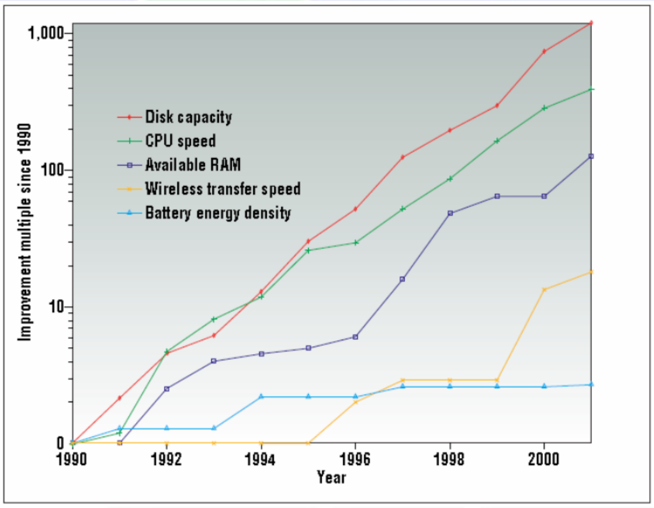
- PV plant in a park, 200,000 sqm in total, by deforestation, in Lans en Vercors....

Conclusions on SC/energy

Technology

- Focus on low overall power consumption thanks to ICs in addition to low-power ICs
- More technology developments away from Moore law towards better control and management of energy, improved power generation and storage
- Energy harvesting
- Central role of sensors, PV, electronic control
- R. KURZWEIL: solar energy will provide 100% of energy needs within 20 years (March 2011)
- Issues....

Energy vs. Electronics improvements (1)



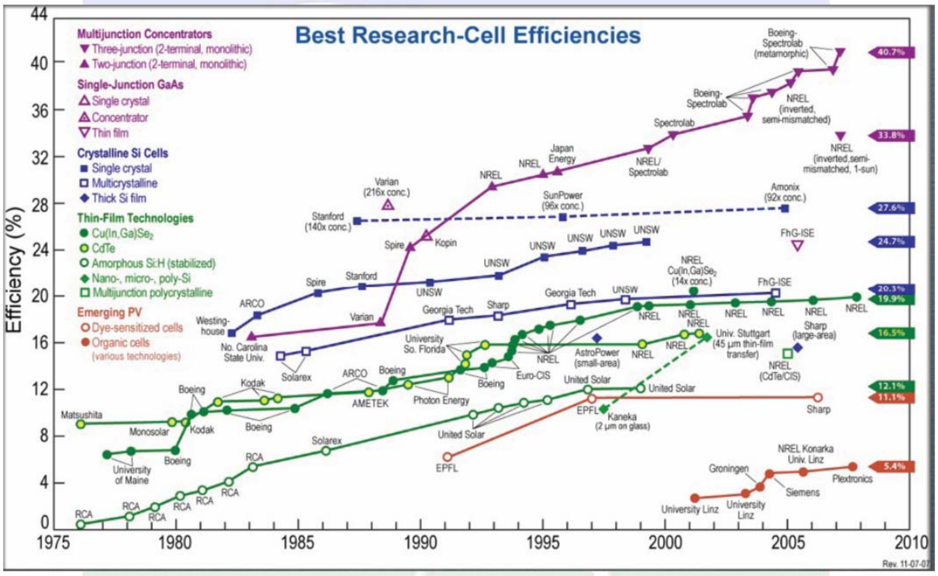
Improvements in laptop technology [STARNER]

Energy vs. Electronics improvements (2)

Batteries: details

- **Pb: 32 Wh/kg**
- **NiCd: 45 Wh/kg**
- **Ni-metal hydride, NiMH: 70 Wh/kg**
- **Li-Ion: 150 to 200 Wh/kg**
- **Li-Air: 1000 to 2000 Wh/kg.... dream**

Energy vs. Electronics improvements (3)



[KAZMERSKI / ZWEIBEL]

EuP Directive (EU)

EuP: Energy using Products

Ecodesign over the lifecycle
Energy to manufacture
Energy to waste....
Avoid pollution, CO_2 transfers, ...
e.g. electric cars: even in France, 126g CO_2/km vs 161g CO_2/km when EuP considered....

Industry – Political challenges...

Rare-earths, necessary for TV and HEV:
e.g. 1,100 tons of neodyme necessary every year for the Prius....

Recycling

- Batteries (2 years lifetime)
- PV (25 years lifetime)
  Cd in some technologies (First Solar, RoHS applicable or not....

From other high-tech disciplines Nanomaterials [D. HWANG, Lux Research]

Product	Application	Relevant sectors	Key developers	Potential energy savings
Tribological coatings	Anti-friction coating for internal combustion engines	Transportation	Nanogate, NanoMech, Sub-one	2%-5% of automobile consumption
Nanofiber filters	Non-woven nanofiber mats for lower-pressure air filtration	Commercial, industrial	Donaldson, DuPont, Elmarco, eSpin Technologies, Finetex, Nanostatics	20%-50% of ventilation systems' consumption
Aerogels and VIPs	Insulation for walls, roofs, and floors in buildings	Commercial, residential	Aspen Aerogels, Cabot, NanoPore, Va-Q-Tec	20%-30% of space heating consumption, 2%-5% of space cooling consumption
	Insulation for piping, furnaces, ovens, and other heating or heat transfer elements	Industrial	Aspen Aerogels, Cabot	1%-5% of process heating consumption, 1%-2% of space cooling consumption
Nanocomposites	Lighter weight body panels and frames for automobiles	Transportation	Arkema, A. Schulman, BASF, Bayer MaterialScience, DuPont, Nanocyl, SABIC InnovativePlastics, XG Sciences	2%-10% of automobile consumption
Thermochromic windows	Auto-tinting building windows to limit cooling needs	Commercial, residential	Pleotint, RavenBrick	10%-15% of space cooling consumption
QD phosphors	Film on LCD display backlights	Commercial, residential	LG, QD Vision, Nanosys, Samsung	7%-35% of LCD consumption
	Film on LEDs for general lighting	Commercial, industrial, residential	QD Vision, Nanosys, Nexxus Lighting, NN-Labs, Renaissance Lighting, Samsung	50%-65% of general lighting consumption

Further longer term research

- Artificial photosynthesis (replace chlorophyll by molecules that capture photons, then transfer the electrons), e.g. @ CALTECH

More challenges: energy vs. water

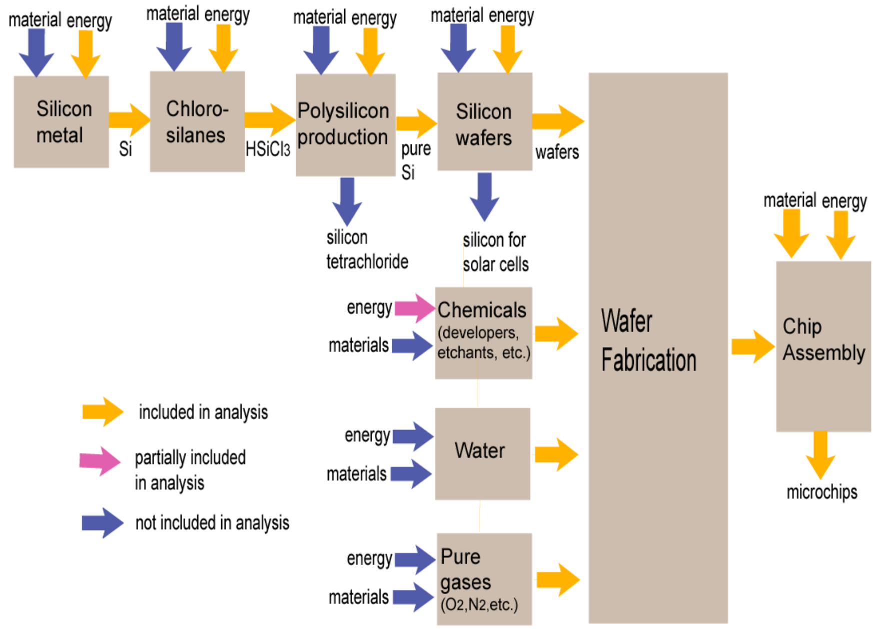
Water: more needs: cooling power plants, irrigation (biofuel crops...) ...

Energy: more energy needed: pumping (deeper and deeper), piping (farther and farther),

➔ less water available, more costly, ...
➔ more energy...

➔ save water ... drink wine

Energy for ICs manufacturing



E. WILLIAMS, United Nations University

ENERGY CONSUMPTION
in production and use of a 32MB DRAM chip

Fabrication of the chip:
5.8 MJ in production of silicon wafer
2.3 MJ in production of etching chemicals
27.0 MJ in fabrication of chip
5.8 MJ in assembly process
0.17 MJ in production of assembly materials
TOTAL for fabrication: 41 MJ per chip manufactured

Use of the chip:
15 MJ electrical consumption during lifetime

TOTAL for both fabrication and use: 56 MJ per chip

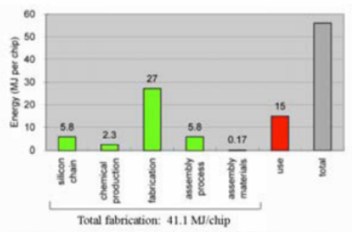


FIGURE 3. Energy consumption in production and use of a 32MB DRAM chip.

(www.ce.cmu.edu/~hsm/NATO-ARW/pres/EricWilliams.ppt)

Breakdown of energy consumption during manufacture per type of activity:
46% clean-room ventilation and air conditioning
35% wafer and chip actual fabrication
7% making liquid nitrogen
7% manufacturing assortment of chemicals
5% water purification

100%

The 1.7 kg microchip

For 32MB DRAM chip:

- Fossil fuels consumed in production = 1,200 grams
- Fossil fuels consumed in use = 440 grams
- Chemicals "destructively" consumed = 72 grams
- Water use is 36,000 grams per chip.

Total fossil fuel and chemical use to produce 2-gram memory chip ≥ 1.7 kg

Source: Williams, Ayres, Heller (2002)

The 290 kg desktop computer

Total fossil fuels to produce a desktop computer with 17 inch CRT monitor = 290 kg, 14 times its weight

Total energy (production + operation) of a computer larger than a refrigerator.

Structure of energy very different: 83% is for production, 17% for operation. For refrigerator, production/operation is 12%/88%.

Source: Williams (2003)

Other key application areas

- Environment
  water quality sensing
  air quality sensing
  etc.
- Security
  many projects ongoing, cf. Homeland security in the USA
- Communication
  "7 trillion devices serving 7 billion persons in 2017", Wireless World Research Forum

Electronics: two major challenges

- How to increase the complexity of systems (despite escalating costs of downscaling) and heterogeneity?
- How to address ultra low-power circuits?

CMP introductions...

- magnetic-CMOS ICs
- self-powering ICs with PV/OPV

- complexity: 3D
- ultra low power: Magnetic Logic Circuits

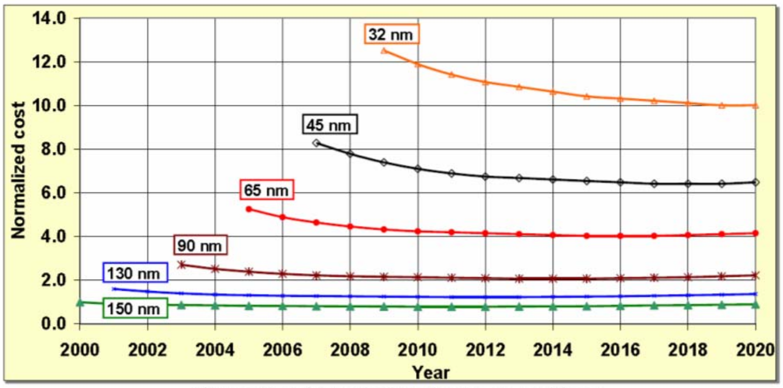
Complexity

Necessity for still increasing the complexity (# devices AND functionality) is still a reality: no saturation in the use of transistors...

How:

- downscaling: not for sure because of cost and acceptance. Anyway reaching a limit sooner or later.
  - + practical: power density, temperature, variability, leakage power, analog design,…
  - + money-making time for a generation is lengthening
  - + costs: cost of fabs, cost of manufacturing if not in (very) large volumes, cost of design

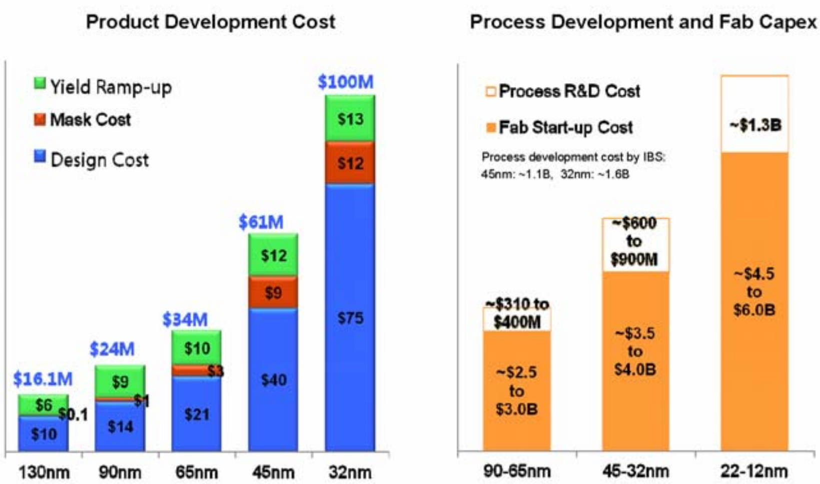
Cost of masks



Normalized Mask Set Costs Over Time

Courtesy of Toppan Photomasks, Inc.

Development Cost and Capex in Nanoscale



Source: iSuppli

Silicon Mitus

Escalating costs for downscaling

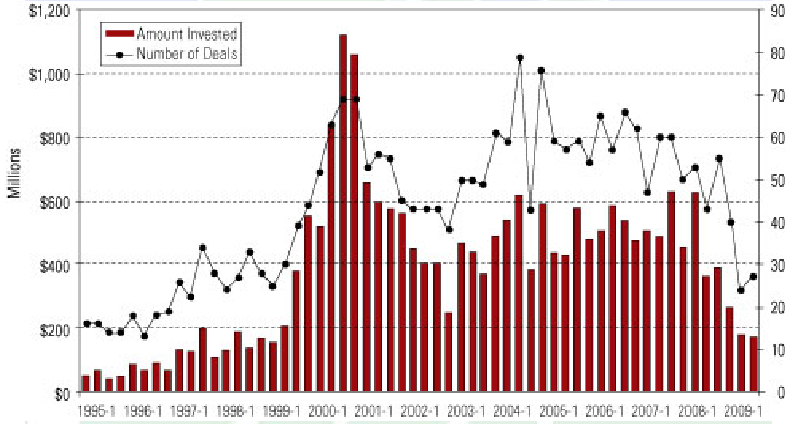
induce changes in VC investments

changes in geography

creation of alliances

number of companies at each technology node

Semiconductor VC Investment and Number of Deals



[Source GSA]

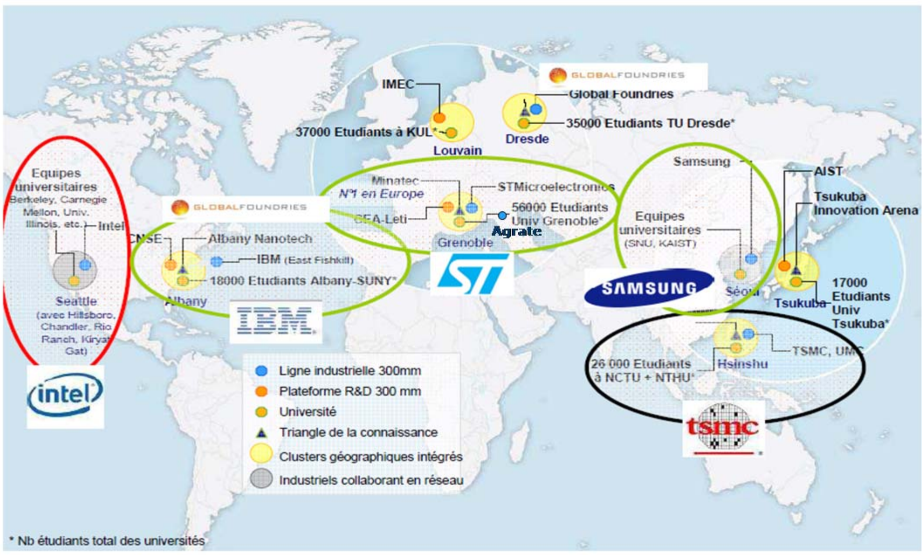
Semi Industry's Changing Geography

	1980	1990	2000	2010
1	TI	NEC	Intel	Intel
2	Motorola	Toshiba	Toshiba	Samsung
3	Philips	Motorola	NEC	Toshiba
4	NEC	Hitachi	Samsung	TI
5	National	Intel	TI	Renesas
6	Toshiba	Fujitsu	ST	Hynix
7	Hitachi	TI	Motorola	ST
8	Intel	Mitsubishi	Hitachi	Micron
9	Fairchild	Philips	Infineon	Qualcomm
10	Siemens	Matsushita	Micron	Elpida

Sources : Future Horizons, Gartner, iSuppli

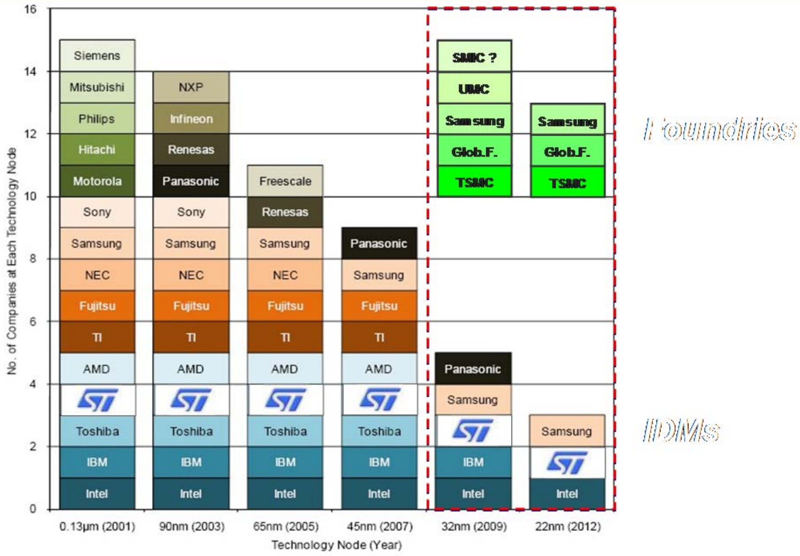
[source P. MAGARSHACK]

VLSI Platform Worldwide clusters



[source P. MAGARSHACK]

Technology Leadership : Leading Edge



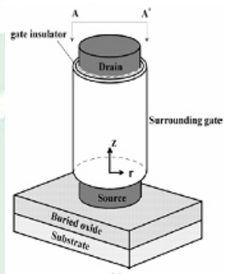
STMicroelectronics

DATE - March 2011

[source P. MAGARSHACK]

+ "it should be pretty clear to everybody that Moore's law, if it is not dead already, is going to die" [MAXIM's CEO]
+ fundamental: thermodynamics, quantum mechanics, electromagnetics,…

- larger die sizes, possibly on not the most possible advanced processes (current-generation geometries)
- 3D gates, e.g. Surrounding Gate Transistor (SGT)



- going manycores: the number of transistors is still increasing, but the source of performance increase is no more coming from the clock speed, power, instruction-level parallelism:

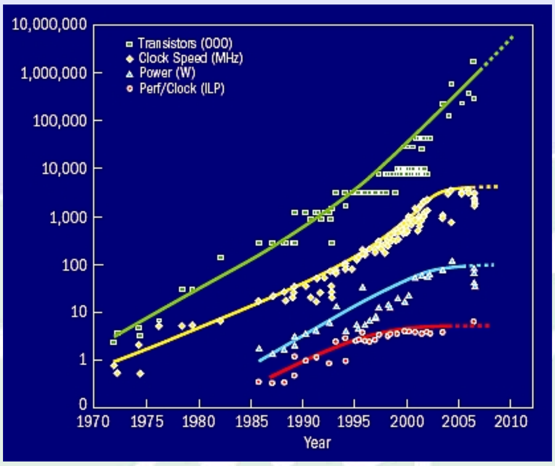


Illustration: A. Tovey Source: D. Patterson, UC–Berkeley

it is coming from multicore architectures

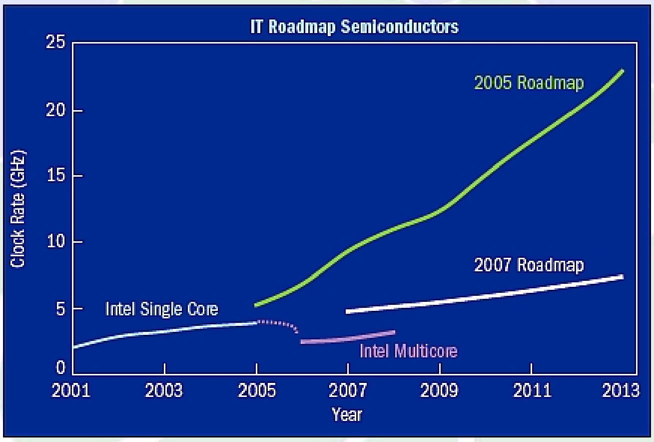
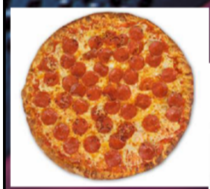


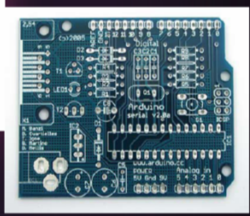
Illustration: A. Tovey Source: D. Patterson, UC–Berkeley

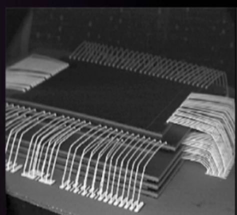
2D Integration vs 3D Integration

2D
- System components are disposed on single carrier layer
- Addition of components/contents increase planar dimension
- E.g. pepperoni pizza, single layer PCB, fold-out street map

3D
- System components are disposed on multiple carrier
- Addition of components accommodated by number of stackable layers
- Increasingly common in microdevices integration
- E.g. lasagna, stacked memory chip, booklet street map







http://chipdesignmag.com/images/idesign/misc/

3D (packaging, process)

- mixed-technology integration: best native process for each part (layer), e.g. 65nm digital, 180nm analog

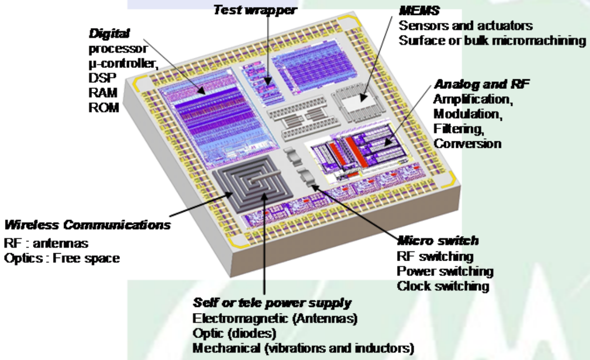
- heterogeneous integration, e.g. silicon, III-V, extending the system value

- cost: use of current-generation geometries

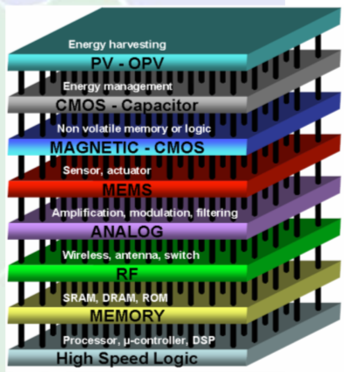
3D: Si + TSVs

In addition:

- interconnects: shorter, so power savings, increased performance
- I/Os: less I/Os, so less power (e.g. 8051 + memory stack: up to 90% power reduction
- increase the level of modularity and reusability: dedicated TSV slices in various technologies
- move from (pizza) SoCs to (lasagna) 3D .....



SoC

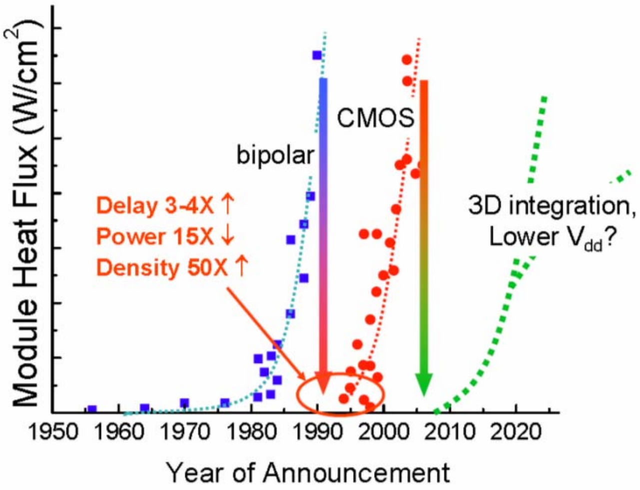


3D IC

[Benoît CHARLOT / Gregory DI PENDINA]

IBM Research

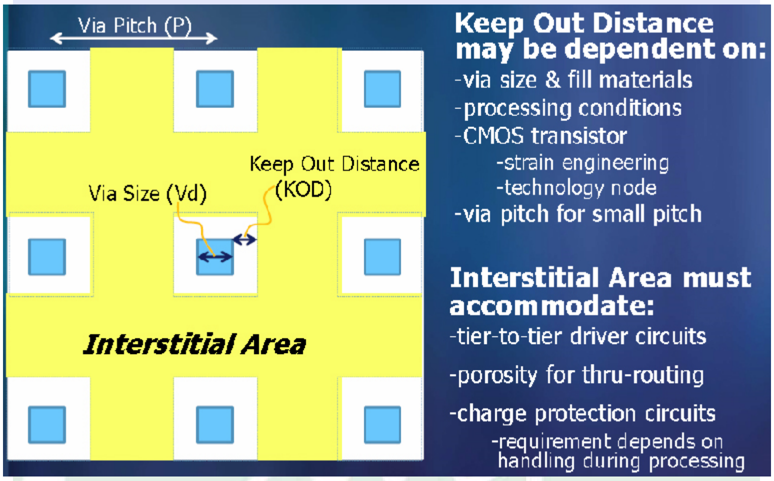
Scaling and the Power Crisis



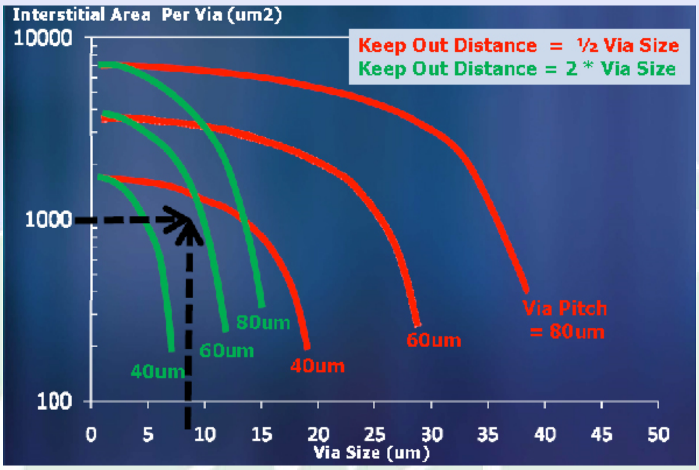
J. BURNS After: R. Schmidt *et al.*, IBM J. R&D, (2002).

but:

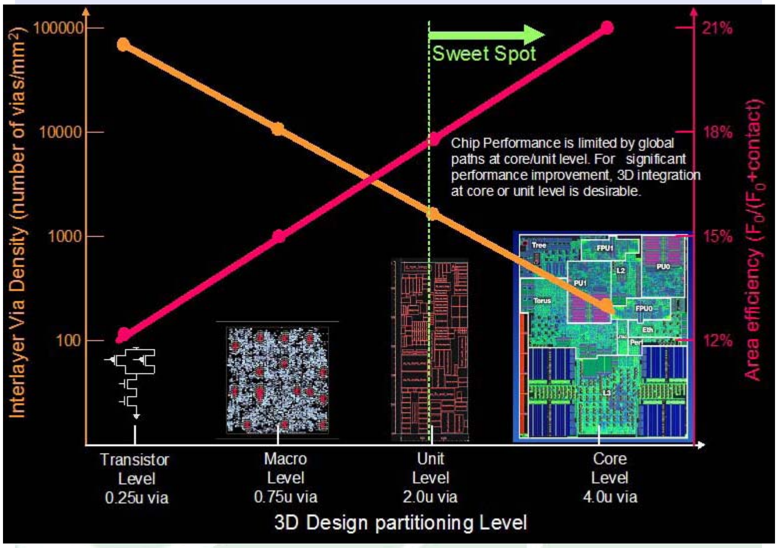
- **no power savings if use of current-generation geometries**
- **CAD software including TSVs**
- **keep out distance (no transistor around TSV)**
- **partitioning level**



M. NOWAK, QUALCOM

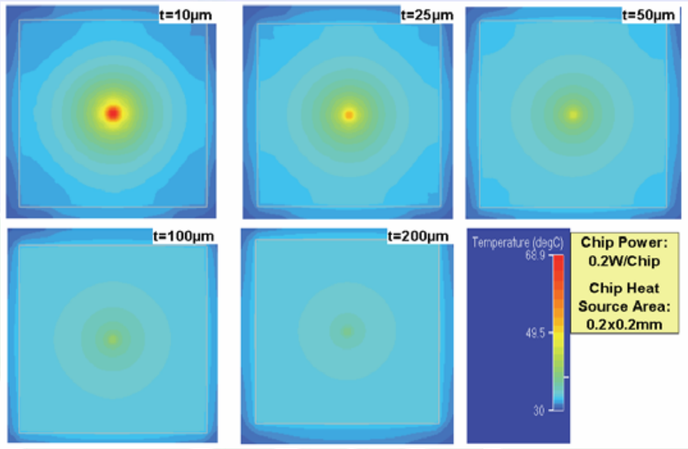


[M. NOWAK, QUALCOM]



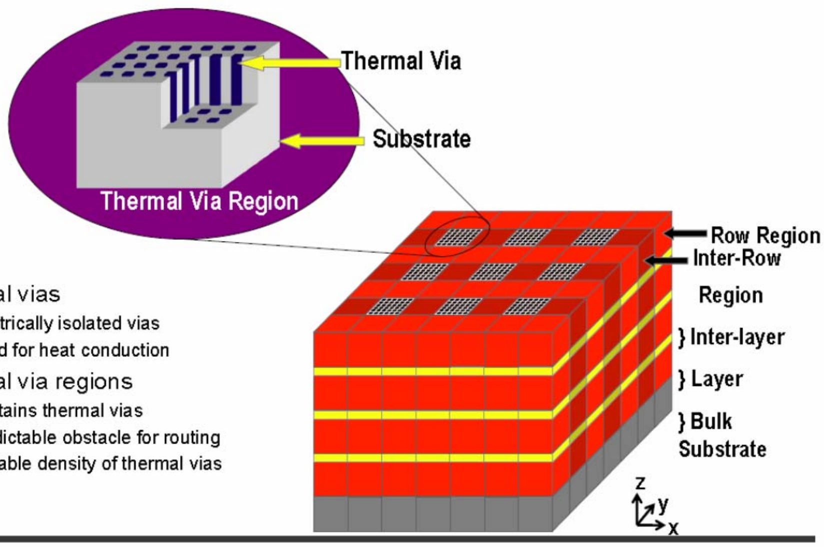
[KUNG, PURI, ASP-DAC 2009]

- thermal issues
  + increased density, so potentially hot spots, electromigration acceleration
  + thermal management theory: multiple sources [M.N. SABRY]
  + thermal resistance of TSVs
  + thermal vias [S. SAPATNEKAR]



Hot spot for various chip thickness
[J. LAU]

Heat removal in 3D through thermal vias



- Thermal vias
  - Electrically isolated vias
  - Used for heat conduction
- Thermal via regions
  - Contains thermal vias
  - Predictable obstacle for routing
  - Variable density of thermal vias

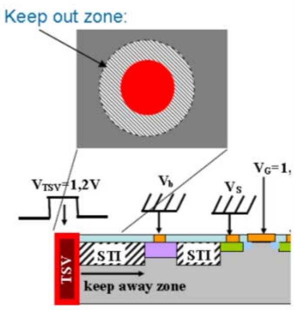
TSV Middle Vs Last

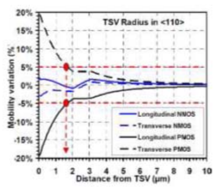
- Via Middle
  - Minimum die thickness is ~50µm
    - Limitations due to Si warpage, stress, etc.
  - Best Aspect Ratio is ~10:1
    - PVD/ CVD limitations (ex. Barrier, Cu seed layer, Cu fill)
  - Meaning ~Ø5µm vias are obtainable
- Via Last
  - Due to Post-CMOS process with temporary handler
    - Minimum die thickness is ~120µm
    - Best AR is ~3:1
  - Meaning ~Ø40µm vias are obtainable

[Mark SCANNELL]

The 3D Paradox

- Must minimize Si surface area sacrificed to TSV placement
  - Therefore, for most target applications, Via Middle is chosen
- But...
  - Via Middle integration limitations remain constant, regardless of CMOS scaling
  - TSV stays at ~Ø5µm
  - As the technology node descends...
    - Cost per mm² of Si increases
    - **Meaning cost of TSV increases with scaling!?**





Investigation on TSV impact on 65nm CMOS devices and circuits
H. Chaabouni, M. Rousseau, P. Leduc et al., IEDM 2010

[Mark SCANNELL]

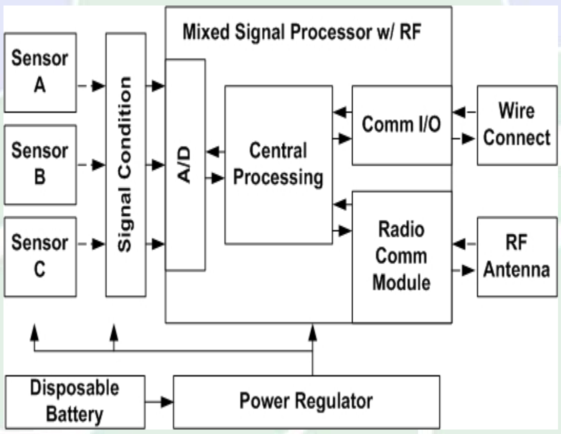
3D organic electronics: 3D Si plus

- cheap
- large area
- mixed applications: electronics, sensors, RFID, PV, batteries,… as in 3D Si
- folded, stacking of layers
- flexible
- biocompatible for BioMed applications
- minus: speed (but research ongoing to transfer Si ICs from wafer to flexible substrate)

Example: multilayer polymer microsensor system

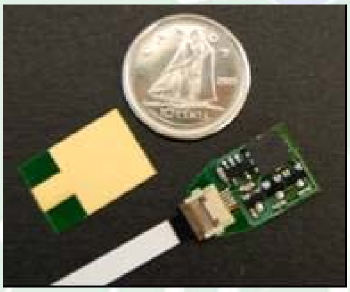
B. KAMINSKA et al, SFU, Canada

IEEE Trans. on BIOCaS



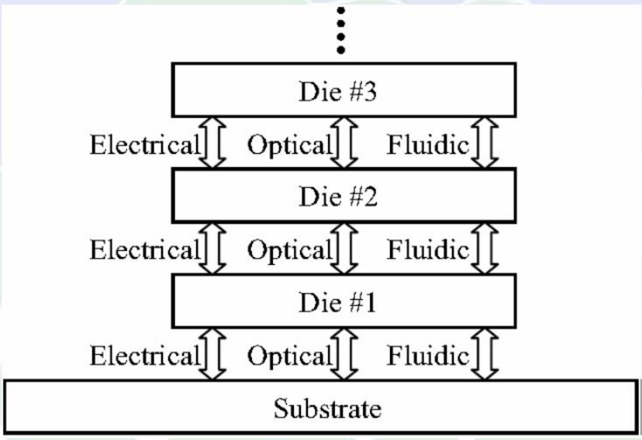
[courtesy of B. KAMINSKA]

Prototype: ECG and body positioning



Flexibility: skin tissue conformity

Electrical + optical + fluidic 3D



Trimodal interconnects [J. MEINDL et al.], electrical and microfluidic TSVs

3D @ CMP

1st run at TEZZARON 2009 including 5 Labs France, 6 Labs Italy, 1 Lab USA plus CMP (private run)

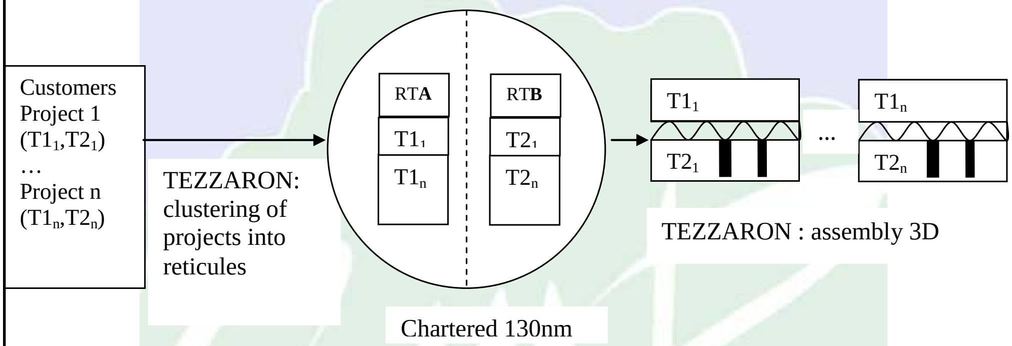
Today:

+ TEZZARON (Chartered/GlobalFoundries)

Tomorrow

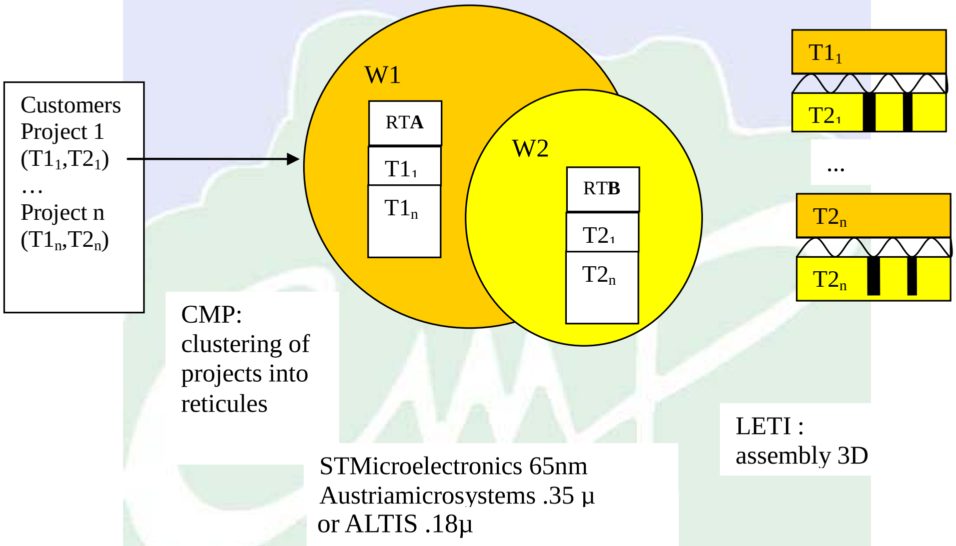
+ LETI (STMicroelectronics plus Austriamicrosystems or ALTIS)

TEZZARON



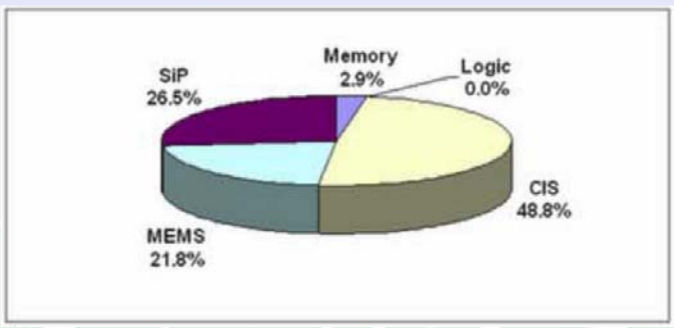
- same wafer: homogeneous process
- interconnect technology: tungsten

CMP / LETI



- Different wafers: heterogeneous process
- interconnect technology: copper

3D Products in 2009



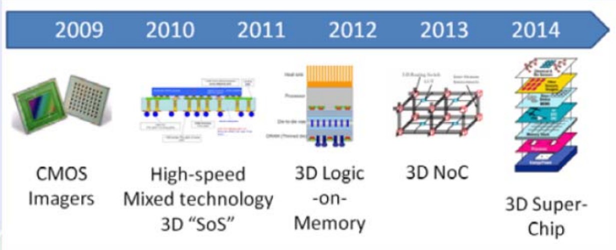
Source: The information Network.

2013: CIS (CMOS image sensors) ➡15%
Memory ➡30%

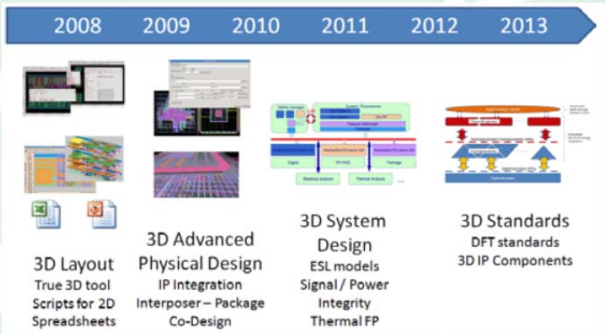
2010: SAMSUNG Memory: 40% power saved

2011: MICRON: 20X bandwidth, @ 10% power, 10% volume of DDR3

Roadmaps



Products



EDA tools

[L. McIlrath, R3Logic]

Ultra Low Power: Magnetic Logic Circuits

Background

Applications

@ CMP

Background

Magnetic circuits: a long way to go....

- magnetic bubbles 70s?
- arithmetic circuits 1968, U. of Washington...
- GMR
- MTJ

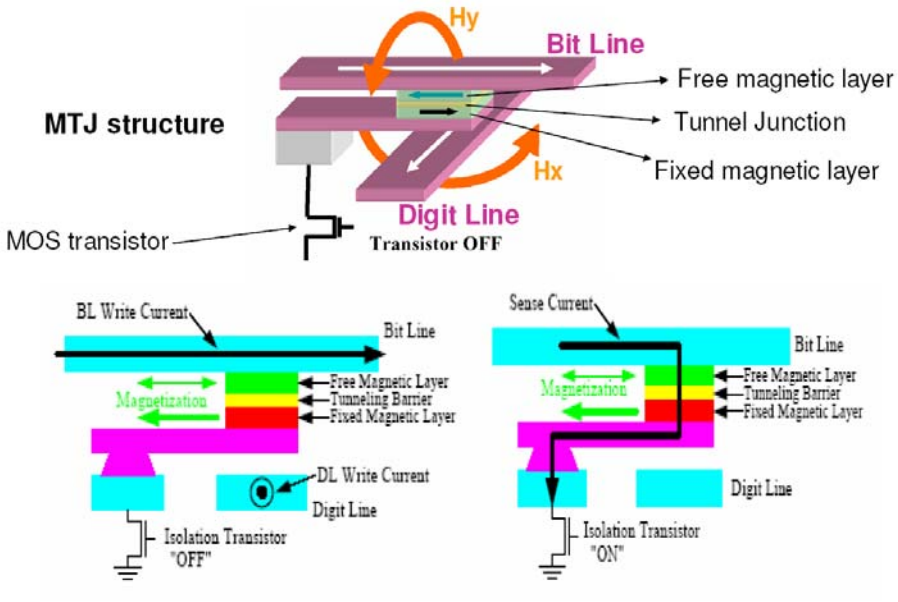
MTJ, Magnetic Tunnel Junction

load of the electron ➔ spin of the electron

2 ferromagnetic layers:

- parallel magnetization directions: low resistance R_P
- anti-parallel magnetization directions: high resistance R_{AP}

CMOS - MTJ Process



Applications

MRAM

MRAM above CMOS

Logic-in-Memory

M-FPGA

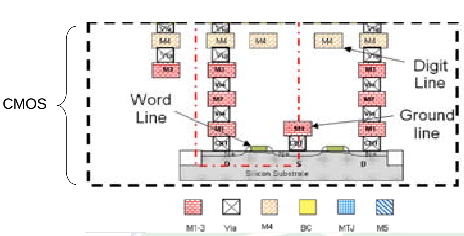
M-TCAM

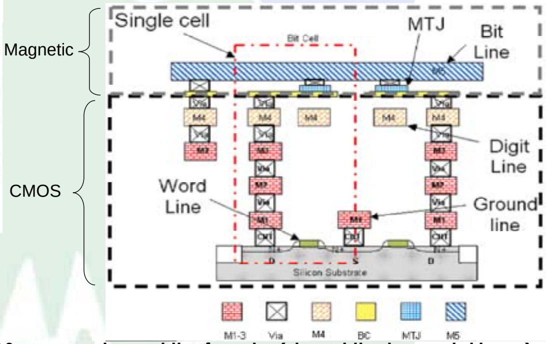
MRAM

- static (SRAM)
- very dense
- very fast (35 ns)
- very low power

MRAM above CMOS

CMOS process done at the foundry (stop at the top metal layer)





CMOS process done at the foundry (stop at the top metal layer)

Magnetic post-process + metallization + passivation + pad openings

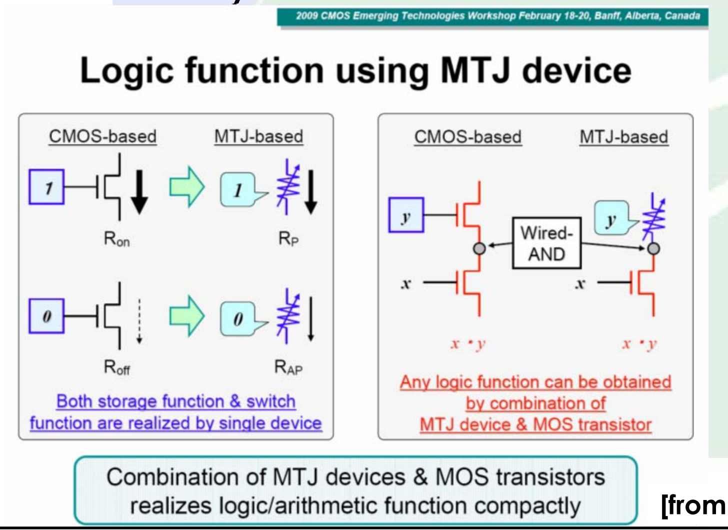
high density

short interconnections

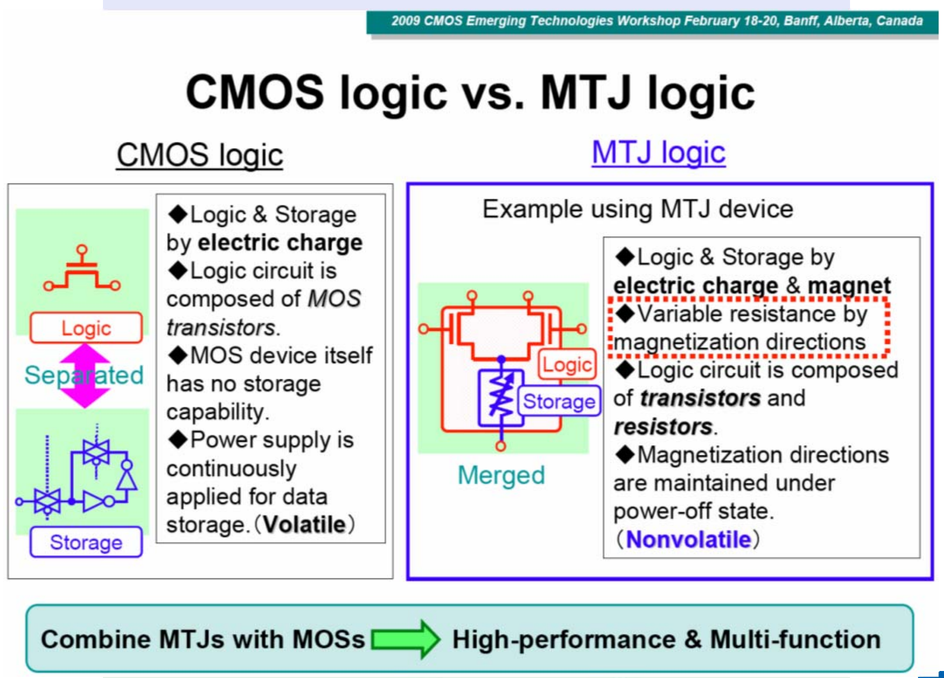
important because the % of eRAMs in SoCs is increasing dramatically (90% in 2010?)

Logic-in-Memory: MCMOS

Non volatile memory elements over logic circuitry.
- ultra low power: no power consumption if no state change
- keep the state if power disappears: no need to reboot from mass memory



[from Tohoku Univ.]



[from Tohoku Univ.]

e.g. full adder, based on .18µ CMOS
- MTJs on top of M4
- manufactured
- CMOS vs. MCMOS

	CMOS	MCMOS
Dynamic power (@ 500 MHz)	71.1 µW	16.3 µW
Static power	0.9nW	0.0nW
Area	333 µm²	315 µm²
Device count	42 MOSs	34 MOSs + 4 MTJs

➔ Dynamic Current-Mode Logic
➔ V_{th} variation compensation
(➔ RF circuits, LED, ...)

M-FPGAs

usual FPGAs:
- SRAM-based, volatile, reprogrammable
- anti-fuse, non volatile but not reprogrammable

trends:
- SRAM-based: dynamical/partial reconfiguration capabilities
- anti-fuse: embedded configuration memory but not on the same chip

M-FPGAs: non volatile, reprogrammable
- Iowa State University, 2000
- LIRMM, IEF, Spintec, France

MTCAM

- non volatile
- ternary CAM: 0, 1, X (don't care) matches
  SPINTEC Lab, France
- CMOS 5M 1P, 130 nm
- 1 cell 1x2 MTCAM: 300 F^2, 1 µW
- CMOS vs. MCMOS: 16 MOSs vs 6 MOSs+ 2 MTJs

MCMOS @ CMP

CILOMAG Project: IEF Lab, SPINTEC Lab, LETI, LIRMM Lab, CROCUS Techonololgy, CMP

Silicon foundries: Austriamicrosystems 0.35 µ CMOS
STMicroelectronics 130 nm CMOS

MRAM postprocess: LETI

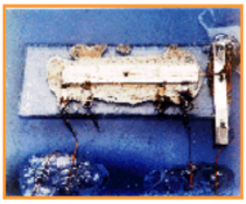
DK on .35 µ CMOS

- Design-Kits on Austriamicrosystems 0.35um CMOS :
- Electrical model developed by SPINTEC (Grenoble) (Spectre model and Verilog-A model)
- Layout, DRC, LVS, P-cell developed by CMP (Grenoble) (DRC / LVS on Assura)

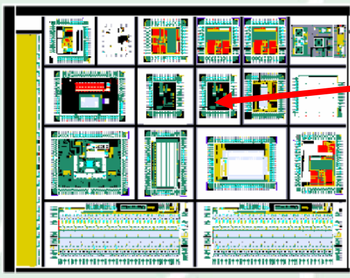
CMOS-MTJ: First Prototype

- Designer : LIRMM (Montpellier)
- Application : Non Volatile FPGA prototype
- CMOS process : Austriamicrosystems 0.35um CMOS
- CMP MPW run : A35C7-2
- MRAM Post-Process : INESC (Portugal)

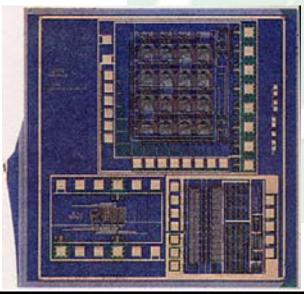
First Point Contact Transistor (1947)



First Integrated Circuit (1958)



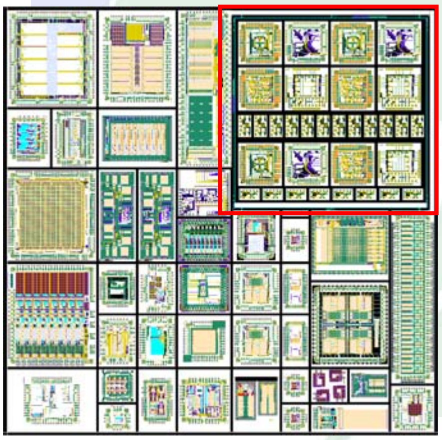
First MCMOS Prototypes ever made in a MPW run CMP (2008)



First MPW CMP (1981)

CMOS-MTJ Second Prototype

- Designers : All CILOMAG partners
- Application : Different block architectures.
- CMOS process : Austriamicrosystems 0.35um CMOS
- CMP MPW run : A35C8-2
- MRAM Post-Process : LIMN / LETI (Grenoble) Delivery : Q1 2009



Embedded CMOS MTJ MPW
in a CMOS MPW

CMOS-MTJ Third Prototype

- Designers : All CILOMAG partners
- Application : Different block architectures.
- CMOS process : STMicroelectronics 130nm CMOS
- CMP MPW run : S13C9-2 (April 2009)
- MRAM Post-Process : LIMN / LETI (Grenoble)
  Delivery : Q4 2009

Self-powering ICs with PV/OPV

2 approaches

LPICM Laboratory, Paris

Thin Film PV:

→ PV cell = stack of aSi PIN or NIP junction

→ TCO on top (Transparent Conductive Oxide)

→ Possibility to adapt the deposition according to the targeted light spectrum

→ Possibility of tandem to increase voltage and power supply

→ Aluminum collection grid to reduce series resistance and to increase the efficiency

→ On substrate or above Silicon

I|D|ME, Canada

Organic PV + Super Capacitors

→ Polymer based

→ Low cost

→ Flexible substrate

→ High Organic PV performances

→ 3D stack OPV / StOR capacitors

COMMON features

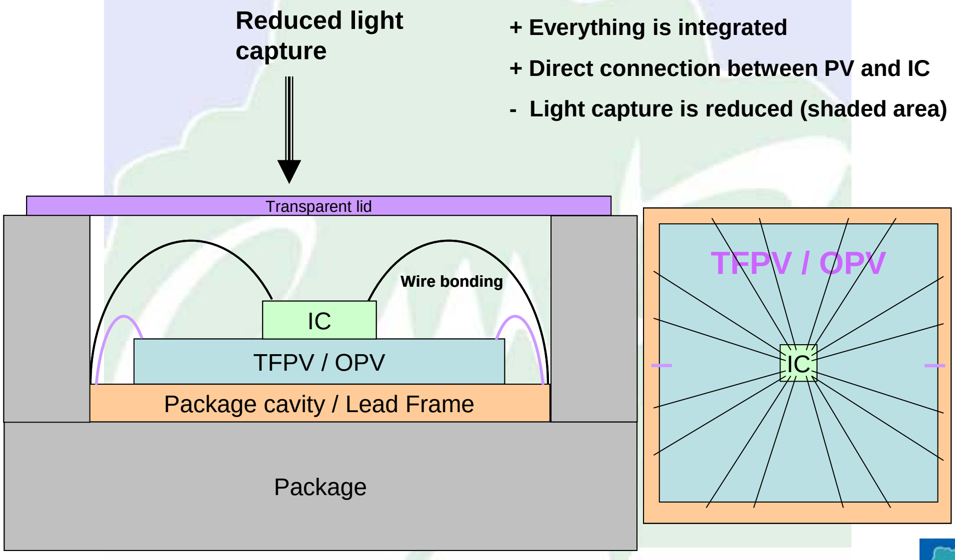
→ Any substrate

→ Bonding pads on top

→ Series / parallel cell connection

Scenario #1 : IC on top of the stack

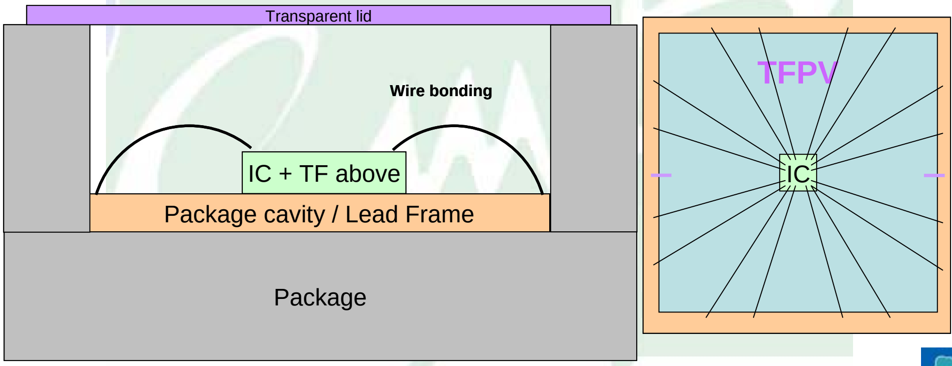
+ Everything is integrated
+ Direct connection between PV and IC
- Light capture is reduced (shaded area)



Scenario #2 : IC + PV on silicon on top of the stack

Optimized light capture

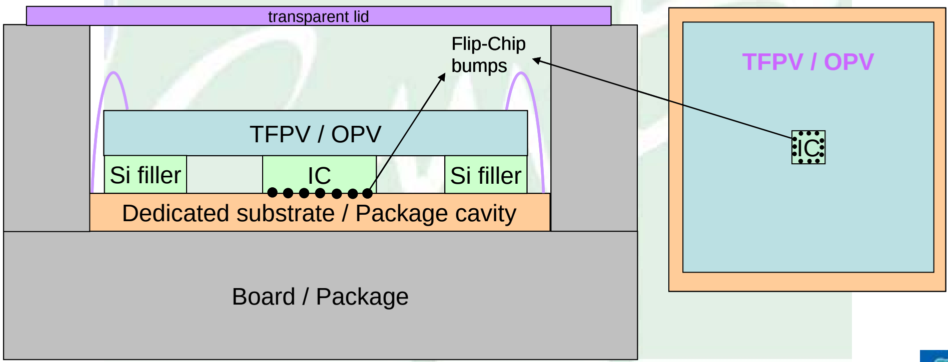
- **+ Everything is integrated**
- **+ Full light capture**
- **- Small PV area**
- **- Post process**



Scenario #3 : TFPV / OPV on top of the stack

Full light capture

- **+ Everything is integrated**
- **+ High Frequency / Ultra low power application**
- **+ Most packages are convenient**
- **- Need a specific development**



Scenario #4 : Standard IC packaging with TFPV / OPV lid

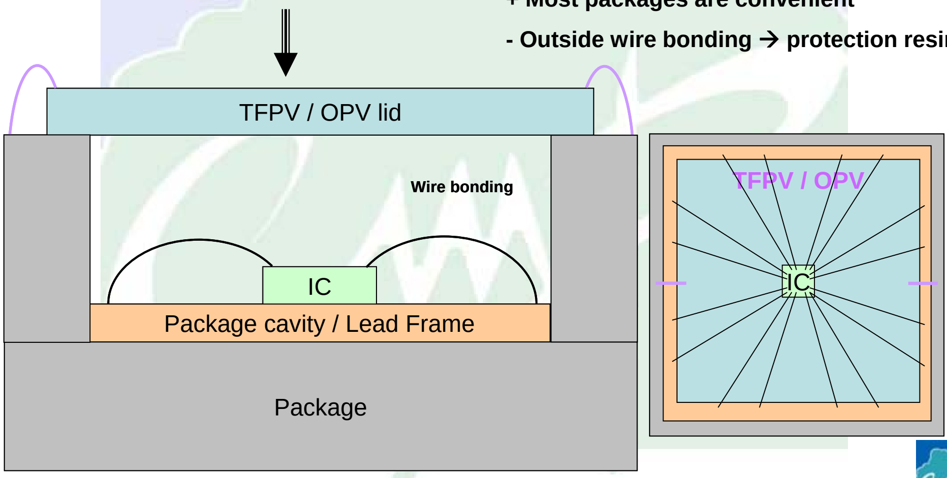
Optimized light capture

+ Easy to setup

+ Full light capture

+ Most packages are convenient

- Outside wire bonding → protection resin



Conclusion on the CMP offer

Important features for PV applications supplying ASIC:

- voltage reachable → ~ 1.4 V @ the MPP
- associated current→ ~ 4.3 mA @ the MPP
- available area → up to ~ 4 cm^2 with lids
- flexible substrate with OPV

} 6 mW / IC

→Convenient for ST processes with 1 cell

→Convenient for austriamicrosystems processes with 2 cells in series

+ PV on Silicon for specific application which need to be unpackaged

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- Energy storage / management → StOR Super Capacitors

→ Lots of applications need an easy and large energy storage

Flyer of the CMP offer………

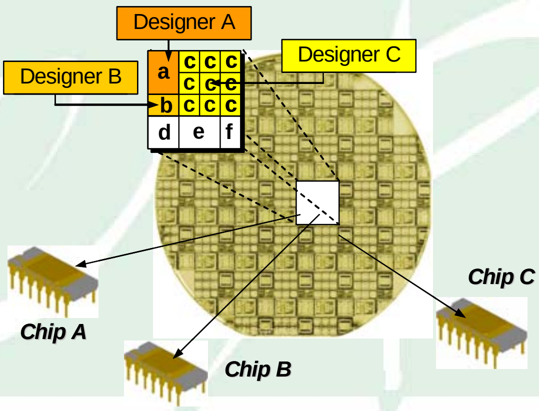
Conclusions (1)

➔ drive a Porsche 918

➔ drink wine instead of water

Conclusions (2)

The CMP help: offer to students, Researchers, Companies to obtain prototypes and small volume production in various technologies at affordable costs.



ICs and MEMS @ CMP over the time

1981–1982	:	launching CMP with NMOS
1983–1984	:	development of NMOS, launching CMOS
1984–1986	:	development of CMOS
1987–1989	:	abandon NMOS, increase the frequency of CMOS runs
1990–1994	:	launching Bipolar, BiCMOS, MESFET GaAs, HEMT GaAs, advanced CMOS (.5 µ TLM)
1995–1997	:	launching CMOS, BiCMOS and GaAs compatible MEMS, DOEs, deep-submicron CMOS (.25 µ 6LM)
1998	:	launching surface micromachined MEMS, abandon MESFET GaAs
1999	:	launching SiGe, .18 µ CMOS
2001	:	.35 µ HBT SiGe BiCMOS
2003	:	130 nm CMOS
2003	:	PolyMUMPS, MetalMUMPS, SOIMUMPS
2004	:	90 nm CMOS
2005	:	ASIMPS, SUMMIT/SANDIA
2006	:	65 nm CMOS
2008	:	45 nm CMOS, 65 nm SOI
2009	:	40 nm CMOS
2010	:	130 nm 3D-IC, TEZZARON / GLOBALFOUNDRIES
2010	:	20 nm FDSOI, LETI – CEA
2011	:	150 nm GaAs pHEMT, TRIQUINT
2011	:	180nm CMOS CIS, TOWERJAZZ
2011	:	28 nm CMOS, STMicroelectronics
2012	:	28 nm FD-SOI, STMicroelectronics, 0.18µ CMOS/HV-CMOS, AMS
2013	:	Analog 130nm H9A CMOS, STMicroelectronics, THELMA MEMS, STMicroelectronics

Beyond 2013 @ CMP

- 28 nm FDSOI✓
- 3D ✓
- magnetic-CMOS ICs
- PV/OPV above/on CMOS ✓

➔ More Moore and More than Moore

➔ Mixing technologies / communities
+ photovoltaics + CMOS
+ magnetics + CMOS

For key application areas
+ BioMed for health care
+ energy management
+ environment
+ security
+ ....