Biofuel Cells for Portable Electronic Applications

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AKERMIN

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IBE 12th Annual Meeting

SEBC™
Stabilized Enzyme Biofuel Cells

Akermin History

- **Founded in 2003**
  - Technology invented at Saint Louis University by Nick Akers and Dr. Shelley Minteer
  - Secured worldwide exclusive license from SLU
- **Seed Funding 2004**
  - Approximately $600,000 from BioGenerator and SLU
  - Established lab at Nidus Center
  - Demonstrated proof of concept prototype
  - Expanded IP position
- **Series A Venture Financing, October 2005**
  - $3M from Chrysalix, OnPoint, Prolog, and Arch Angel Network
  - Expanded management and technical team
  - Identified key market opportunities
  - Delivered all technical milestones, including several world firsts
- **Series A.2, March 2007**
  - $3.5 M from existing investors
  - Continue to add management and technical skills
  - Advance technology towards product introductions

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Catalyst Materials Are An Essential Part of Many Industrial Processes

- **Catalysts accelerate the rate of a chemical reaction, but are not changed in the reaction**
  - Chemical and materials manufacturing
  - Energy conversion (i.e. fuel cells)
  - Pollution control systems
  - Production of biofuels (i.e. ethanol and biodiesel)
  - Platinum, ruthenium, palladium, nickel compounds and various metals
- **Enzyme catalysts (proteins) desirable as replacements for metal catalysts**
  - Renewable, environmentally benign, low cost and reaction selective
- **Catalyst industry generates $18 billion in annual sales**
  - Johnson Matthey, BASF, Umicore, Proctor and Gamble, Cargill, etc.

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Akermin Breakthrough in Enzyme Catalysts Has Significant Market Value

- **Unique, low cost enzyme catalyst structures desirable in many chemical reactions**
  - **"Polymer encapsulation"** provides long life and high power
- **Pursuing a $2 billion market potential in fuel cells**
  - Reaction selectivity allows **100% oxidation of fuel**
  - Up to 4 times energy density of current fuel cells
  - Fuel cell material costs reduced by 50%
  - Up to 5 times energy density of batteries
- **Other applications exist in catalyst industry**
  - Multi-billion $ opportunity to be explored
- **Initial revenues start at end 2007**
  - Fuel cell revenue of $88 million and EBIT of $15 million in 2011

Dual Business Paths Defined to Maximize Value from Large Diverse Market

- **Main focus to engineer, produce and sell portable fuel cells**
  - Operate mobile electronic devices
  - Sell direct to OEMs and to end users through retail product distributors
  - Option to manufacture in-house or through contracted services
  - Provides maximum value from fuel cell applications

- **Opportunistically explore business alternatives outside fuel cells**
  - Alcohol sensors, ethanol and biodiesel production, fuel cells for transportation systems, pharmaceutical production, etc.
  - Manage effort to maintain focus on fuel cell development
  - Provide revenues from funded development efforts, supply of enzyme catalysts, up front license fees or long term royalties

First Application for Fuel Cells

- Integration of functionality increases power demand
- $6B rechargeable battery market
- ~700 million cell phones sold per year
- Military heavily dependent on portable power
  - Individual soldier carries 30 lbs of batteries
  - $56 M batteries per month in Iraq 2004
- Need and price tolerance make battery replacement viable

Micro PEFC recharger

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Biofuel Cell History and Classification

- **Microbial – Enzyme catalysts contained within living cells**
  - Long term stability through self renewal of cells
  - High energy densities through complete oxidation of fuels
  - Low power densities (mW/m^2) due to mass transfer across cell wall
  - Potential applications where size is not a constraint

- **Enzymatic – Employ isolated enzymes**
  - Traditionally have suffered from limited enzyme stability, ~8 hours
  - Complete oxidation requires multiple enzymes
  - Can achieve higher power densities (mW/cm^2)
  - Applicable for small portable electronics

Water treatment plant

Sea floor batteries

Tender, L. et al. *Nature Biotechnology.* **2002**

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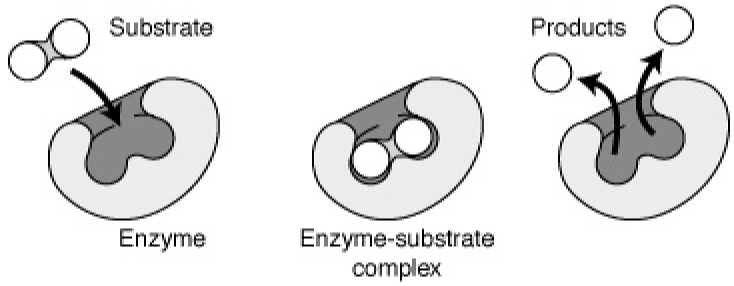
Enzymes and Power Generation

- **Distinguishing catalyst properties**
  - Increase rate of oxidation in biological systems
  - Highly selective for substrate

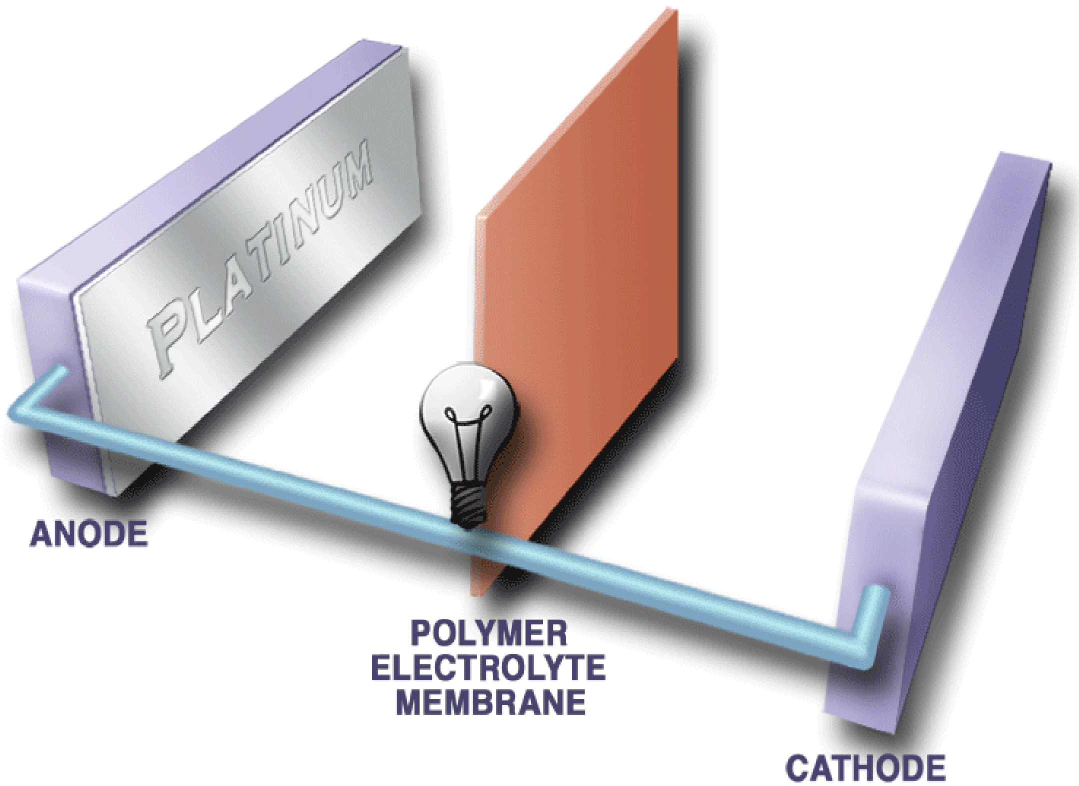
- **Enabling features in biofuel cell**
  - Oxidize fuel to release electrons and protons
  - Renewable catalyst
  - Wide options for fuel choice
  - Selectivity can greatly simplify fuel cell operation
  - Efficient oxidation increases fuel cell efficiency

Mechanism of enzyme activity



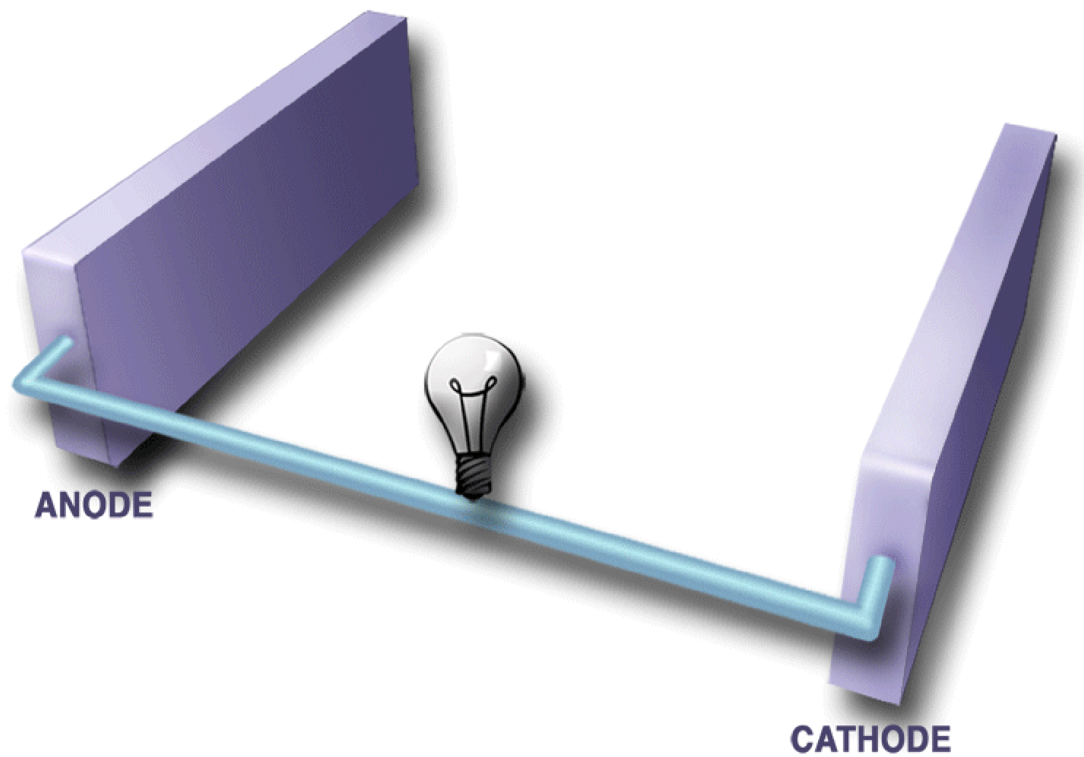
Conventional Fuel Cell

- **Single unit consists of a positive and negative electrode**
  - Platinum oxidizes both fuel and oxygen
  - Expensive PEM required to keep fuel flows isolated



Biofuel Cell

- **Stabilized Enzyme Biofuel Cell (SEBC) operation similar to traditional fuel cells**
  - Precious metal catalysts replaced by enzyme catalysts
  - Specialized separator (PEM) replaced by low cost material



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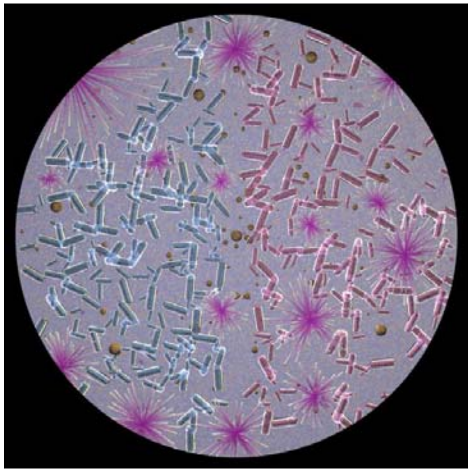
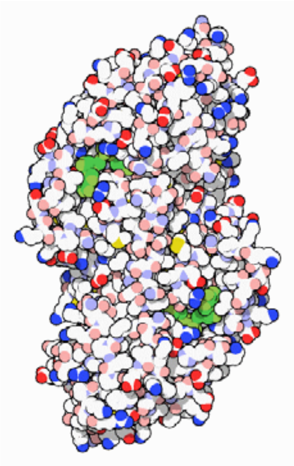
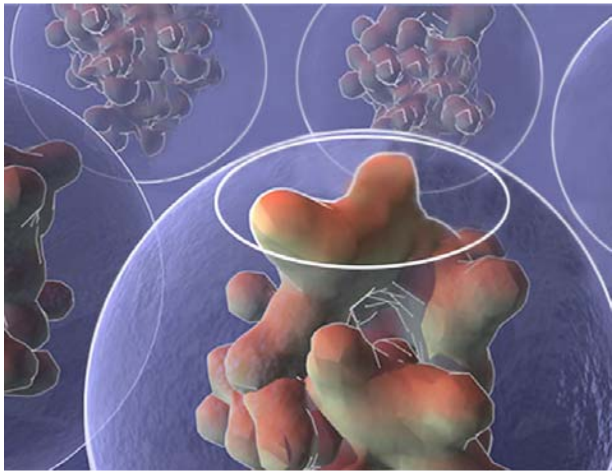
Unique, Polymer Encapsulation Protects Enzyme Catalysts to Provide Long Life

- Enzymes (proteins) are attractive but fragile catalysts
  Harsh chemicals and high temperature cause failure







- Living Bacteria (yeast)
- Grown at low cost

- Isolate non-living enzymes
- Problem: Unprotected life of 2 weeks max.

- Solution: Encase enzymes in polymer micro-environment
- Over 2 years of life
- Up to 140 degrees Celsius

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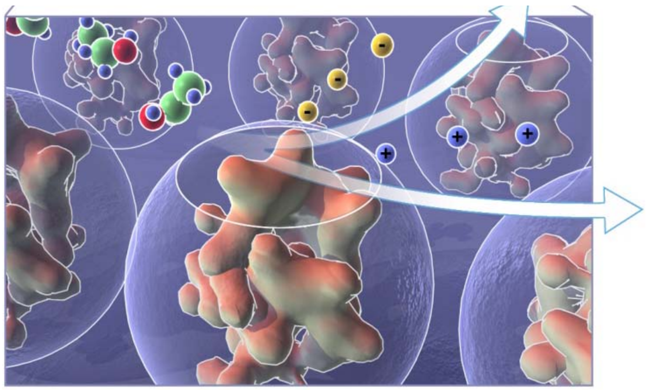
Polymer Encapsulation Technology Key to Enzyme Catalyst Performance

- **Encase enzymes in protective, polymer structure**
  - Creates nano-meter scale, micro-environment for each enzyme



- **Immobilizes enzyme for attachment to support structure**
  - Maintains contact with reactants
- **Protects enzyme from denaturing**
  - Stabile operation for over 2 years in ethanol fuel cell
  - Stabile operation up to 140 degrees C
- **Foundation for significant improvements in power density**
  - Already demonstrated 15 mW/cm^2 in fuel cells
- **Opportunity for substantial improvements in life and power density**
  - Still very early in technical evolution
  - Capitalize on polymer science and biochemical engineering

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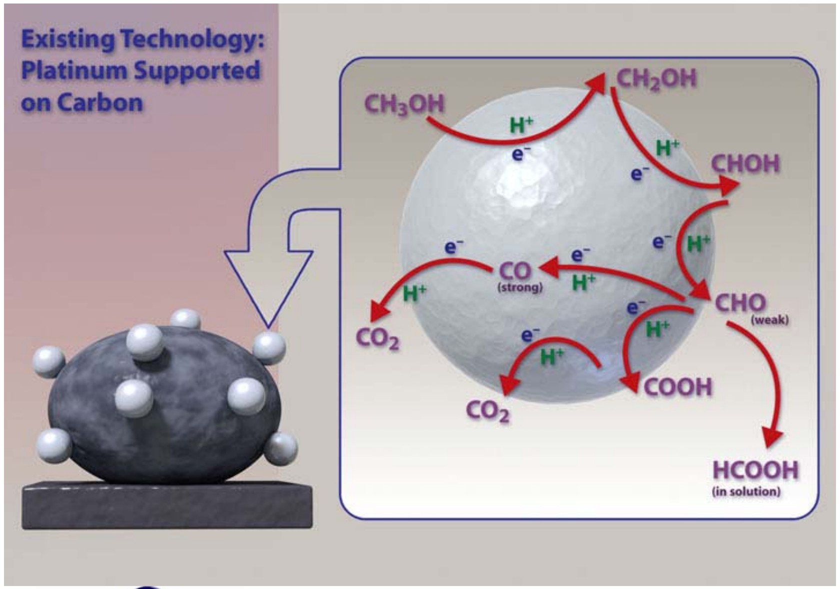
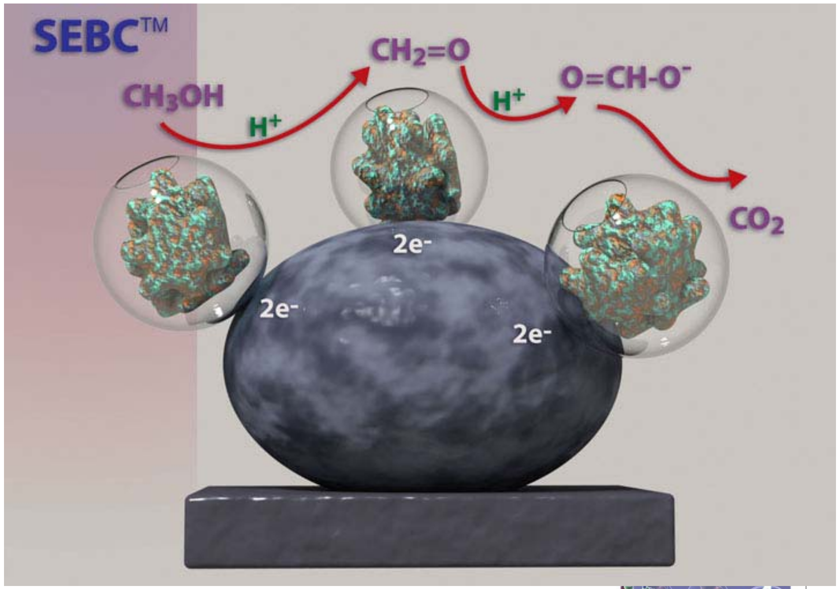
Reaction Selectivity Enables 100% Fuel Oxidation, the Key to High Energy Density

- **Methanol fuel conversion with metal catalysts ~ 20%**
  - Intermediate reactions and by-product formation generate heat not electricity
- **Methanol fuel conversion with enzyme catalysts ~ 45%**
  - Enzyme for each chemical step results in 100% fuel oxidation
  - Minimizes intermediate reactions and heat

Metal Catalyst



Enzyme Catalyst



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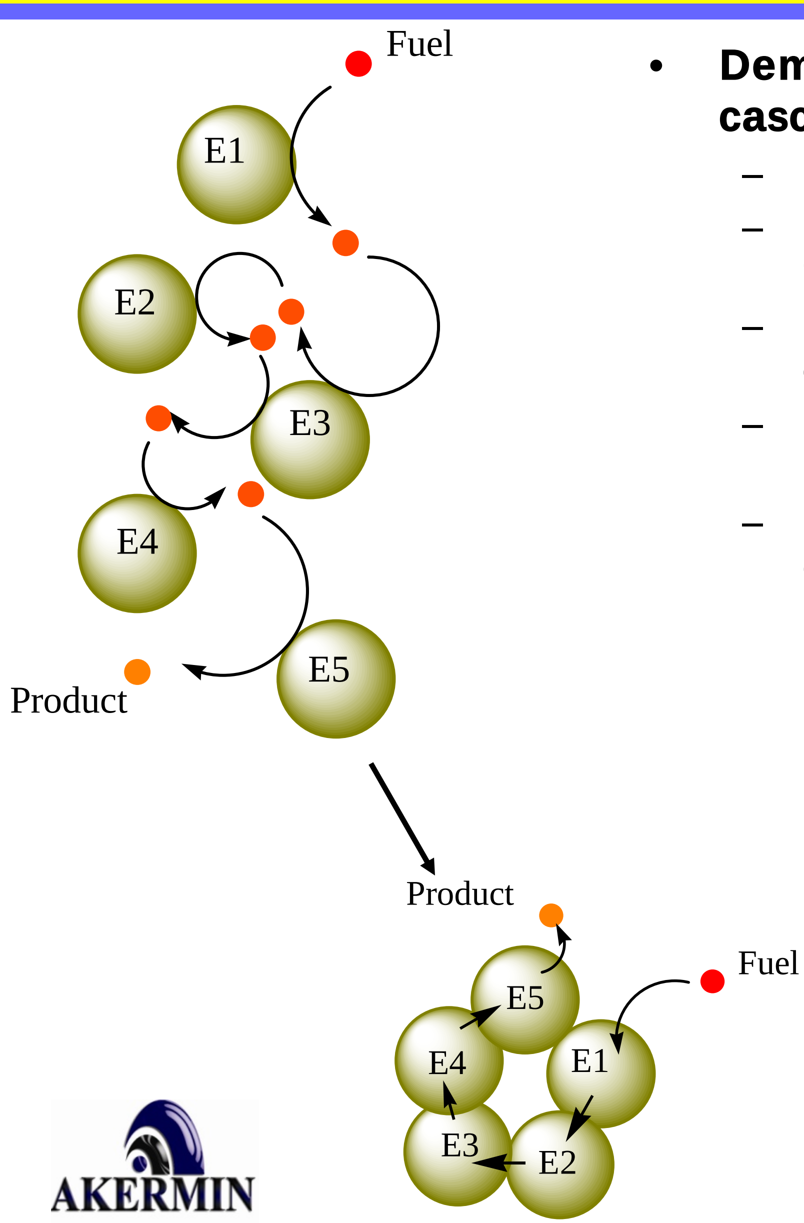
Effectively Employing Multi-enzyme Pathways



- **Demonstrated strategies for employing enzyme cascades for complete oxidation of ethanol**
  - Reproduce biologic pathways outside of living cells
  - For fuel cells, this results in highest efficiency for conversion to electrical energy
  - For other applications, represents opportunity for novel catalyst or synthetic processes
  - Employing synthetic approaches to developing ideal microenvironments for enzyme catalysis
  - Employing bio-inspired “click” chemistry to develop three-dimensional enzyme scaffolds (complexes)

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Achieved All Technical Milestones in Last 2 Years and Validated Design Concepts

Key Milestones:	Delivered
– 15 mW/cm^2 power density	✓
– 100 mW prototype	150 mW
– Enzyme pilot production	✓
– Complete oxidation scheme for ethanol	✓
– 5 mW/cm^2 glucose	5.37 mW/cm^2
– 5 mW/cm^2 soybean oil	6.27 mW/cm^2
– Fuel tolerant immobilization membrane	✓
– Environmental characterization	✓
– Air breathing biocathode	✓

Continue to deliver technology improvements through2007

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Prototype at End of 2007
Suitable for Customer Sampling

- **1W stack + BOP**
- **Physical example of commercial packaging concept**
- **Key milestone to support 2008 funding needs**

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Biofuel Cells

SEBCs Have Significant Advantages Over Competing Portable Power Options

Stabilized Enzyme Biofuel Cells (SEBCs)

Portable Power Source Feature	Potential SEBC Advantages	
	vs. Rechargeable Batteries	vs. Fuel Cells
Energy Density	Up to 5 times increase	Up to 4 times increase
Cost	Reduce cost per Whr by 50%	Reduce material costs by 50%
Environmental Impact	• Enzymes are renewable • No disposal restrictions on enzymes as with some battery materials	• Enzymes are renewable • No disposal restrictions on enzymes as with metal catalysts

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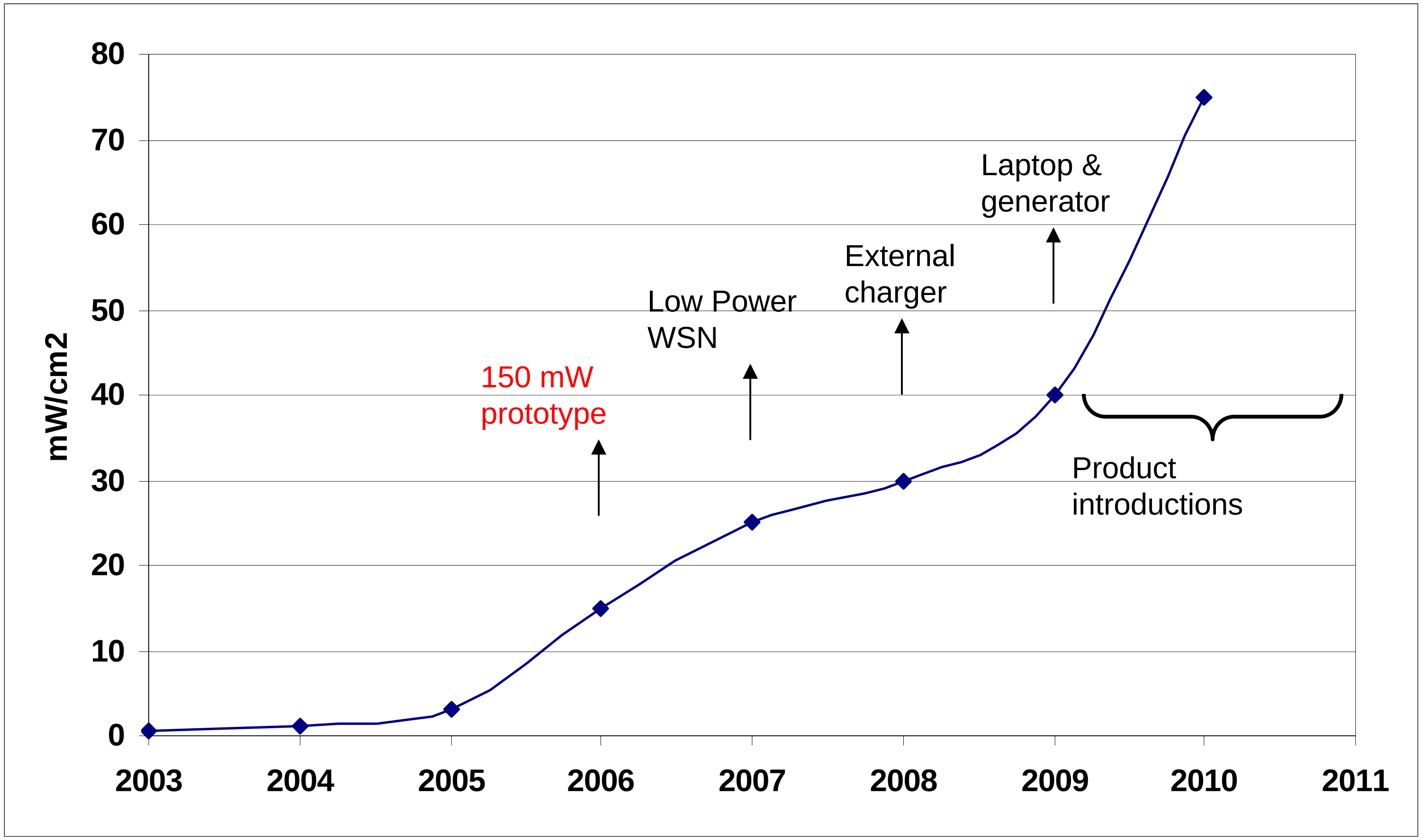
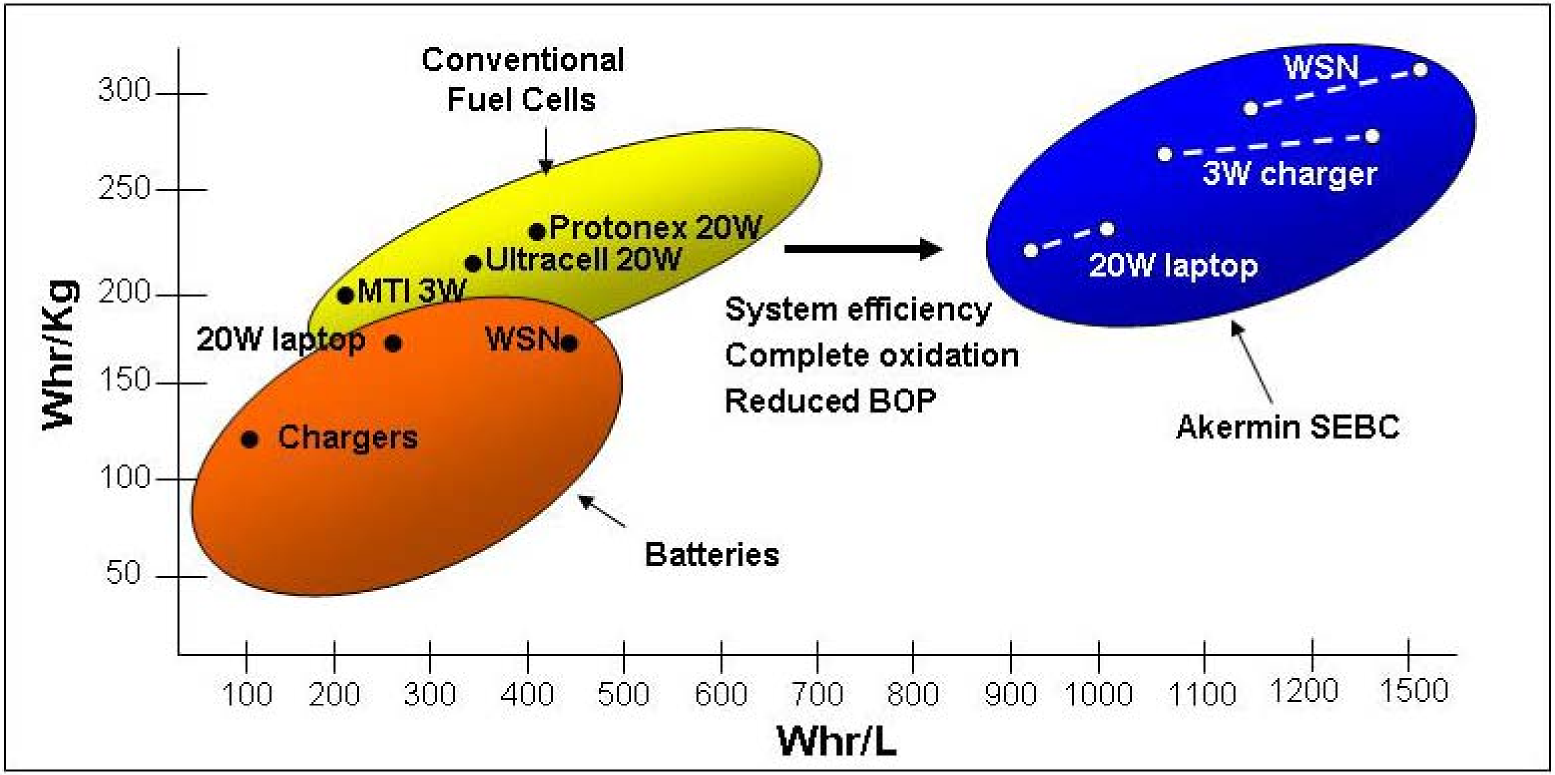
Increased Power Density Supports Penetration of New Applications

SEBC Electrode Power Density History and Goals



Projected SEBC Energy Densities Several Times Greater Than Competitive Devices

- **Energy densities for current portable power systems and projected SEBC products**
  - Dashed lines indicate range of SEBC performance based on assumptions for amount of fuel and BOP design



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Focus on Devices and Users with Greatest Need for Long Runtime

- **Users that carry extra batteries are a key target**
  - Soldiers on field missions
  - Field service technicians
  - First responders/emergency workers
- **Low power applications (under 3 watts) in first generation**
  - Wireless sensor networks (WSNs) and charger power packs
  - Initiated early contacts with US military, WSN OEMs and potential retail distributors
- **High power applications (over 10 watts) in second generation**
  - Capitalize on ongoing improvements in enzyme catalyst power density
  - Penetrate notebook computers and portable generators
- **Market segmentation is key to product definition and early adoption**

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Akermin Stabilized Enzyme Catalyst Technology Can Have Revolutionary Impact

- **Unique polymer encapsulation enables many uses of enzyme catalysts**
  - Renewable, low cost, environmentally benign and reaction selective
- **Skilled management team leading the Company**
- **Focus on fuel cells to capitalize on benefits of 100% fuel oxidation**
  - Increase energy density up to 4 times and reduce cost up to 50%
  - Potential for over 1000 Whr/liter systems
  - Operated first biofuel cell stack at 150 mW
  - Complete system prototype planned by end 2007
- **Opportunistically explore catalyst applications outside fuel cells**
- **Initial revenues in late 2007 and 2008**
  - Development contracts and sale of qualification prototypes
- **SEBC product introductions in 2009**
  - Revenues of $88 million with EBIT of $15 million in 2011

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