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# Batteries and Beyond

## *Power Sources for the Next Generation of Wireless Sensors*

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# Presentation Overview

- Market Issues & Opportunity
- Overview of Current Battery Technologies
- New Power Source Technologies
- Summary

# Wireless Devices - A Rapidly Expanding Market

- Batteries are a multi-billion dollar market, spread across a variety of industries (materials, precious metals, cellular telephones, PDAs, wireless sensors, etc.)

- Yet, cellular telephone penetration was just 16% in China in 2003

# What is Slowing this Market? - Energy Density

- Electronics performance grows exponentially
- New wireless technologies provide large increases in bandwidth and range
- Silicon, board, and device geometries dramatically shrink

- Yet, it took a decade for energy density in Li-Ion batteries to double

# What is Slowing this Market? - Energy Density

- The slow growth in energy density has fostered the multi-billion dollar power management market
- Engineering teams spend inordinate time optimizing for energy consumption
- Solving the energy density problem will allow dollars and talent to be used to create better devices

# Overview of Current Battery Technology

- Two Types of Batteries
  - Primary
  - Rechargeable
- Each has advantages and disadvantages

# Primary Batteries

- Different Types
  - Carbon-Zinc
  - Alkaline
  - Silver Oxide
  - Zinc Air ($ZiO_2$)
  - Lithium ($LiFeS_2$ and $LiMnO_2$)

# Comparison of Primary Battery Types

| Chemistry | Cell Voltage (V) | Cell Capacity (mAh) | Gravimetric Energy Density (WHr/kg) | Volumetric Energy Density (WHr/l) | Capacity loss per YEAR (@ 20C) |
|---|---|---|---|---|---|
| Carbon-Zinc | 1.5 | 10-5000 | 105-195 | 100-180 | 5% |
| Alkaline | 1.5 | 10-5000 | 125-225 | 150-440 | 4% |
| Silver Oxide | 1.5 | 5-200 | 155-285 | 250-500 | 3% |
| Zinc Air | 1.4 | 30-1000 | 245-455 | 470-1450 | 5% (sealed) |
| Lithium | 1.5, 3.0 | 10-3000 | 32-260 | 340-500 | 1% |

# Characteristics of Primary Batteries

- Primary batteries have higher energy density (vs. rechargeables)
- Primary batteries have lower capacity loss over time (vs. rechargeables)
- Carbon-Zinc and Alkaline are commodity “drugstore” batteries

# Characteristics of Primary Batteries

- Lithium batteries are good all-around performers with flat discharge curves, high energy density, and excellent shelf life and low-temperature capacity
- Zinc-Air batteries have relatively high energy density, and use oxygen in chemical reaction, so care must be taken to ensure adequate shelf-life

# Rechargeable Batteries

- Different Types
  - NiCad
  - NiMH
  - Li-Ion

# Comparison of Rechargeable Battery Types

| Chemistry | Cell Voltage (V) | Cell Capacity (mAh) | Gravimetric Energy Density (WHr/kg) | Volumetric Energy Density (WHr/l) | Capacity loss per MONTH (@ 20C) |
|---|---|---|---|---|---|
| NiCad | 1.2 | 50-5000 | 55 | 170 | 10% |
| NiMH | 1.2 | 10-5000 | 70 | 250 | 15% |
| Li-Ion | 3.6 | 25-1600 | 120 | 350 | 3% |

# Characteristics of Rechargeable Batteries

- Rechargeable batteries are reusable, reducing cost and environmental issues
- Li-Ion batteries are best performers, but are costly and require tight control of charging algorithms
- NiMH and Li-Ion can be dangerous if overcharged
- NiCad is simpler with better overcharging tolerance, but lower performing

# Battery Life Estimates for Common Scenarios

- Smart sensor - 50mW on; 0.5mW sleep; 2% on time
  - 3 AAA Alkaline cells (Energizer): ~2700 hours
  - 1 Li-Ion cell (iPAQ): ~2900 hours
- PDA - 900mW on; 200mW idle; 5mW sleep; 1% on time; 3% idle time
  - 3 AAA Alkaline cells (Energizer): ~200 hours
  - 1 Li-Ion cell (iPAQ): ~200 hours

# New Technologies

- Fuel Cells
- Harvesting
- Others

# Fuel Cells - The Hype

- >10X energy density increase over today's Li-Ion technologies
- Instant recharging
- Environmentally friendly

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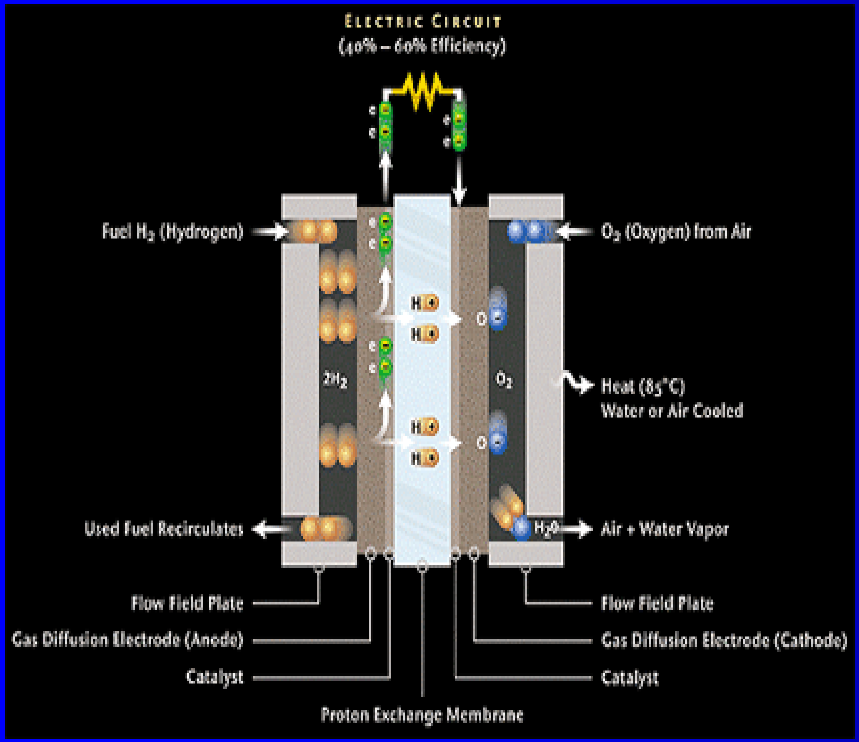
# Fuel Cells - How They Work

- Uses hydrogen and oxygen to produce electricity
- Many different types
  - Proton Exchange Membrane (PEM)
  - Direct Methanol (DMFC)
  - Solid Oxide (SOFC)

# Fuel Cells - How They Work




- PEM
  - $H_2$ flows on one face, $O_2$ on the other
  - catalyst spurs $H_2$ to oxidize protons and give up electrons
  - electrons flow to load
  - water/heat produced

# Fuel Cells - The Reality

- Cost/watt-hour is too high, especially for use in automobiles
- Likely to appear in small devices first, starting in 2004 or 2005
- Governing issues
- Issues with cold temperature operation

- Still several years away (recent study by ABI Research estimates only 10-15% of laptops will use fuel cells in 2012)

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# Fuel Cells - Example

mtimicro

- Micro-Fuel Cell
  - DMFC approach
  - Focusing on handheld device market
  - Product launch planned for end of 2004

# Fuel Cells - Example

MANHATTAN SCIENTIFICS, INC.

- Micro-Fuel Cell
  - Uses methanol
  - Initial focus on creating battery chargers for small devices

# Fuel Cells - Example


- Micro-Fuel Cell
  - Uses DLFC (direct-liquid fuel cell) technology
  - 130 cu. cm
  - 200 grams
  - Initial focus on creating auxiliary power sources and chargers for handheld devices

# Fuel Cells - Example

- NEC, Hitachi, and Toshiba are developing fuel cells for notebook computers
  - Methanol-based cells weigh about 900 grams, and provide 12-24 Watts
  - first fuel-cell notebooks planned in 2004-2005
  - Toshiba achieved 5 hours of use on a 50cc methanol fuel cartridge
  - NEC achieved 50 $mW/cm^2$ and plans a 40-hour system by the end of 2005

# Harvesting - Old and New

- Power “harvesting” involves transducing ambient energy into electrical power
- Harvesting has been around for years
  - solar
  - wind
  - hydro
- There are interesting new approaches

# Solar Cells

- Convert solar energy into electricity
- Typical efficiency of 50-100mW/in2
- Useful in recharging batteries at remote locations
- Limited by availability of direct sunlight, size, and fragility

# Solar Cells - Example


- SunPal PDA Charger
  - 6.25x3.25 inches
  - 5 ounces
  - 1-3 hour charging time

# Solar Cells - Example

Konarka technologies

- Solar Charger and Power Source
  - Charges handheld devices
  - Can be embedded in a laptop's case

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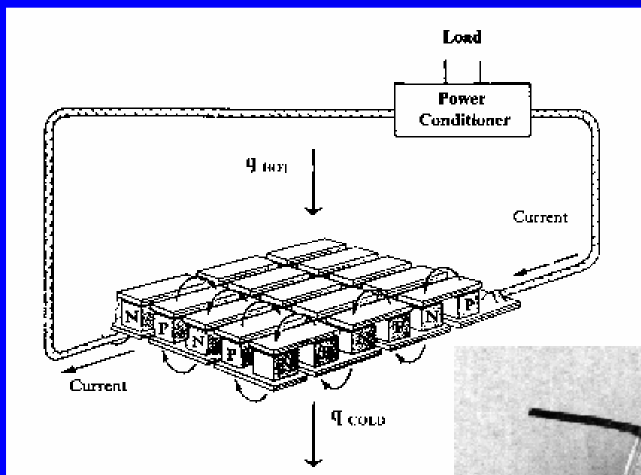
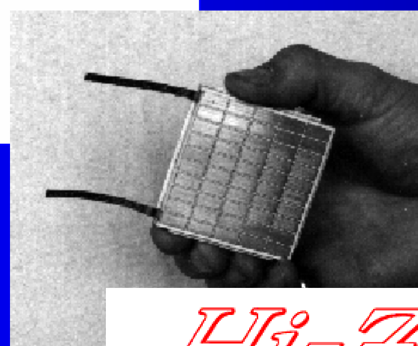
# Thermal Energy

- Convert heat and temperature difference into electricity
- Heat sources may include engine exhaust, body heat, etc.

# Thermal Energy - Example



- Thermoelectric Generator
  - As small as 1 cu. in.
  - 5mW at 3V for wireless sensors
  - Harvests power from shipboard interior thermal environment

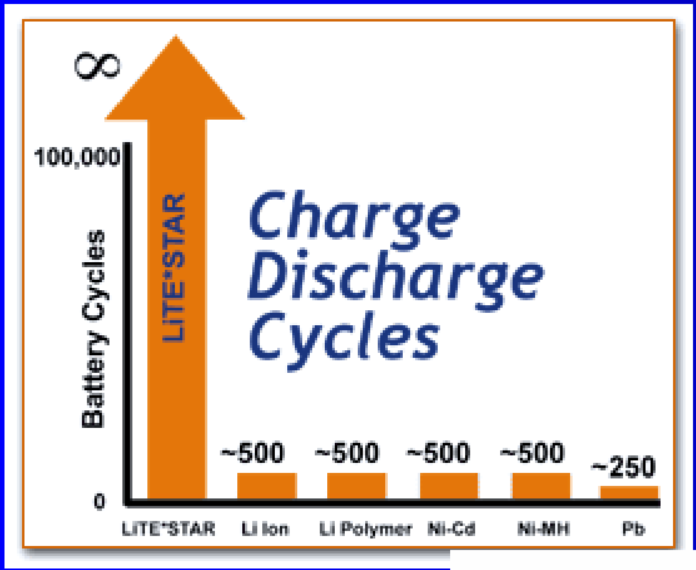
# Other Approaches

- Lots of venture capital is being provided for startups developing fuel cells and other new power source technologies
- Types of approaches are quite varied

# Other Approaches - Example

- SuperCaps
  - Aero-gel capacitors with low resistance
  - Deliver "pulse" power efficiently at peak current
  - Pulses can last seconds or minutes; up to amperes of current
  - Can be charged by small batteries
- Hybrid Batteries
  - Combo of high-energy and high-power batteries

# Other Approaches - Example



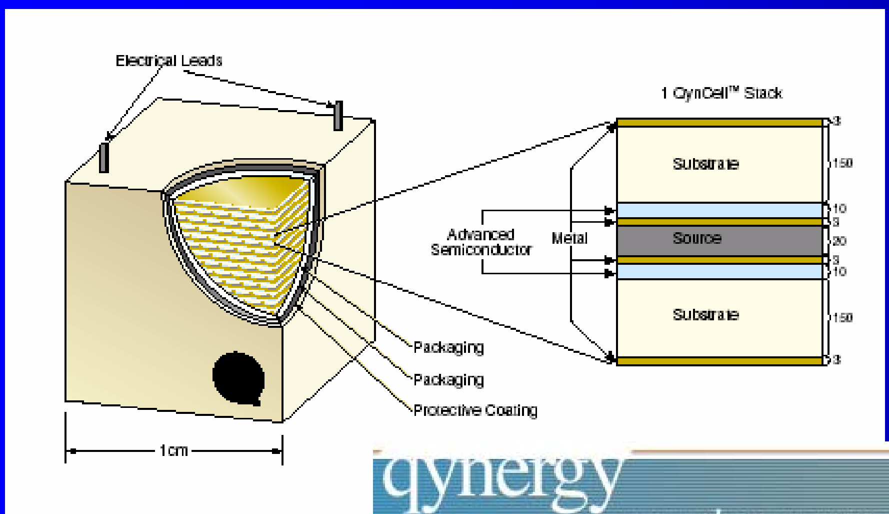

InfinitePowerSolutions

- Lite*STAR
  - Thin-film batteries
  - Wide temperature range
  - 100-150mW loads
  - >90,000 charging cycles
  - <1% energy loss/year

# Other Approaches - Example

- Advanced Battery
  - MIT spinoff
  - Based on Li-Ion, but with nano-scale dimensions
  - 600WHr/l and +225WHr/kg

# Other Approaches - Example




qynergy
*energy that matters*

- Qyncell
  - Radiation-insensitive material converts radiation to electricity
  - cm$^3$ cell: 50mW for years

# Summary

- Today’s battery technologies are inexpensive and plentiful, but limited in energy density
- Powering wireless sensors for months or years at a time will require new advances in power sources
- Fuel cells, harvesting, and other technologies have significant potential, but most are not yet in production