



Infinite Power Solutions®

Energy Harvesting Storage Technologies

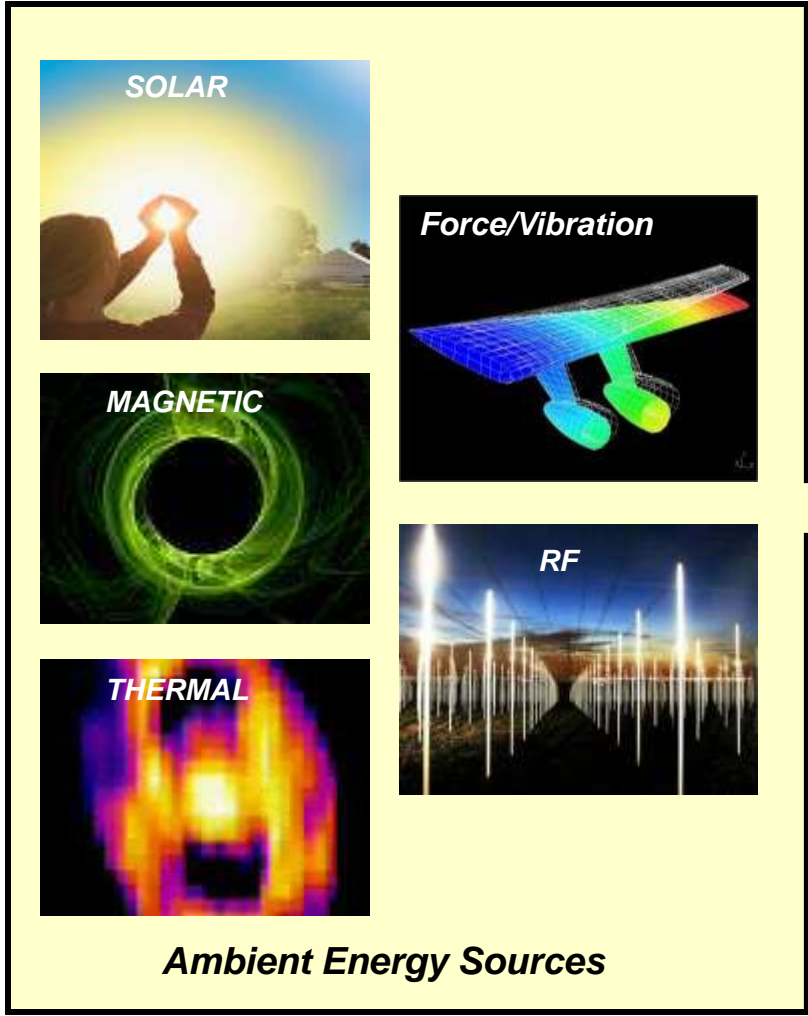
APEC 2012 Industry Session
PSMA Energy Harvesting Forum
February 7, 2012



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Infinite Power Solutions, Inc.**

Micro Energy Harvesting



SOLAR

Force/Vibration

MAGNETIC

RF

THERMAL

Ambient Energy Sources

Potential Applications

- Remote patient monitoring
- Efficient office energy control
- Surveillance and security
- Agricultural management
- Home automation
- Long range asset tracking
- Implantable sensors
- Structural monitoring
- Machinery/equipment monitoring



When Is Energy Harvesting Used?

- To reduce Total Cost of Ownership (TCO)
 - 1 battery change is often too expensive (labor cost)
- When traditional battery solutions are too big or heavy
- To eliminate disposable battery waste
- To increase lifetime and reliability. Zero maintenance with no battery change-out.
- When the application is a deeply embedded or implanted device that requires costly or dangerous battery replacement procedures

Commonly Available Energy Harvesters

4 General Categories

Thermal Electric:

- Requires energy conversion (voltage boost)
- Produces high energy for its size with sufficient ΔT



Solar:

- Inexpensive
- Best acceptance
- Well understood
- Reasonably efficient



Motion/Vibration/Strain:

- Resonant or impulse
- Can double as a sensor
- Very compact when using MEMS

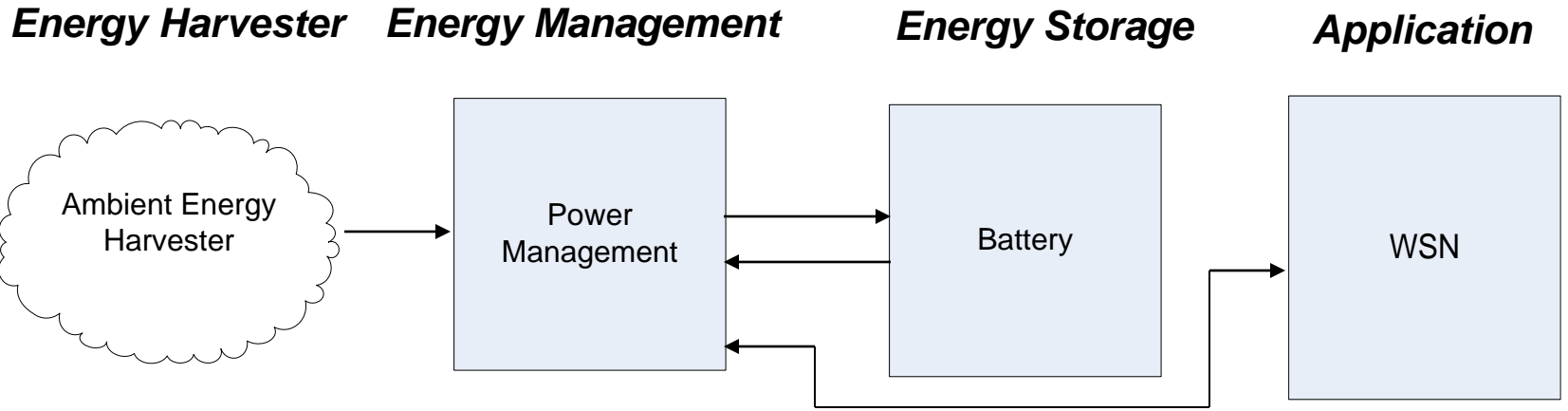


RF:

- Far Field - Low average power
- Near Field - Very high power



Elements of Autonomous Micro-Power Solution



- Photovoltaic
- Electro-Mechanical
- Thermo-Electric
- Radio Frequency

- Energy Conversion
- Manage Energy Storage
- Powers Application

- Thin Film Battery
- Capacitor
- Traditional Battery
- Etc.

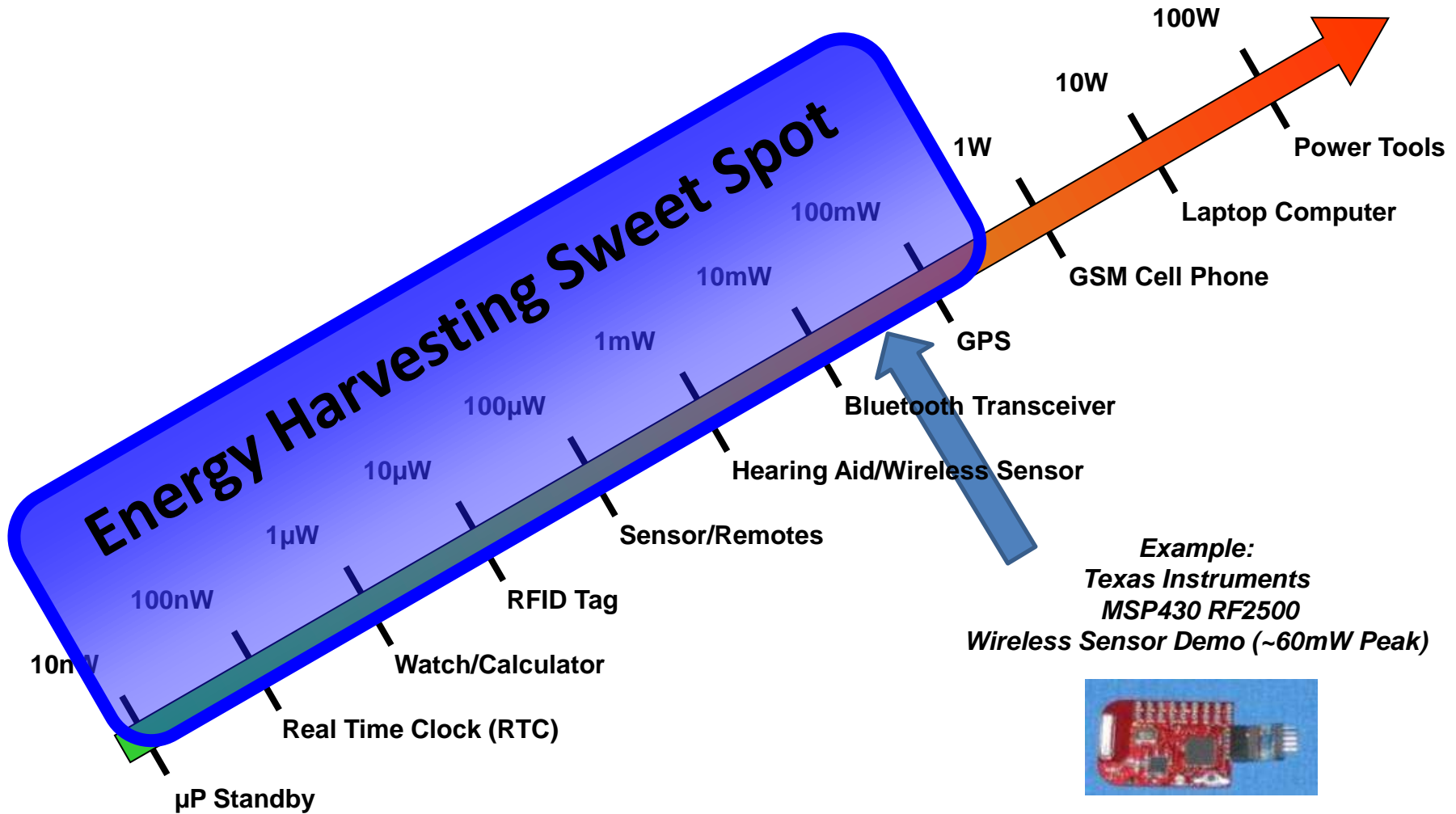
- Wireless Sensor
- Powered Card
- Implantable Medical
- Many, many more...



Application Space (power)

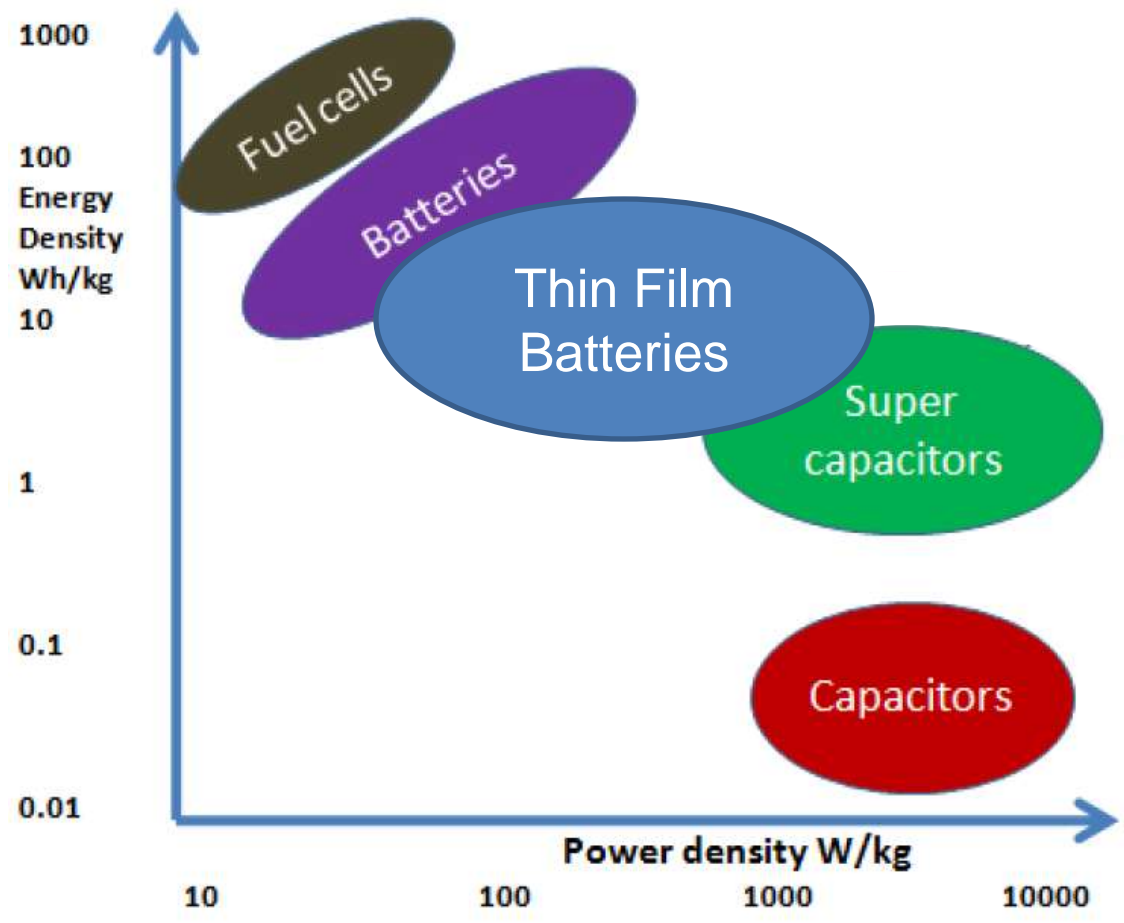
Low Power Applications <500mW

Peak Power



Batteries vs. TFBs vs. Supercaps

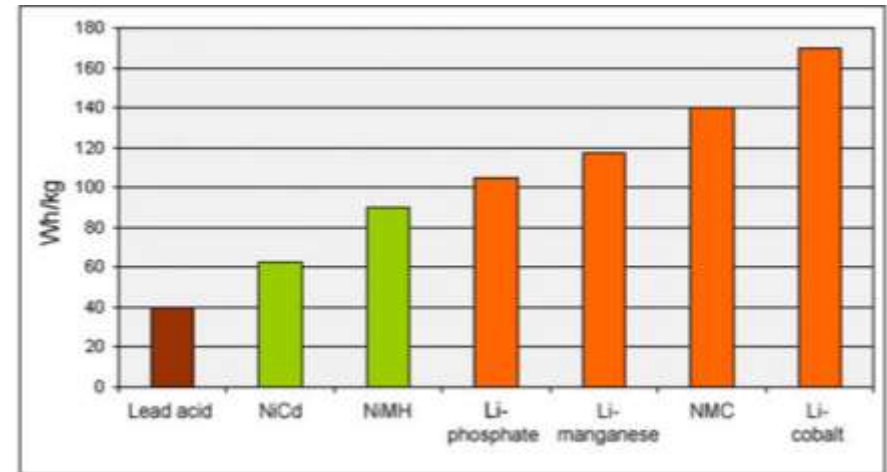
Where Do TFBs Fit In Comparison (Gravimetrically)?



What is the Right Chemistry

Cathode Materials Drive Wh/kg Performance

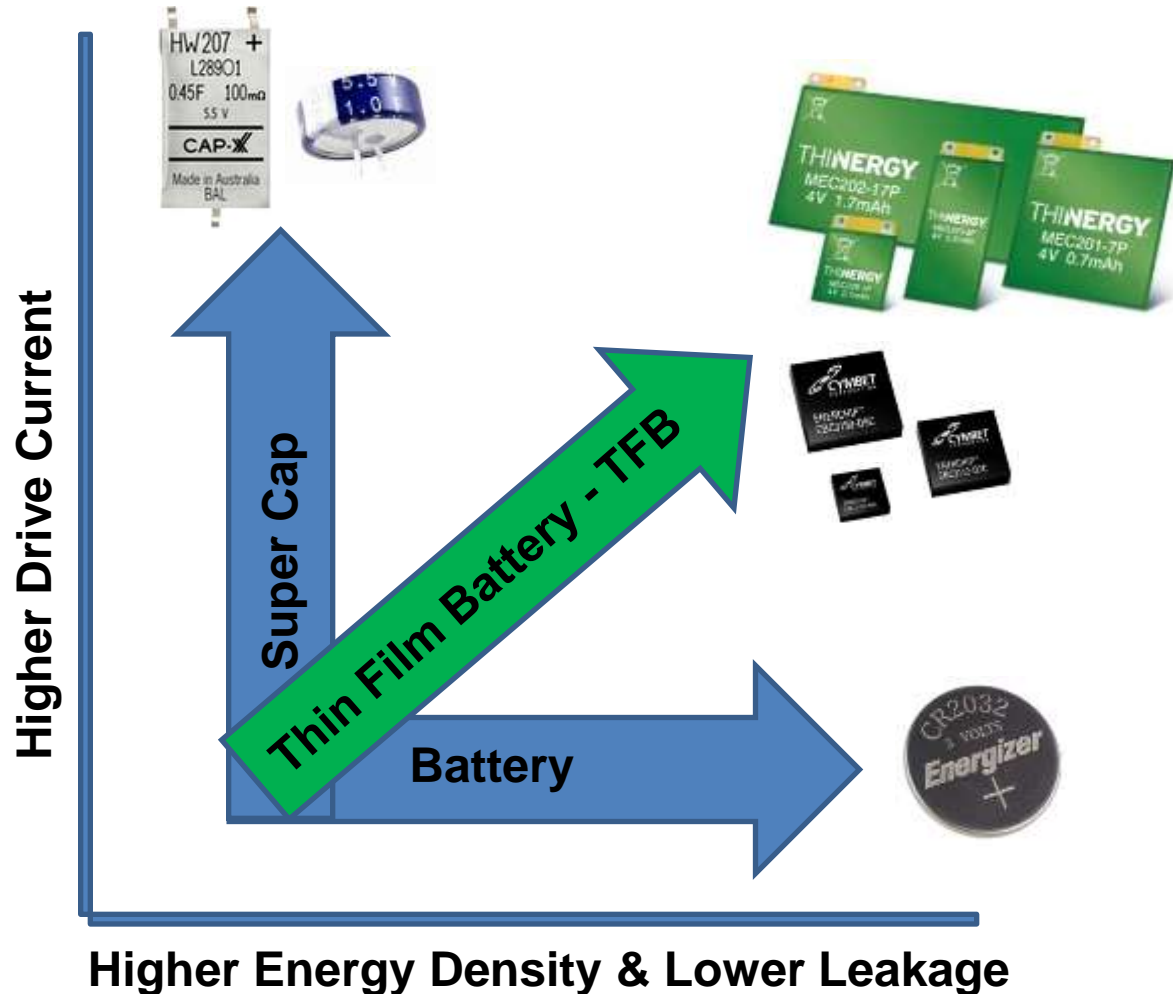
Chemical name	Material	Abbreviation	Short form	Notes
Lithium Cobalt Oxide ¹ Also Lithium Cobaltate or lithium-ion-cobalt)	LiCoO ₂ (60% Co)	LCO	Li-cobalt	High capacity, for cell phone laptop, camera
Lithium Manganese Oxide ¹ Also Lithium Manganate or lithium-ion-manganese	LiMn ₂ O ₄	LMO	Li-manganese, or spinel	Most safe, lower capacity than Li-cobalt but high specific power and long life. Power tools, e-bikes, EV, medical, hobbyist.
Lithium Iron Phosphate ¹	LiFePO ₄	LFP	Li-phosphate	
Lithium Nickel Manganese Cobalt Oxide ¹ , also lithium-manganese-cobalt-oxide	LiNiMnCoO ₂ (10–20% Co)	NMC	NMC	Gaining importance in electric powertrain and grid storage
Lithium Nickel Cobalt Aluminum Oxide ¹	LiNiCoAlO ₂ (9% Co)	NCA	NCA	
Lithium Titanate ²	Li ₄ Ti ₅ O ₁₂	LTO	Li-titanate	





Storage Alternatives

Thin Film Batteries, Supercaps and Coin Cells



TFB = Best of Both

- High Drive Current
- High Energy Density
 - 50 X SuperCap
- Lowest Leakage
 - 4,000 X < SuperCap
- Rechargeable/Long Life
- Superior Lifetime Energy

Energy Storage Comparisons

Conventional Batteries



- + High discharge current
- + High energy density
- + Inexpensive
- Limited life
- Replacement labor cost
- Unsafe, polluting
- Form factor

Supercapacitors



Vs.

- + Peak power delivery
- + Long life
- + Inexpensive
- High leakage
- Very low energy density
- High temperature degradation
- Form factor

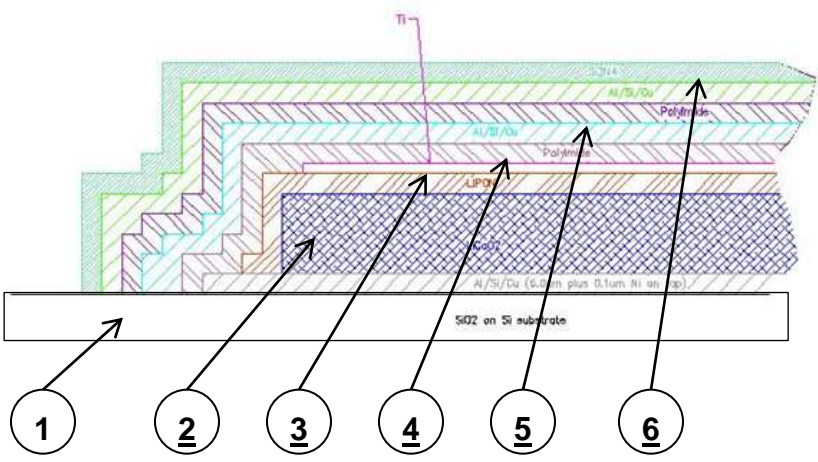
Thin Film Batteries



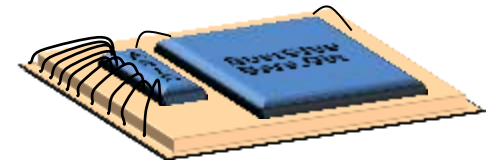
Vs.

- + High discharge current
- + High energy density
- + Near Zero Leakage
- + Long life / Permanent
- + Low cost of ownership
- + Form factor
- + Safe / Eco-Friendly
- + Broader Temp Range

TFB Construction and Assembly



1. Substrate – Kapton, Metal, or Silicon
2. Lithium Cobalt Oxide Cathode
3. Completely Solid State Electrolyte
4. Anode and Current Collector
5. Sealing Layers
6. Packaging as Commercial Product

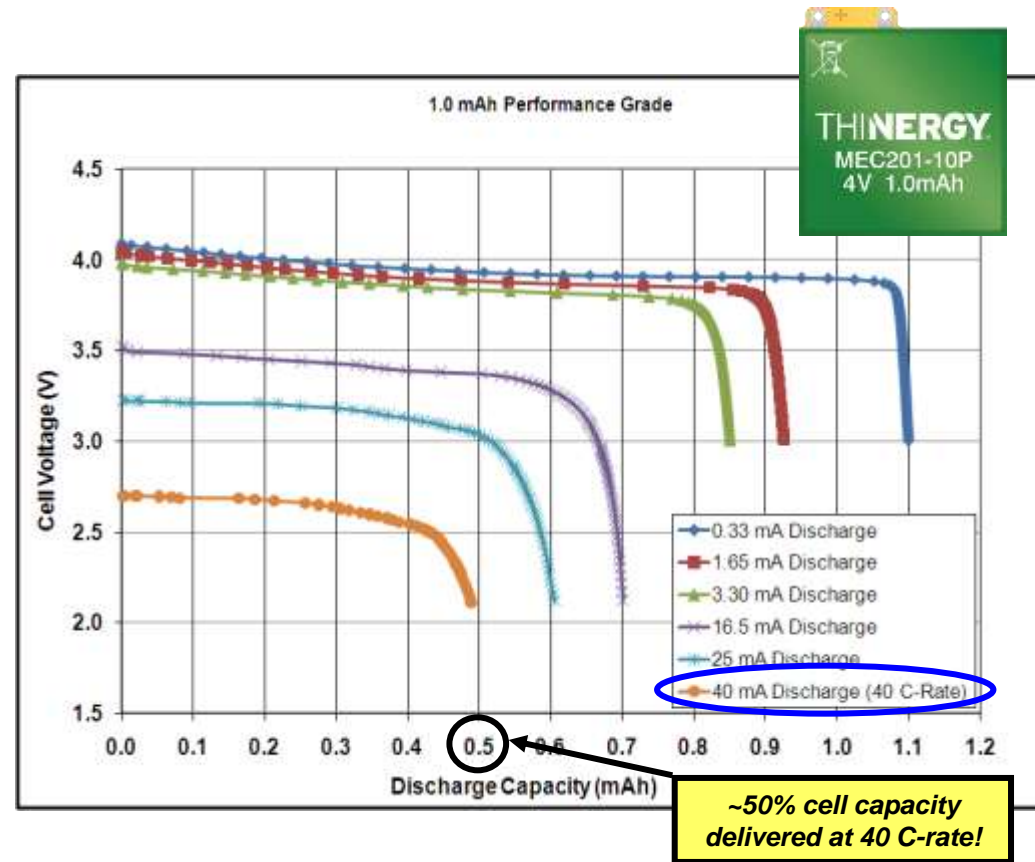


- A. Ultrathin packages
- B. Bare Die Batteries
- C. Co-package TFB and ASIC
- D. TFB in System In Package (SIP)
- E. Various Attachment Mechanisms
- F. Automated Assembly

High Discharge Rate

High Power Delivery and Efficient Energy Storage

- **High discharge rates**
 - 40 C-rate capability
- **Peak power delivered as a pulse or continuously**
 - No external capacitors required like other solutions
 - No pulse width limitations
- **Useful voltage is sustainable at high currents**
 - Voltage maintains flat profile unlike supercaps or other batteries
- **Majority of capacity can be delivered at very high C-rates**
 - Not possible with other batteries



Universal Applicability

Wireless Sensor Nodes (WSN)



Powered Cards / Secure ID



Medical Devices & Sensors



Military & Commercial Aviation



Thin Film
Solid State
Batteries

Hand-held Devices

- Memory/RTC Backup

Memory/RTC Backup



Next-Gen Consumer Electronics



Active RFID / RTLS / Asset Tracking



Flexible / Printed Electronics





Thin Film Batteries

Ideal for Micro-Energy Harvesting Storage

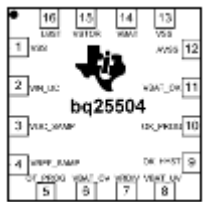
TFB Value Proposition for Energy Harvesting

- **Extremely low self-discharge rate: ~1% per year (~3nA)**
 - Near loss-less energy storage!
 - Enables low current EH charge sources (not possible with supercaps)
- **Extremely long cycle life in typical applications**
 - Some TFBs provide >100,000 recharge cycles - Never wears out!
- **High energy density (especially compared to supercaps)**
- **High power density**
 - Available continuous current >40mA per (MEC201)
- **Broad Operating Temperature Range**
 - Survives broader temp. excursions than other batteries or supercaps
- **Ultra Thin & Permanent**
 - Some TFBs <170µm total package thickness
 - Permanent integration – Never needs replacement

Power Management Solutions for TFB

Single Chip EH Conversion and Battery Management

- Linear Technology LTC4071
- Maxim MAX17710
- Texas Instruments BQ25504
- Cymbet EnerChip EP CBC915

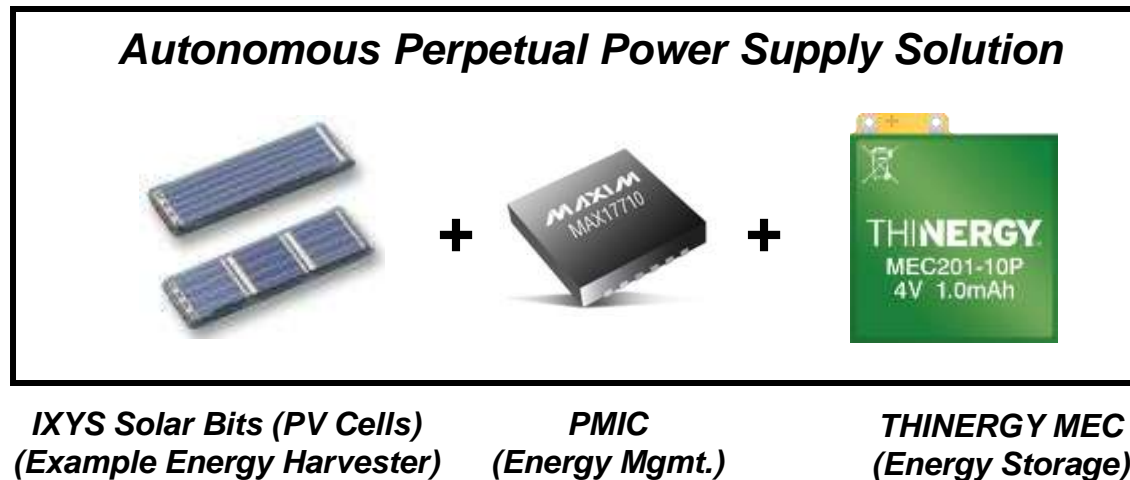


Perpetual Power Is Now Available

Enabled by TFBs, PMICs & Energy Harvesting

Energy Harvester + PMIC + Thin Film Battery = Perpetual Power Solution

- Thinnest & most efficient solution available with smallest footprint
- Highest energy density & power available for its size
- Ultra-low quiescent current allows >10yrs of charge retention on a single charge (other solutions consume stored energy when not harvesting)
- Users can easily integrate within their own systems



Summary

- Thin film batteries are "game changing" energy storage solutions
 - High performance and longer life
 - Unrivalled cycle life & near loss-less storage for embedded micro-electronics
 - Never need replacement for life of system
- Ambient energy harvesting is *THE* emerging power solution for low power autonomous applications – TFBs are a key enabler!

Evaluation Tools Are Available From the Industry

