Innovating For The Future - Ultra Low Power Electronics in the Next Decade

Ajith Amerasekera

Texas Instruments Inc.
Dallas, USA

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OUTLINE

- Innovation
- Roadmap for the Next Decade
- What Do We Need?
- Next Steps in Low Power Electronics
- Key Challenges
- Conclusion

INNOVATION

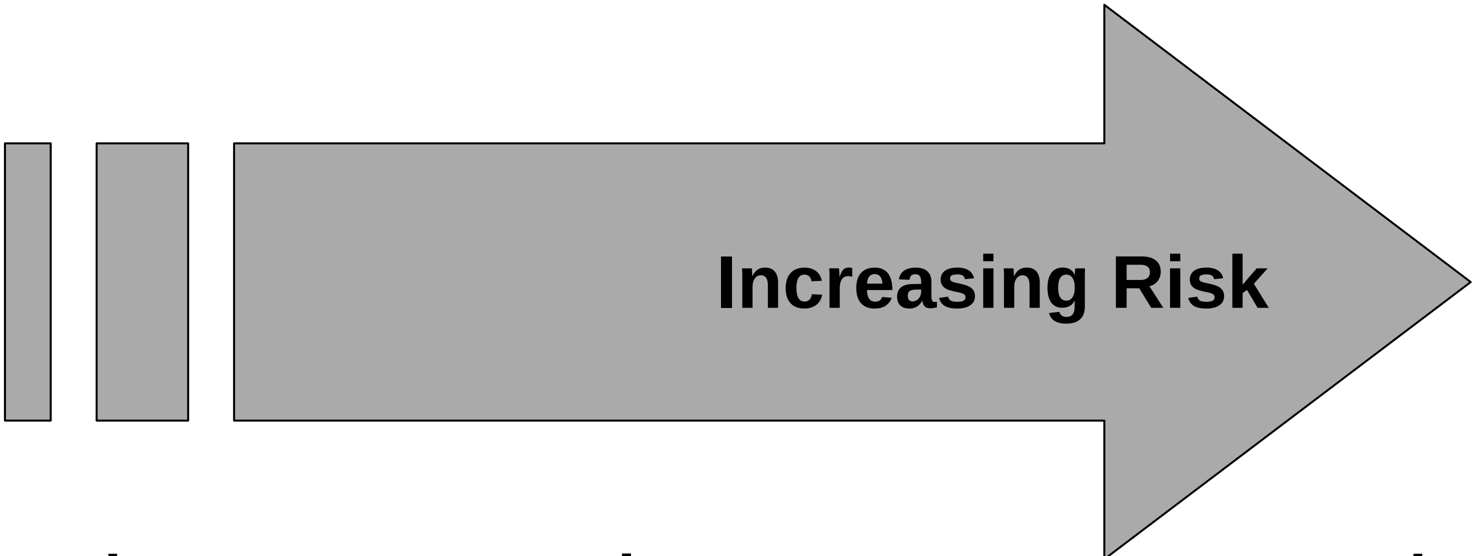
What is Innovation?

- Innovation is defined as the successful implementation of creative ideas within an organization.
- All innovation begins with creative ideas
- But creativity by individuals and teams is a starting point for innovation; the successful implementation or proof of concept is what makes innovation.

- Some general principles:
- ***Anticipate*** and ***exploit*** early information through 'front-loaded' innovation processes
- ***Experiment*** frequently but do not overload the organization
- ***Integrate*** new and traditional technologies to unlock performance
- Organize for ***rapid*** experimentation
- ***Fail*** early and often but avoid 'mistakes'
- Manage projects as ***experiments*** => prove/disprove solutions.

Looking for New Things

- Research is about looking at the unknown



Execution
Minimum Unknowns

Development
Some Unknowns

Research
Many Unknowns

- Research projects could have return on investment in very short timeframe
  - Not limited to long-term multi-year projects
  - Depends on level of effort required to resolve the unknowns.

Types of Innovation

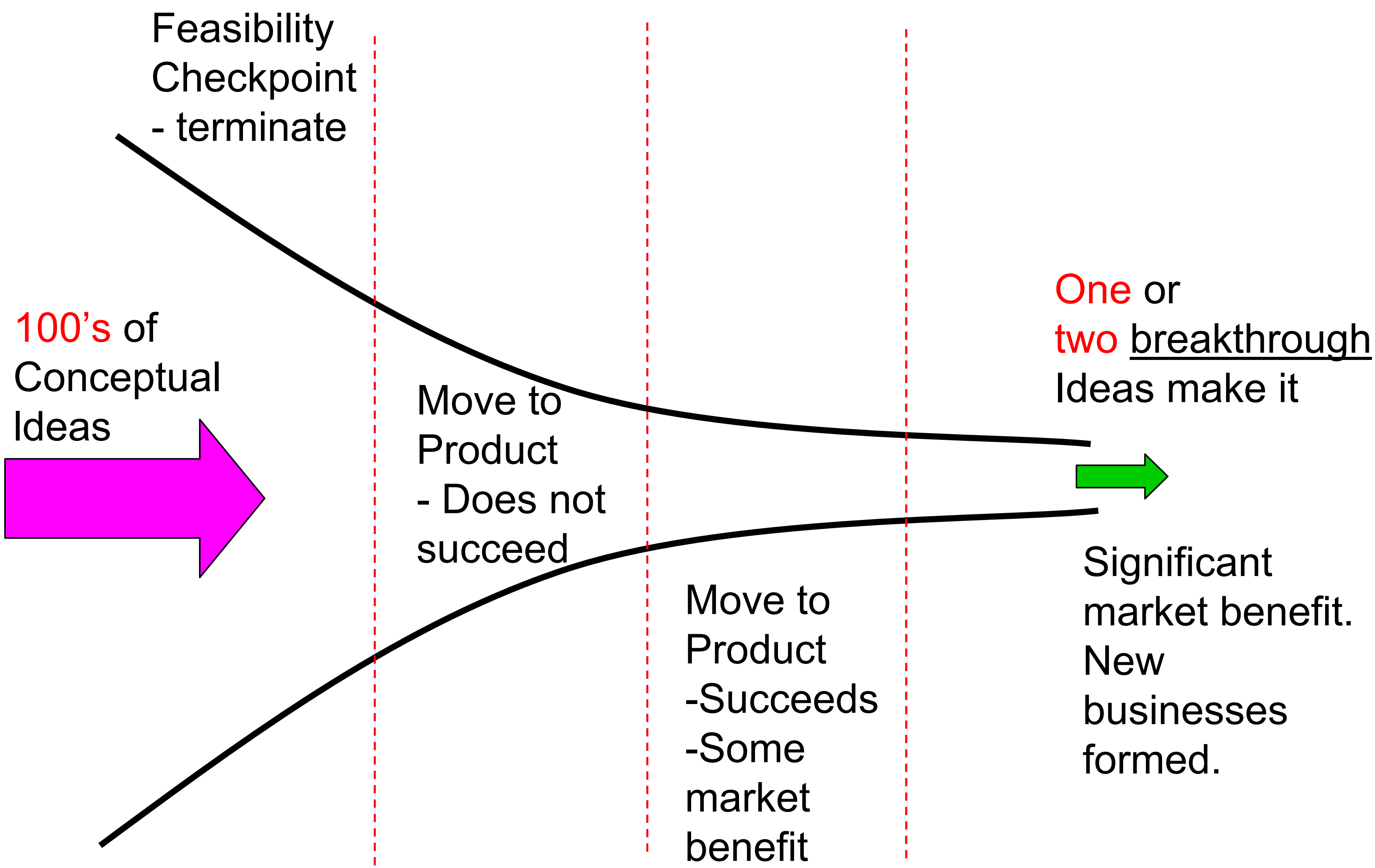
(from Christensen, 1997)

- **Sustaining**
  - **Revolutionary or discontinuous**
    - An innovation that creates a new market by allowing customers to solve a problem in a radically new way. (E.g., the automobile)
  - **Evolutionary**
    - An innovation that improves a product in an existing market in ways that customers are expecting. e.g. fuel injection, high efficiency car engines
- **Disruptive**
  - An innovation that creates a new (and sometimes unexpected) market by applying a different set of values (e.g. lower price); e.g. Flash drives for computer storage.

Innovating for the Future

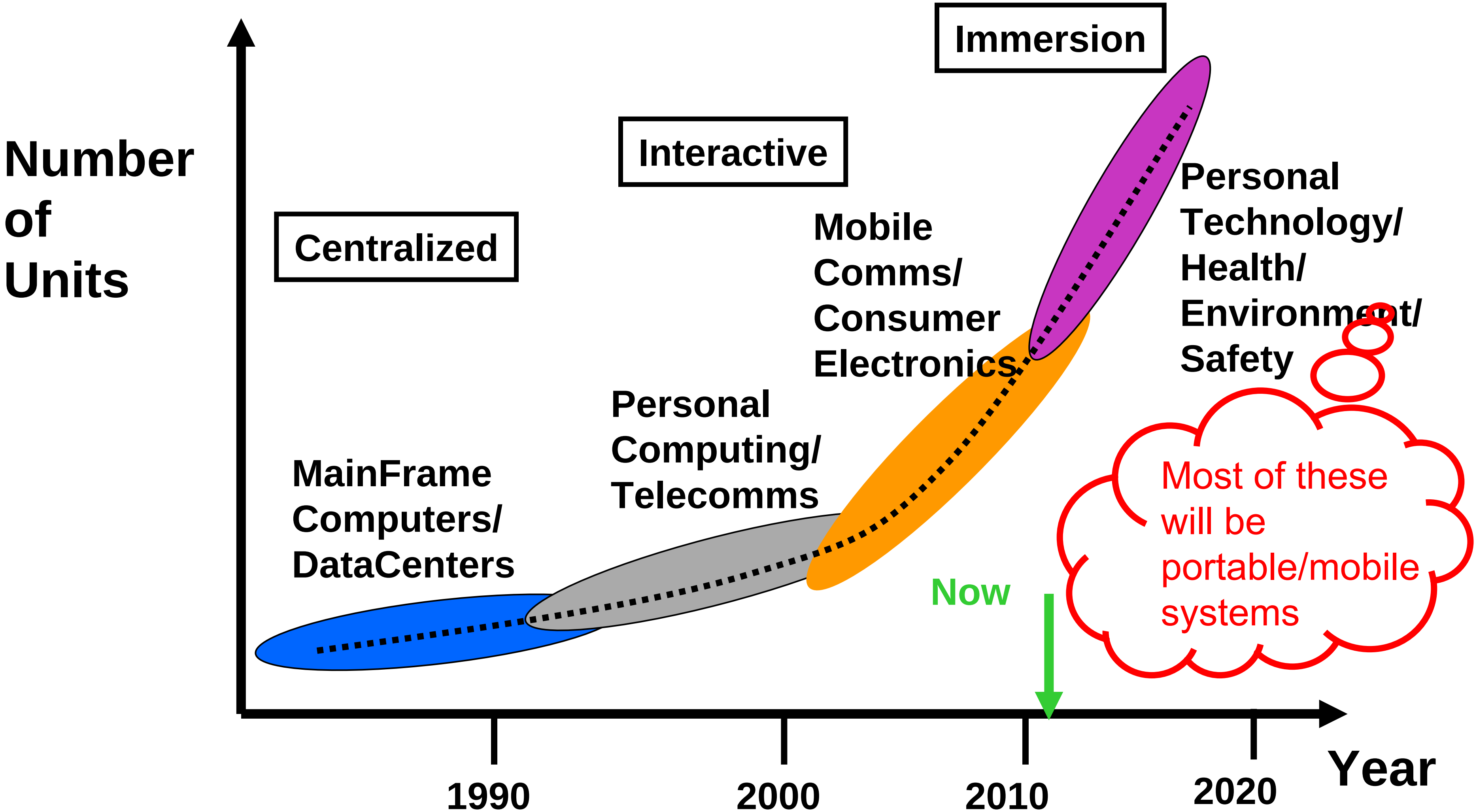
- **The past is littered with wonderful innovations that were too early or too expensive at the time.**
  - PDA, Irridium, Newton, Velo, Digital Cassettes, BetaMax, etc.
  - Right place, right invention, right time
- **All it takes is one brilliant idea**
  - But you will go down a lot of dead ends.
  - Need to take lots of risk, with lots of small investments.
  - Keep picking the winners until the top ideas emerge.
  - Fail quickly, learn from the failures, and move forward fast.
  - Few people have more than one brilliant idea in their lifetimes!

Innovation for the Future

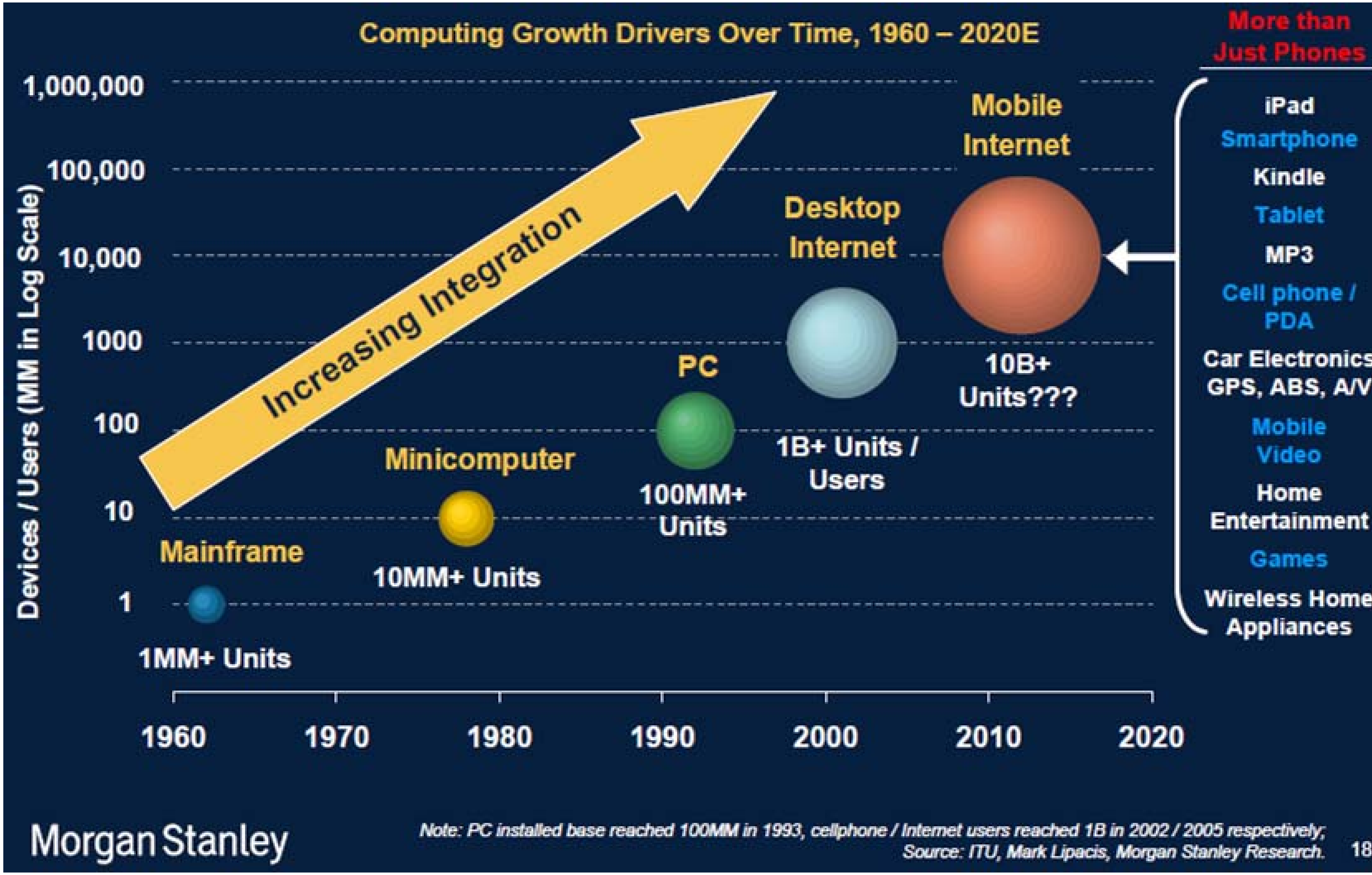


CREATING A ROADMAP FOR THE NEXT DECADE

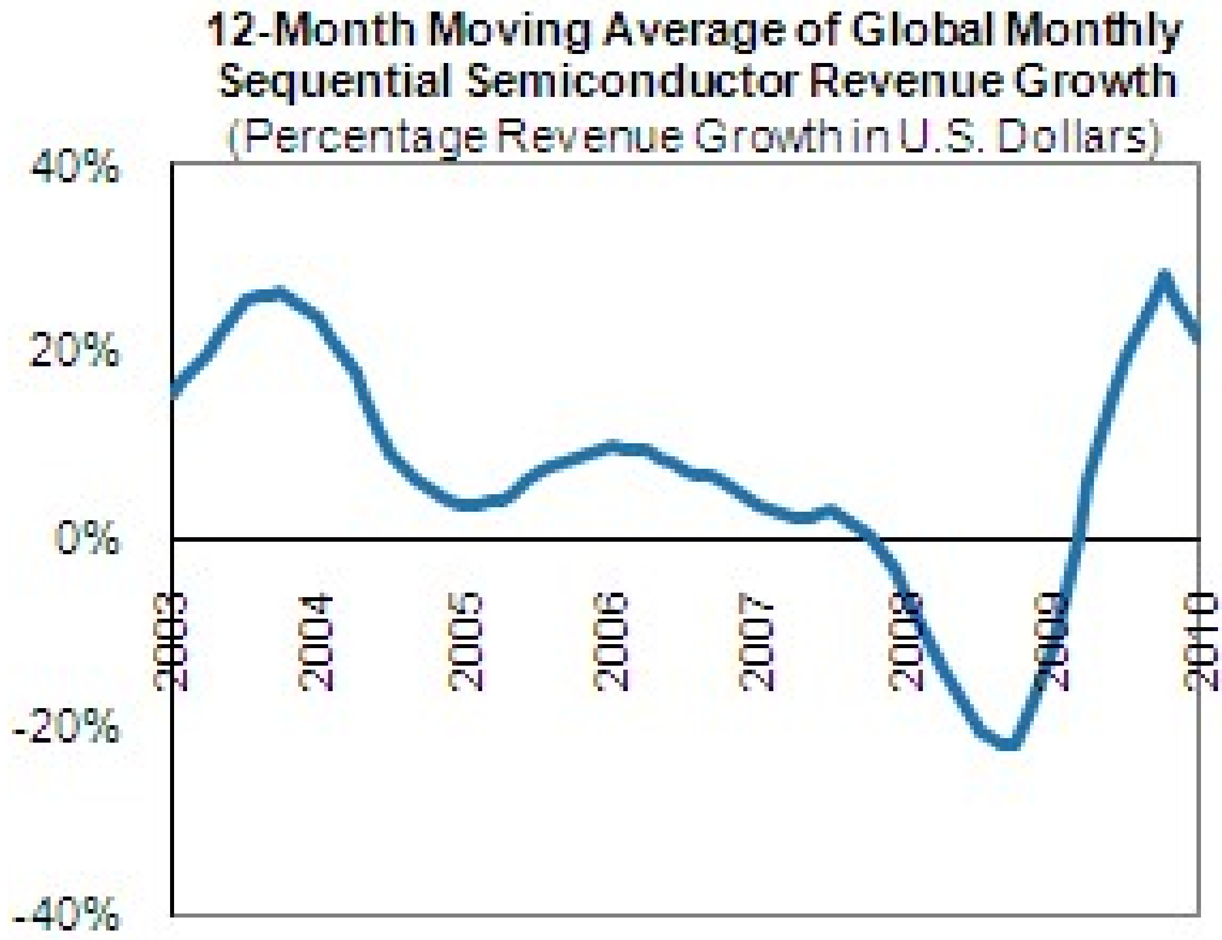
Growth in Electronics



10x to 100x Increase in Units



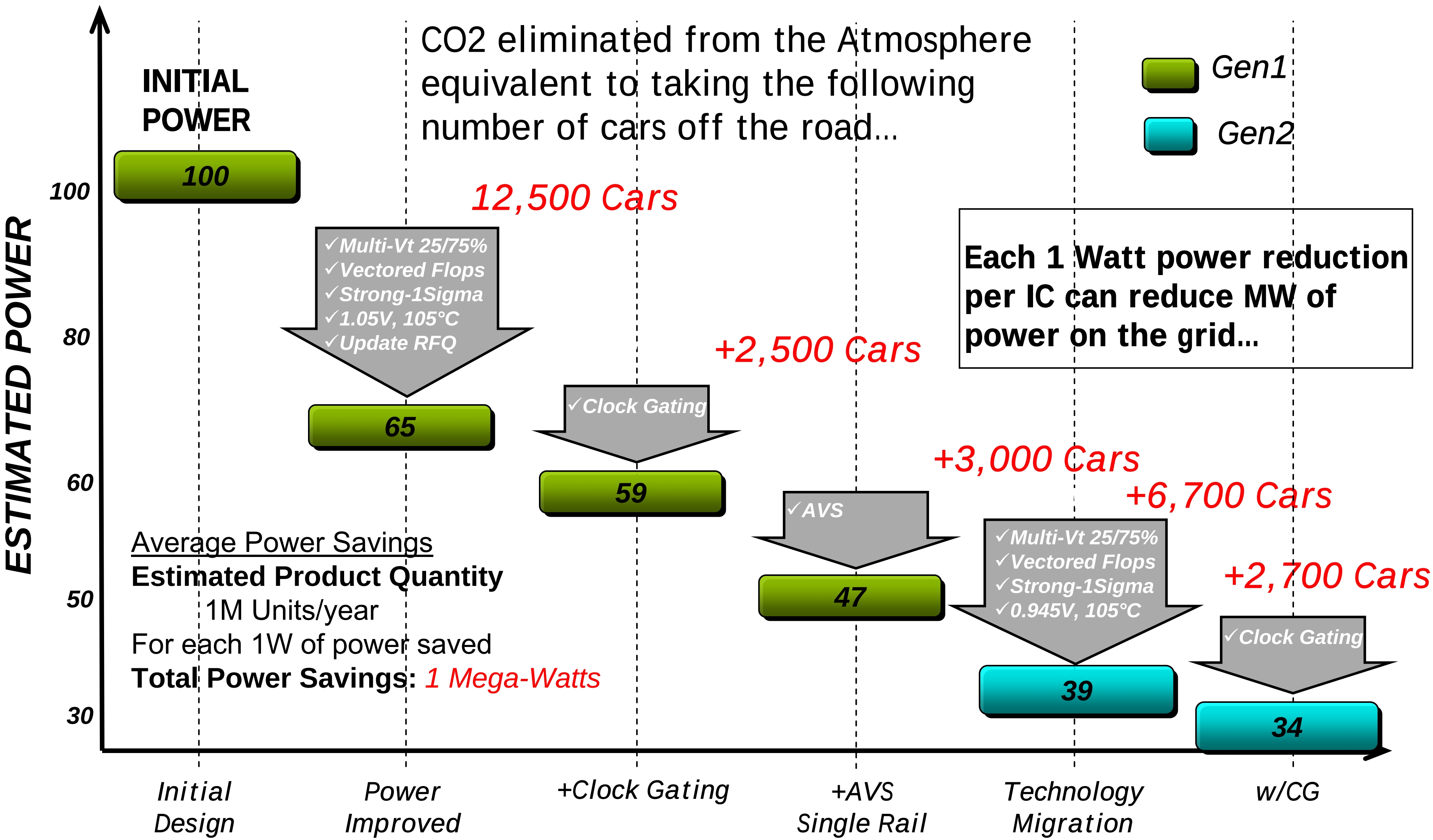
………But Cost is Important



Source: iSuppli

- Semiconductor Revenue grows at <10%/year on average.
- Low cost solutions are critical to growth.

Chip Power Reduction Impact On Cost



Wireless?

EE Times: Latest News

Wireless is everywhere; ignore it at your peril

Bolaji Ojo

Page 1 of 2

EE Times

(01/07/2008 9:00 AM EST)

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SEND AS EMAIL

REPRINTS

The search is over for the next killer app. It is wireless, it is all around you, and it will leave no sector of the global economy untouched.

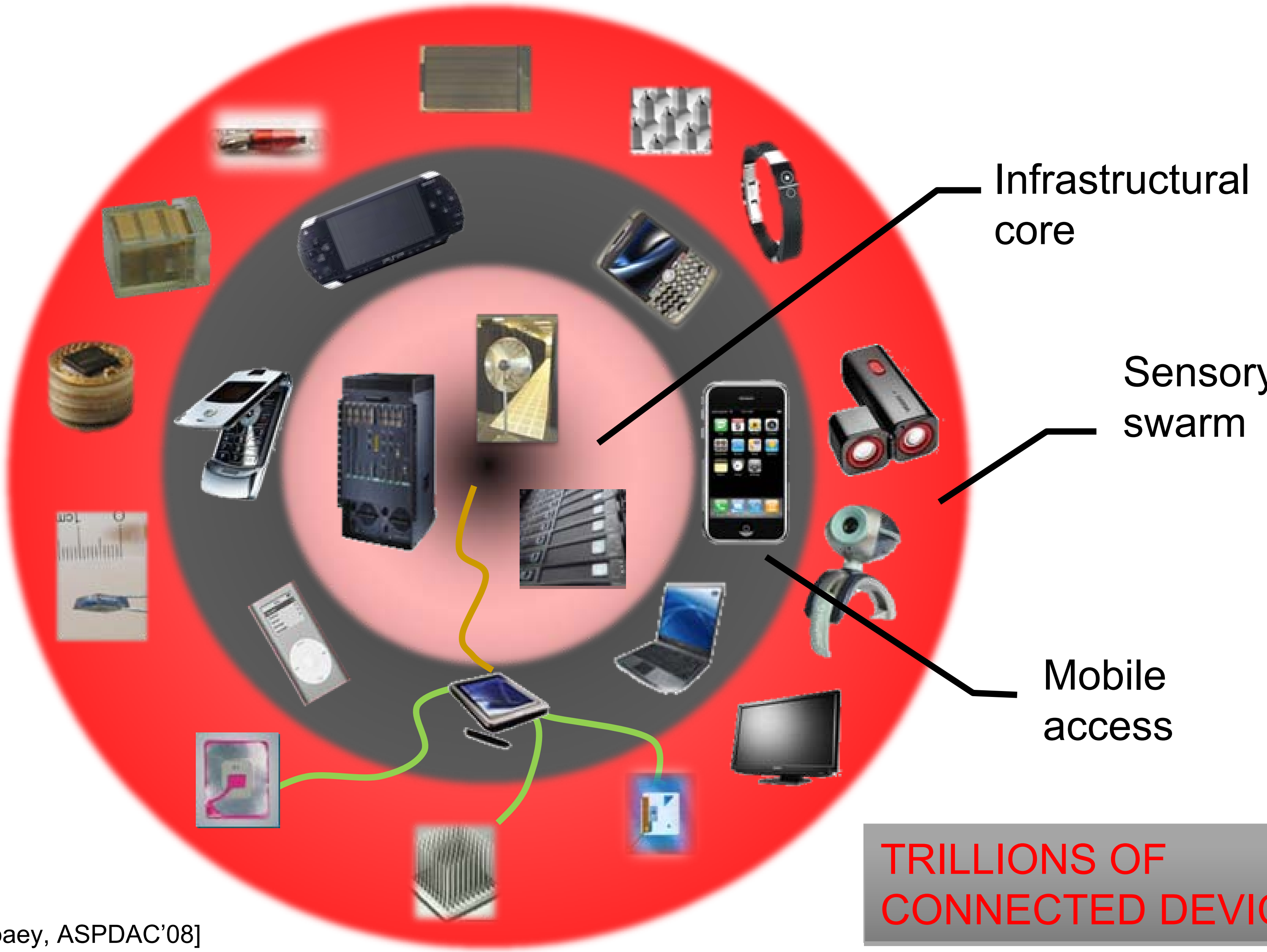
EE Times,
January 07, 2008

Growth of Wireless to Continue Unabatedly!

- 5 Billion people to be connected by 2015 (Source: NSN)
- 7 trillion wireless devices serving 7 billion people in 2017 (Source: WWRF)
  - 1000 wireless devices per person?

[Courtesy: Niko Kiukkonen, Nokia]

THE IT PLATFORM OF THE NEXT DECADE(S)



TRILLIONS OF CONNECTED DEVICES

[J. Rabaey, ASPDAC'08]

WHAT DO WE NEED?

Life in the Future

From back in the 60's!!

Technology was changing the world.

- Man on the Moon
- Concorde and Jumbo Jets
- Electric Music, Video, Cassettes
- etc……

But……major limitations to the Jetson's World

- Power, Cost, size

What does it take?

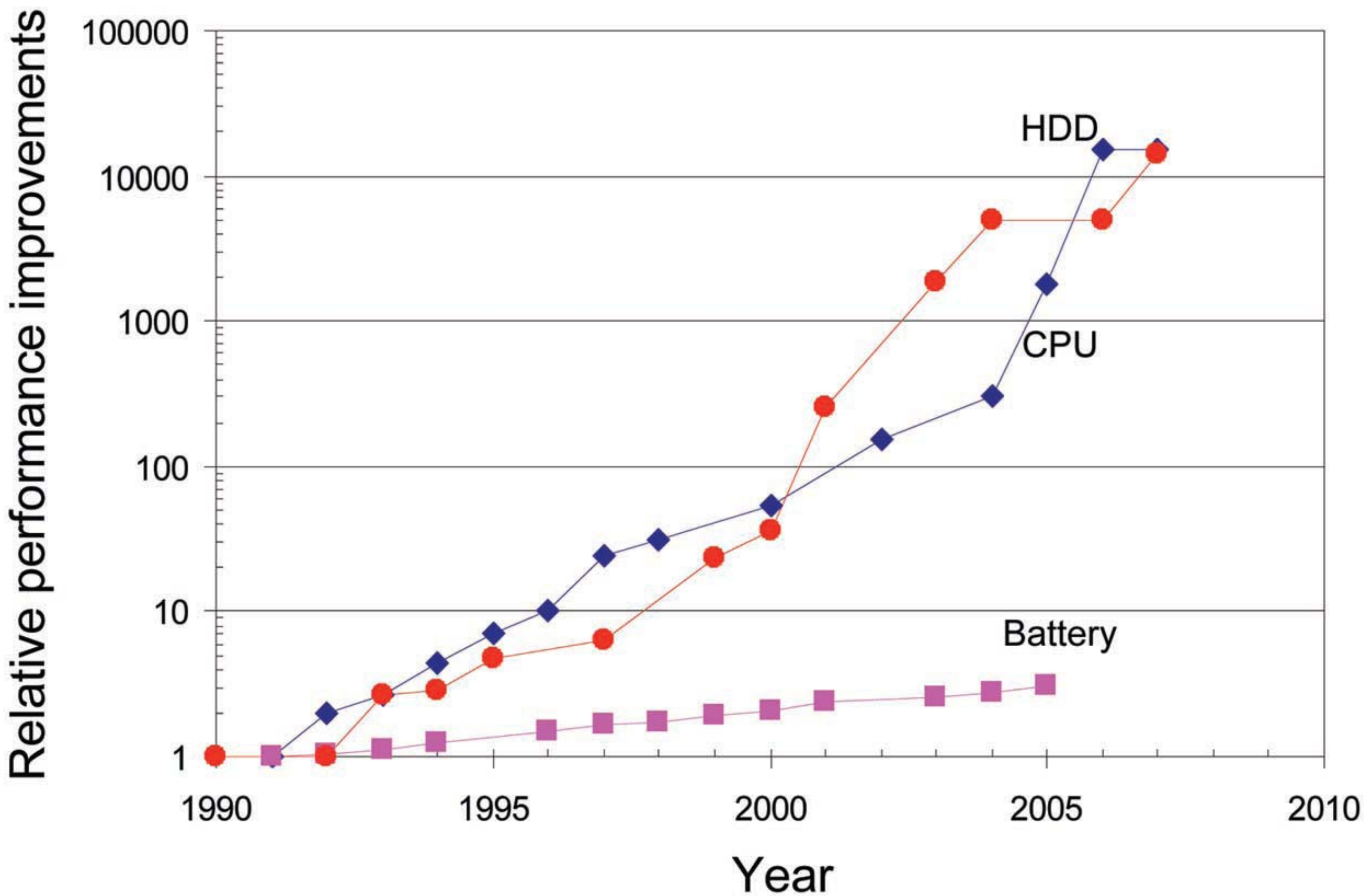
- Wireless Networks
- Low Power Circuits
- Sensors
- Human Machine Interfaces
- Energy Harvesting
- RF/Analog
- High speed Data Communication
- Data Analysis

Energy Generation and Management

- **Major limitation for expansion of the application space for semiconductors**
  - Intelligent environment requires wireless and autonomous systems that can operate for approximately 10 years.
  - Two types of portable electronics:
    - Performance "hub" devices such as computers, multi-media devices, wireless hubs and PDAs which have 1W to 5W needs today.
    - Distributed systems with micro and nano watt needs.
- **Typical autonomous system would be:**
  - 10 years life.
  - Battery size/cost point is ~1mAh.
  - Average power available from battery < 1nW.

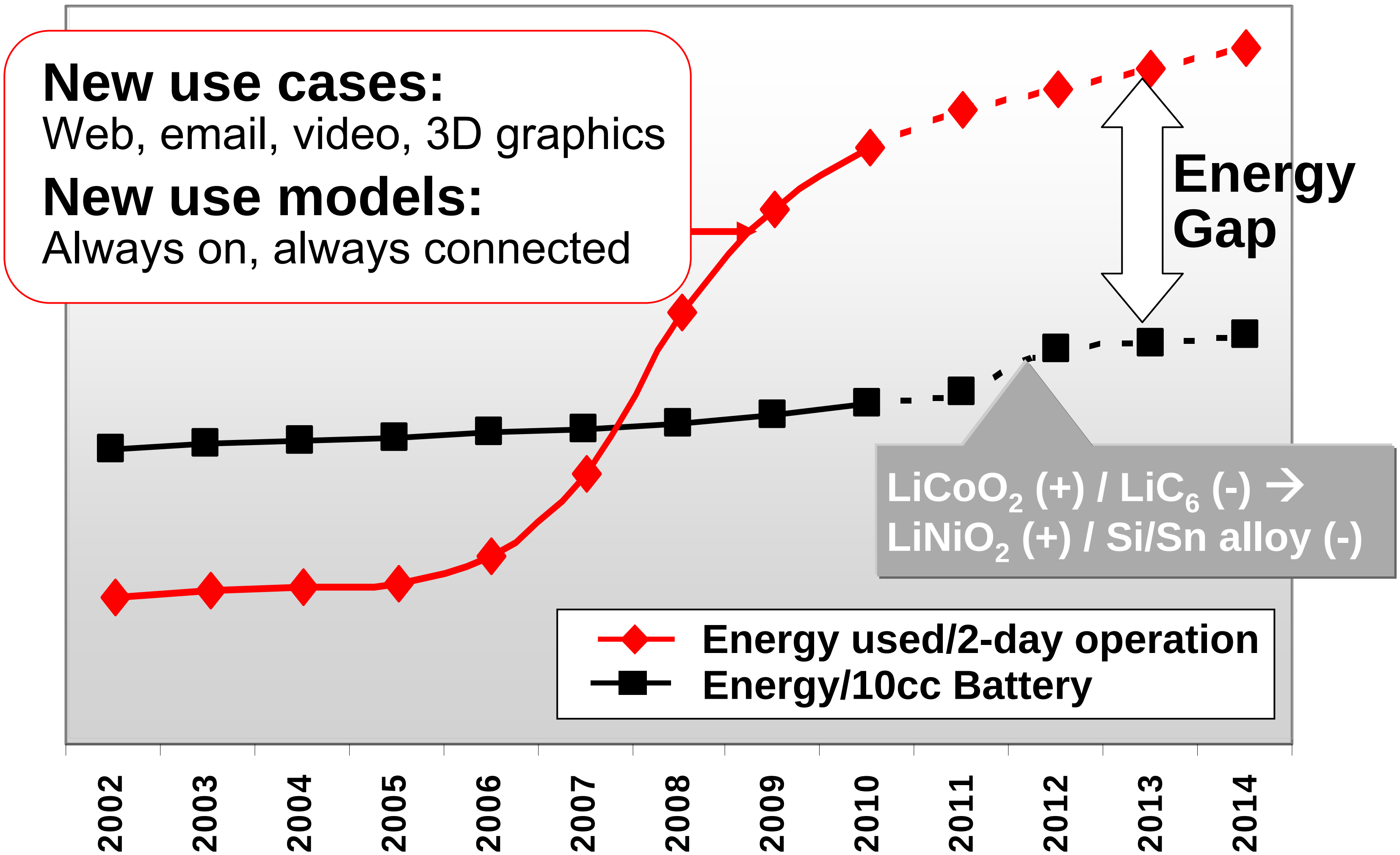
Battery Technology Is Trailing Demand

- Battery technology scaling at about 2x every 10 years compared to semiconductor technology at 2x every 18 months.



Ref: Chalamal, Proc. IEEE, 2007

Energy gap of a mobile device

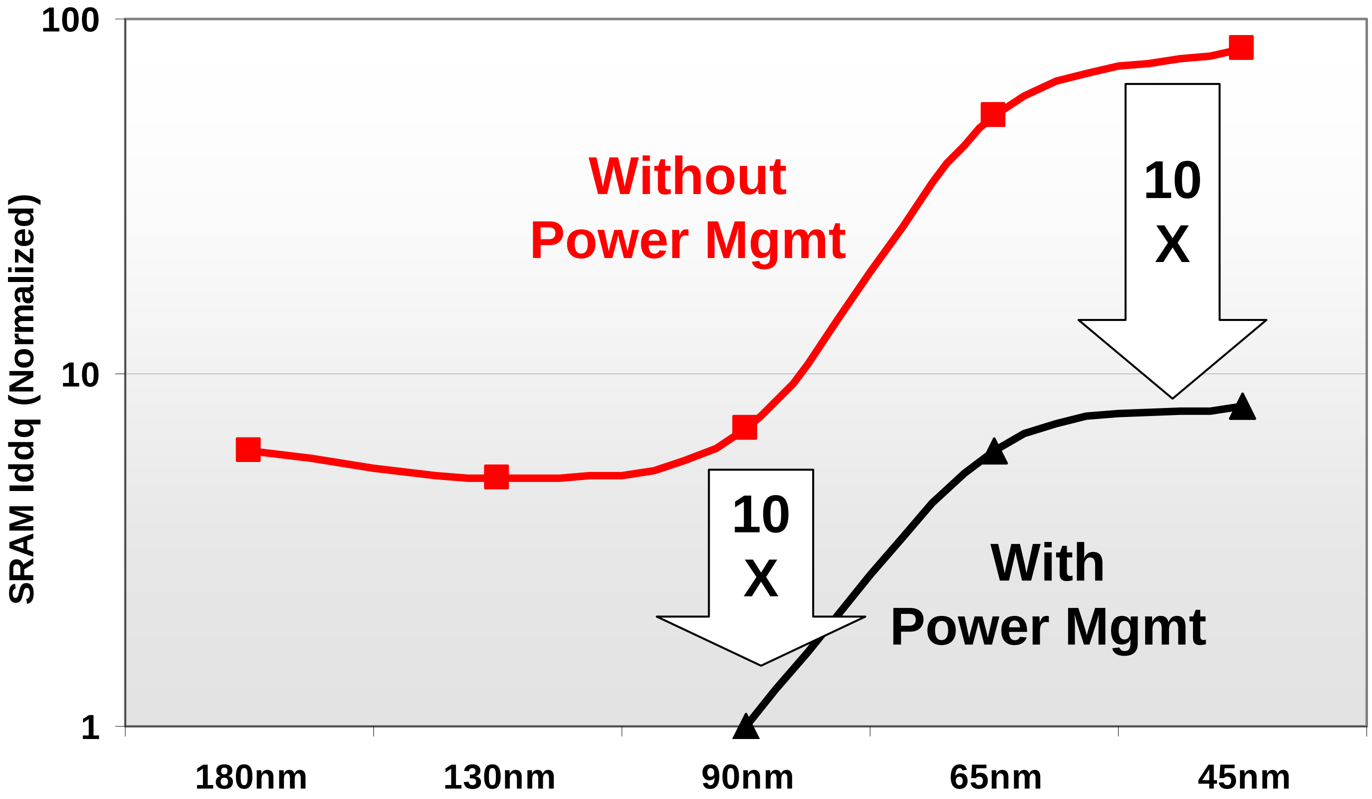


Delagi, ISSCC10

Source: Öfversten [IWPC'08], Samms [IWPC'08]

Silicon performance advances require power management

Delagi, ISSCC10



Source:
Gammie [ISSCC'08]

- **Performance: +20~30% node-to-node**
- **Leakage: a concern in 90nm, required fundamental change in 65nm**

Circuit-level power mgmt

Power Management Techniques

	Dynamic Power Reduction[1]	Leakage Power Reduction[1]
Multi-VT and Multi-L	Varies	34%/~7x
Clock Gating	~12% - 30%	Varies
Memory PM Modes	~2x	3-30x
Voltage Islands	CV^2F	~1.5x
Adaptive Voltage Scaling Static (Open Loop)	~9-15%	~10% -27%
Adaptive Voltage Scaling Dynamic (Closed Loop)	~10-19%	~15%-50%
Optimized IP	Varies	Varies
Power Islands	NA	~20-100x
Dynamic Voltage and Frequency Scaling (DVFS)	Varies	Varies

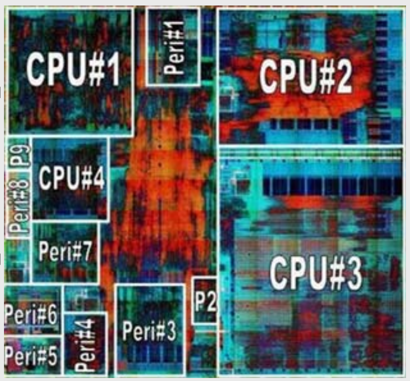
1 Figure of Merit, Impact is design dependent

Industry breakthrough examples (published)

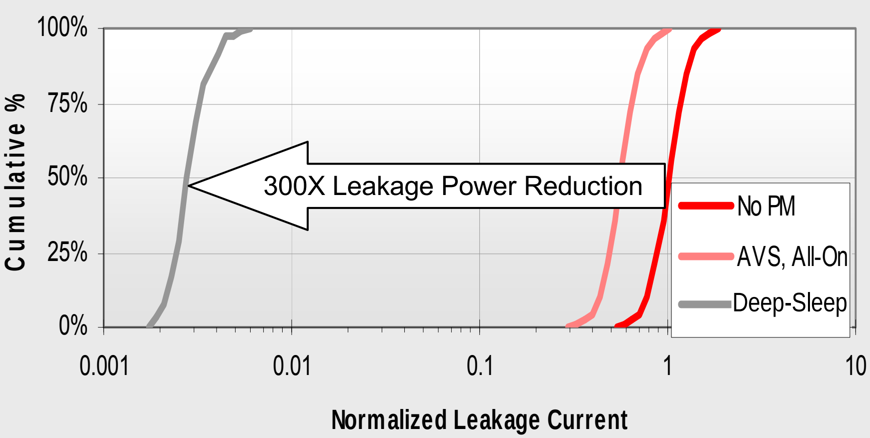
- **<u>Power</u>** & **<u>performance</u>** management technology
- Reduces both leakage <u>and</u> active power, increases performance

65nm leakage power reduction: 300X

Mair [VLSI'07]

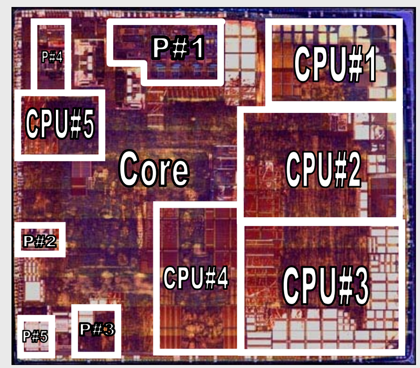


- SRAM retention
- Logic power gate
- Channel length
- Logic retention
- Process/temp AVS
- DVFS

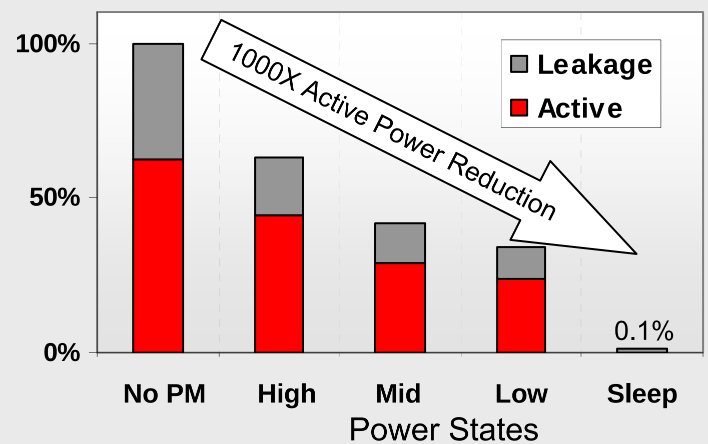


45nm active power reduction: 1000X

Gammie [ISSCC'08]



- Adaptive Body Bias (ABB) for performance & power
- Retention 'Til Access (RTA)

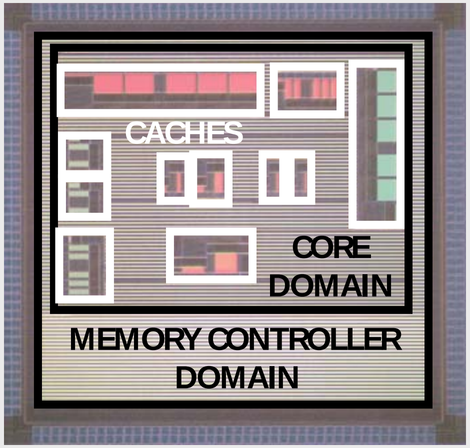


Delagi, ISSCC10

Directions in ultra-low power

Ultra-low power video codec

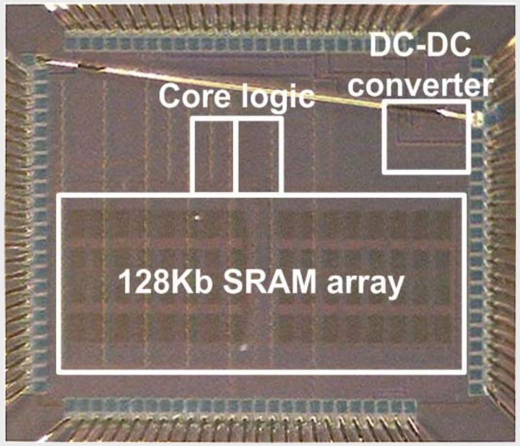
Source: JSSC Nov 2009



Video decoding for <2 mW at Vdd = 0.7V

Ultra-low power medical processor

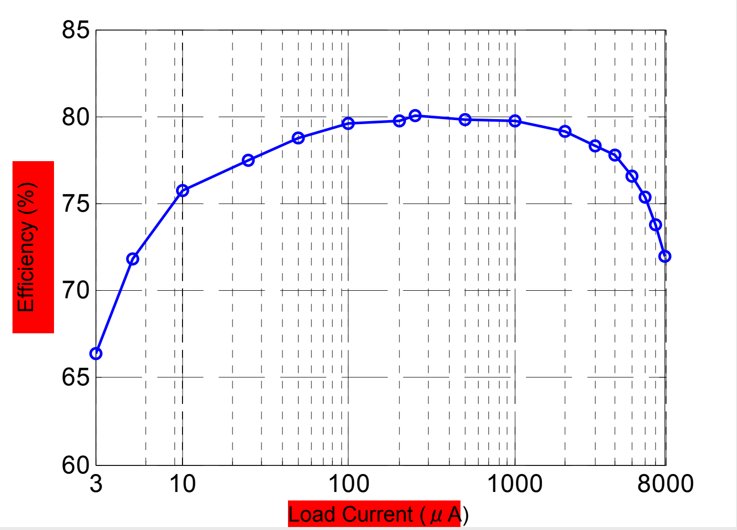
Source: ISSCC 2008



MSP430 uC with SRAM at Vdd = 0.3V

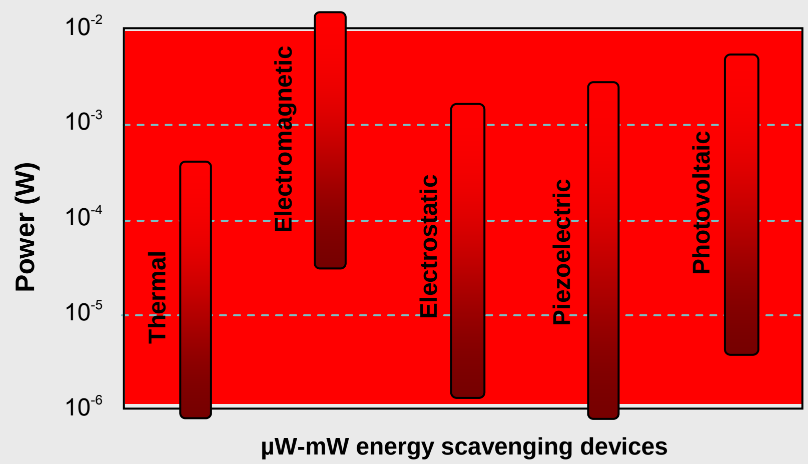
Ultra-low power DC-DC converter

Source: MIT research



DC-DC with 75% efficiency down to 10 uA

Energy scavenging

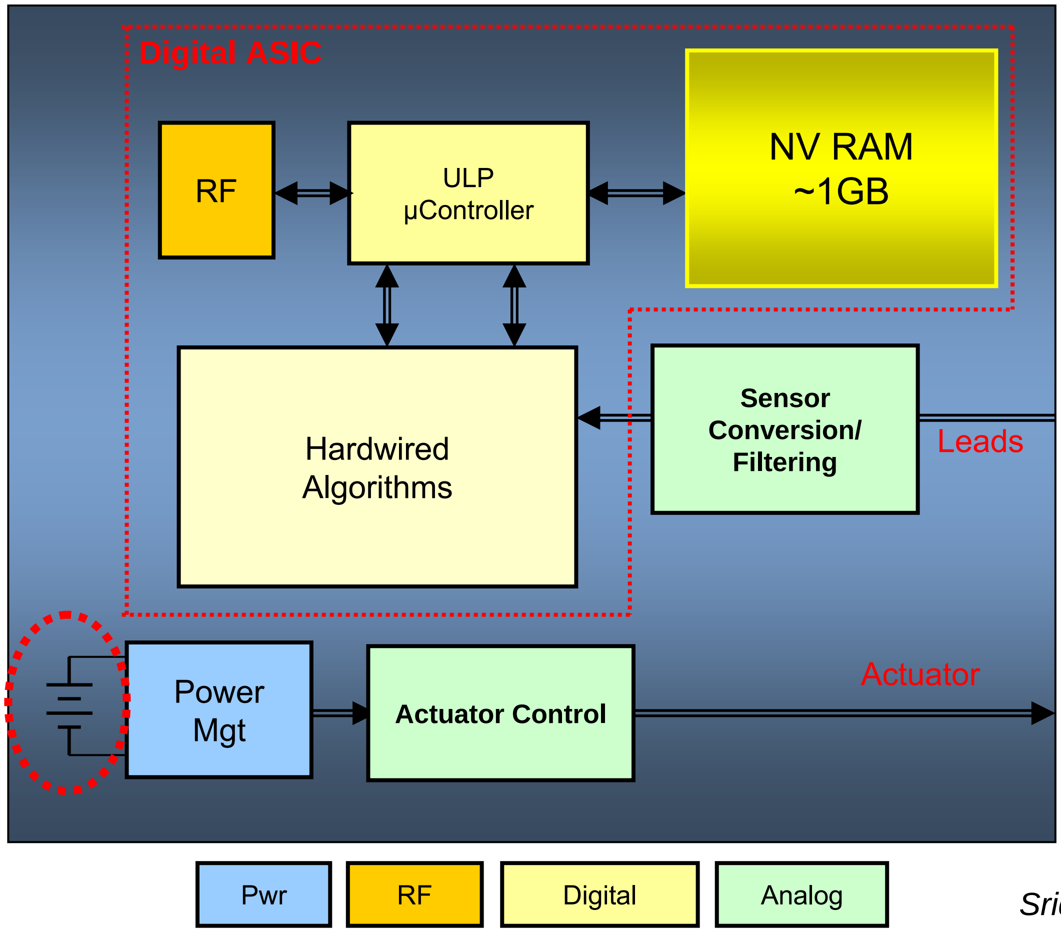


Scavenging energy from the environment

Next Steps in Low Power Electronics

Ultra Low Power Chip Design

Typical Design for Intelligent Ambient Applications



1mA-Hr Battery for 10 years
1uA average power budget
<1uA average for digital system

- Use circuit design techniques for optimizing energy-performance
- Then apply system design and software management to reduce power by another order of magnitude

Sridhara, VLSI Symp. 2010

Battery Technology is Critical

- **Li-Ion was the game-changer for the 2000's.**
  - In 1990s nickel cadmium and nickel metalhydride rechargeable batteries were the preferred energy technology
  - In last 10 years, lithium batteries have taken over with a current market share of over 70%.
  - lithium cell is its high energy density, => small size, lightweight, longer lifespan than comparable battery technologies.
  - Also, high power, high-energy efficiency, low self-discharge, and good cycle life. Specific energy densities greater than 190 Wh/kg.
  - But now approaching its limit with small incremental gains

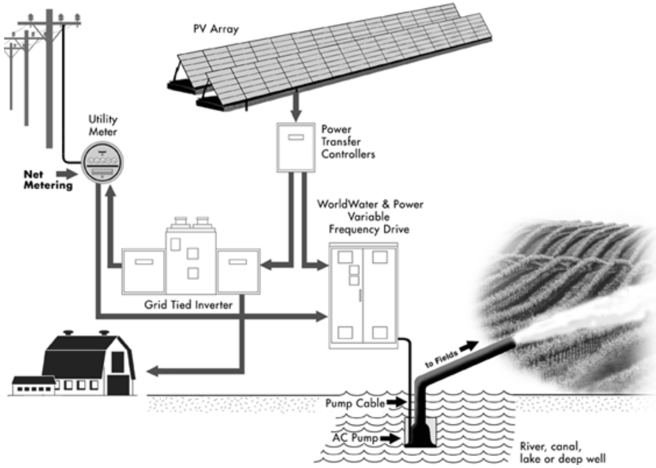
- ***We need the next breakthrough in energy delivery for the 2020s!!***

  - Capacity, Cycles, Rate, are critical parameters.

Renewable Energy

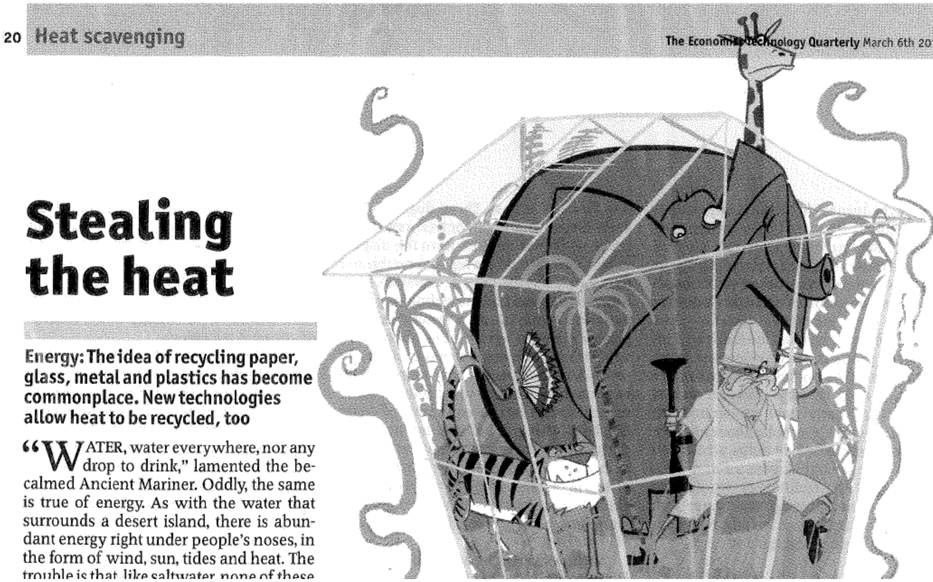
- Renewable Energy Has Tremendous Potential

- Solar energy products
  - Photovoltaic systems
  - DC/AC power inverters
- Wind energy products
  - Wind turbines
- Hydro energy products
- Heating systems



Energy Harvesting

Economist, March 2010



Stealing the heat

Energy: The idea of recycling paper, glass, metal and plastics has become commonplace. New technologies allow heat to be recycled, too

"WATER, water everywhere, nor any drop to drink," lamented the becalmed Ancient Mariner. Oddly, the same is true of energy. As with the water that surrounds a desert island, there is abundant energy right under people's noses, in the form of wind, sun, tides and heat. The

- Vibrational, thermal, photovoltaic, RF power have been proposed.
  - Harvest energy from motion, heat, light and RF.
  - Great for triggering imagination.

- But micro and nano ampere power levels are very inefficient.

- Laws of conservation usually apply
  - Inserting a harvester can increase the energy usage by the generating system.

Need a lot more understanding to appreciate trade-offs and practical solutions.


STARTUP TO WATCH

nPower Makes Battery Charging a Walk in the Park

By Jack M. Germain
TechNewsWorld
01/05/10 11:05 AM PT

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The idea behind Tremont Electric's nPower PEG


guardian.co.uk

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Environment

Nokia developing phone that recharges itself without mains electricity

Prototype harvests radiowaves from TV, radio and other mobiles

~ 5mW from 1000 energy sources.

Energy Scavenging Efficiencies

Energy Source	Characteristics	Efficiency	Harvested Power
Light	Outdoor Indoor	10~24%	100 mW/cm^2 100 µW/cm^2
Thermal	Human Industrial	~0.1% ~3%	60 µW/cm^2 ~1-10 mW/cm^2
Vibration	~Hz–human ~kHz–machines	25~50%	~4 µW/cm^3 ~800 µW/cm^3
Embedded Energy	Chemical Radioactive	~90+% ~30%	~90+% ~1- 20 µW/cm^3
RF	GSM 900 MHz WiFi	~50%	0.1 µW/cm^2 0.001 µW/cm^2

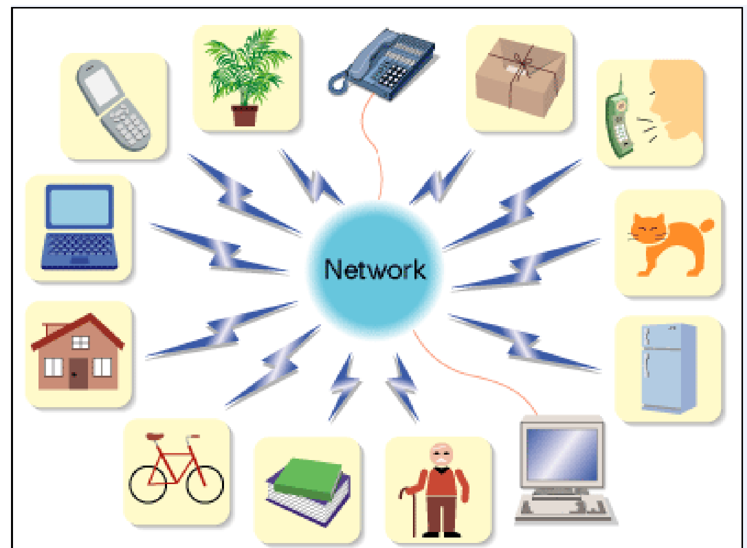
⇒Need to look at non-traditional areas for scavenging energy. What else do we have?

⇒Energy generation using biological, micro-fuel cells, etc.

Mobile Internet System

- **It will really be a more distributed system**
  - The internet of things – ***THE SWARM***
- **Use multiple energy sources**
  - Battery for general functionality
    - energy management and control, wake-up functions, etc.
  - Storage caps for high current functions
    - storage, communications
  - Energy scavenging for extended battery life
  - Wireless power sources for connection to grid
    - Directional use of RF, light, etc. in localized area for “topping up”.
- **Intelligent energy management and control**
  - Highly efficient on-chip power processing
  - Control of energy sources and delivery
  - Management of power demand and access
  - Unreliable energy sources

Swarm…….



Ubiquitous computing will enable diverse wireless applications, including monitoring of pets and houseplants, operation of appliances, keeping track of books and bicycles, and much more.

Ubiquitous Computing

KEY CHALLENGES

Challenges for Next Decade - 1

- **Low-Power Electronic Design**
  - Need another two to three orders of magnitude of power reduction.
  - Most known circuit design approaches have been utilized
  - System-level power optimization is needed
  - Can the process technology help? Not just digital any more.

- **System Design**
  - Managing interconnectivity: wireless and network connectivity; protocols are expensive in power and complexity
  - Partitioning for power optimization
  - Security

- **Low-Power Sensor Technology**
  - The intelligent environment requires a wide range of high performance sensors
  - Sensor interface and control needs to become sophisticated

Challenges for Next Decade - 2

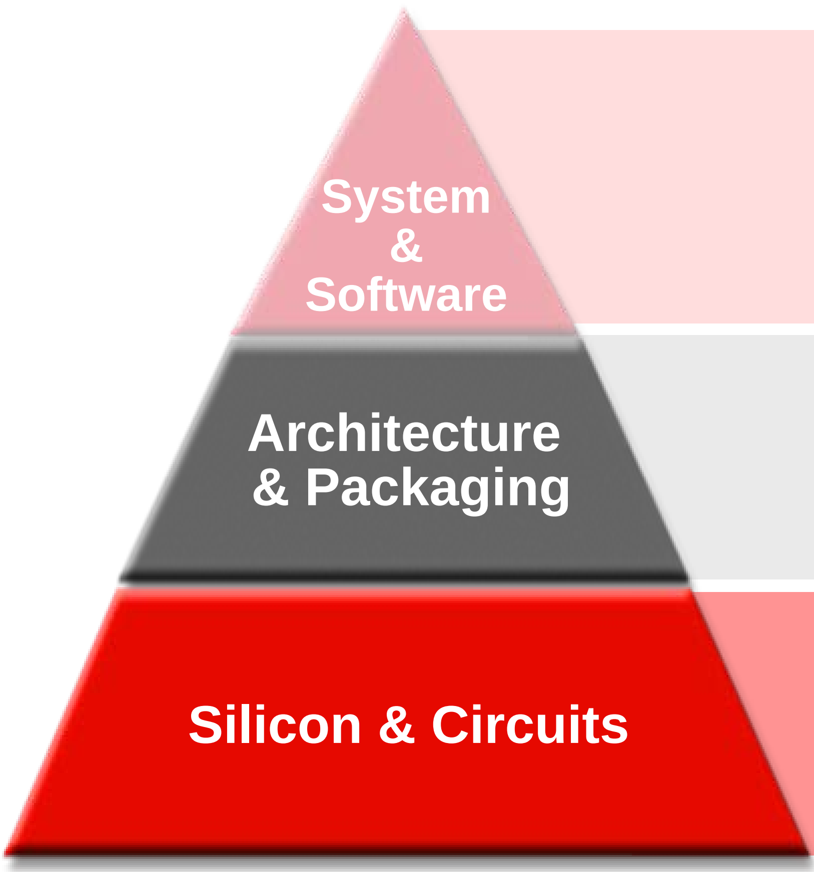
- **Battery and Storage Technology**
  - We need micropower and nanopower battery capability
  - Nanotechnology can provide some of the solutions
  - Smart Batteries, intelligent power management

- **Energy Scavenging**
  - Truly scavenged from waste
  - Efficiency in collection and storage.
  - We need more work in understanding availability, applicability, and harvest/storage.

- **Off-grid power distribution**
  - Local wireless power to storage elements
  - Sense and deliver on-demand
  - Connecting to the grid

CHANGING PARADIGM

Optimizing the system requires collaboration and co-design



- **System & Software:**
  - Essential to maximize circuit level advances
- **Architecture & Packaging:**
  - Duty-cycle of CPUs
  - 3D ICs
- **Silicon Technology:**
  - Low-power optimized
- **Circuit Technology:**
  - Power management

Delagi ISSCC 2010

CONCLUSIONS

Concluding Reflections

- We are on the threshold of a new wave of electronic technology as we move into the decade.
- Process technology not driving the roadmap any more
  - applications driven roadmaps will define what we do.
- Innovation requires risk-taking and exploration
  - step outside the box and use lateral thinking processes.
- Ubiquitous intelligence is going to drive wireless connectivity.
- Energy generation and management are critical.
- Low power and cost are key drivers for market growth.
- Close collaboration across all disciplines of electronic engineering from transistors to systems to software.

THANK YOU!!