

Direct Carbon Conversion

Thomas Tao



Direct Carbon Conversion: How it Started



•1993 -1998

-Basement Laboratory



In 1997, demonstrated a direct carbon fuel cell yielding 3.3 mA for 30 seconds using conductive carbon as fuel

Background

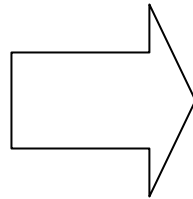
- CellTech Power founded in 1998 by Dr. Tom Tao to pursue direct carbon fuel cell technology
- Total of \$10M venture capital raised in 3 rounds since 2000 – currently focused on natural gas fuel
- Core technology developed internally
- 15,000 Ft² building west of Boston, MA with 28 Staff
- *Company has been in “stealth mode” while developing its proprietary SOFC technology, but is now ready to get somewhat more public*



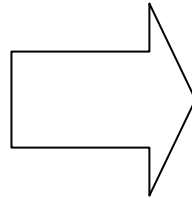


- An early stage company developing solid oxide fuel cells for distributed generation applications

Dec 2000



April 2003



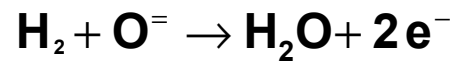
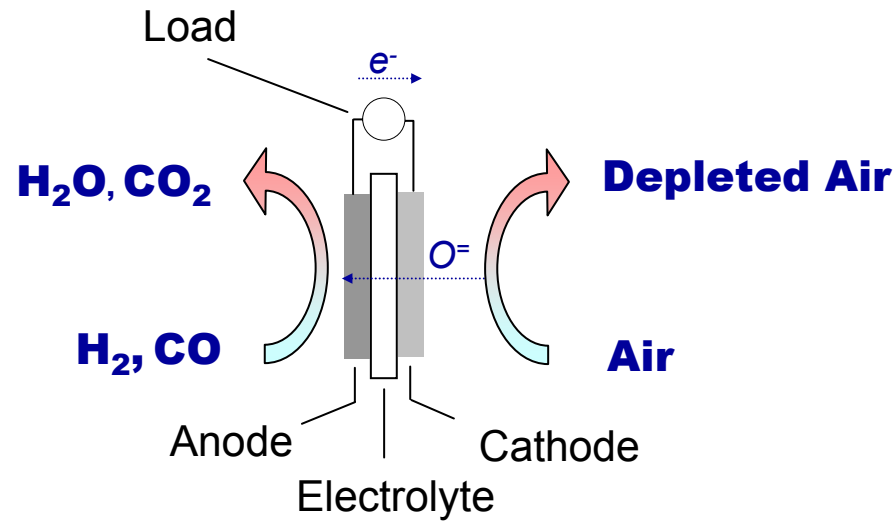
The CellTech Innovation:

A New Chapter in Electrochemistry

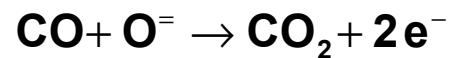
- *A unique device with the properties of a primary battery, a secondary battery, and a fuel cell*
- **A true, demonstrated multi-fuel capability including:**
 - *Solid Fuels:* Carbon blacks, graphite, glassy carbons, cokes, even coals, woods and other biomass
 - *Liquid fuels:* gasoline, diesel, kerosene and alcohols
 - *Gaseous fuels:* hydrogen, natural gas and propane



Traditional Solid Oxide Fuel Cell (SOFC)

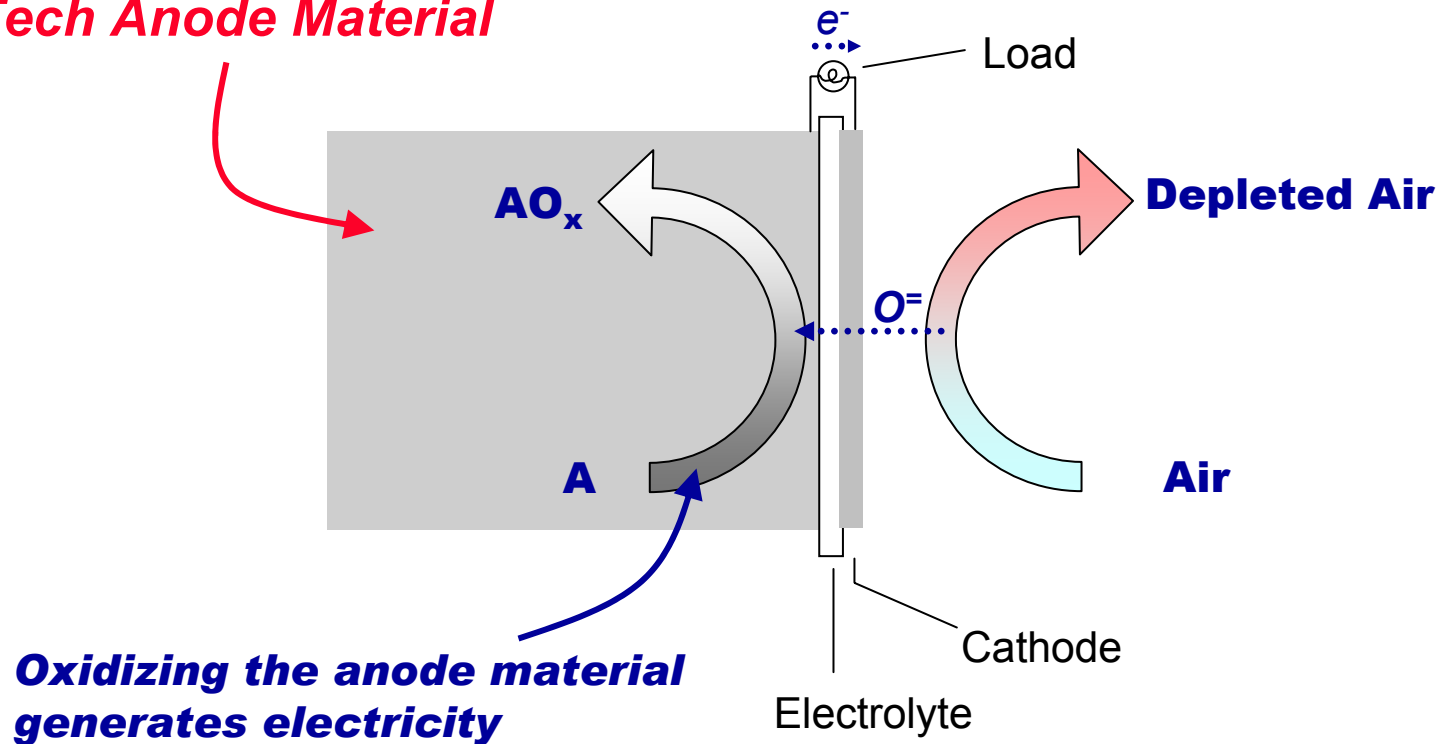


-or-



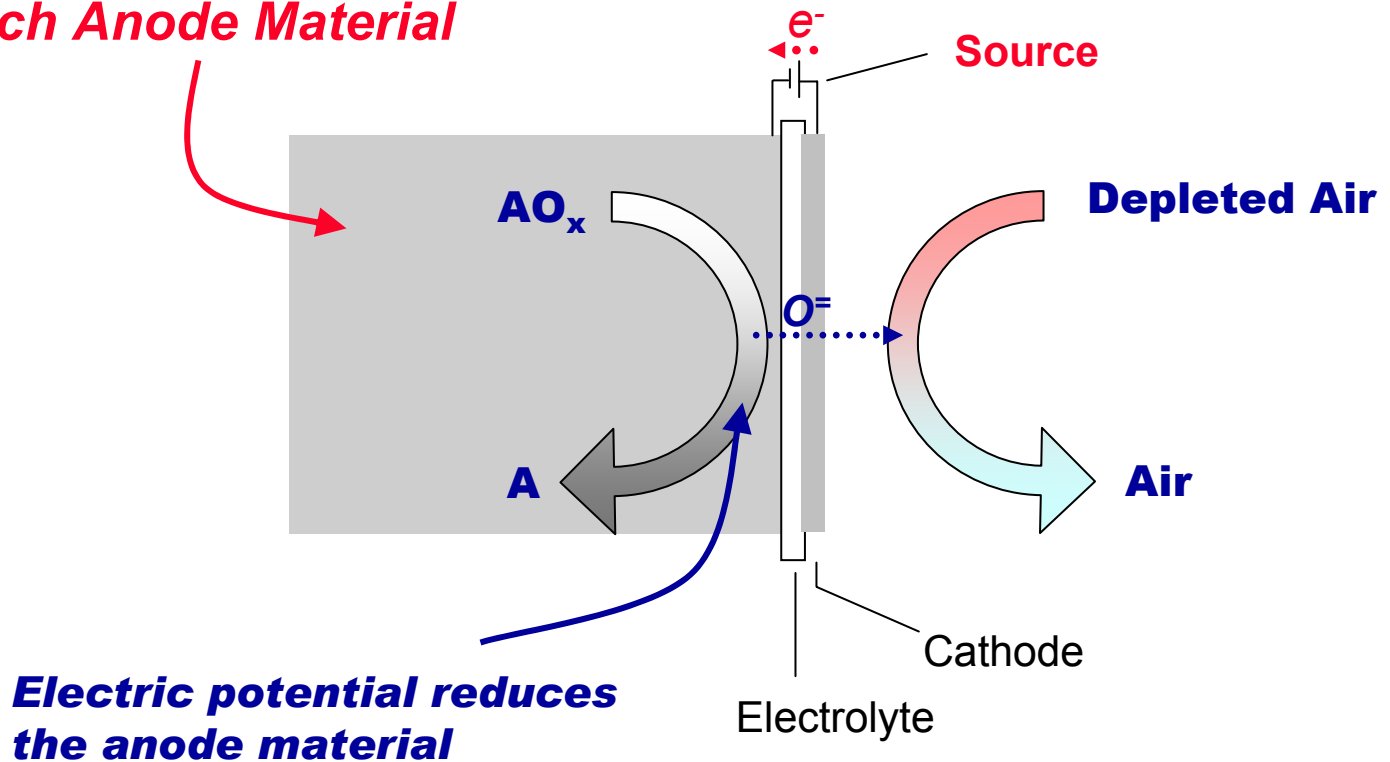
How CellTech's Fuel Cells Work (Discharging in Battery Mode)

CellTech Anode Material

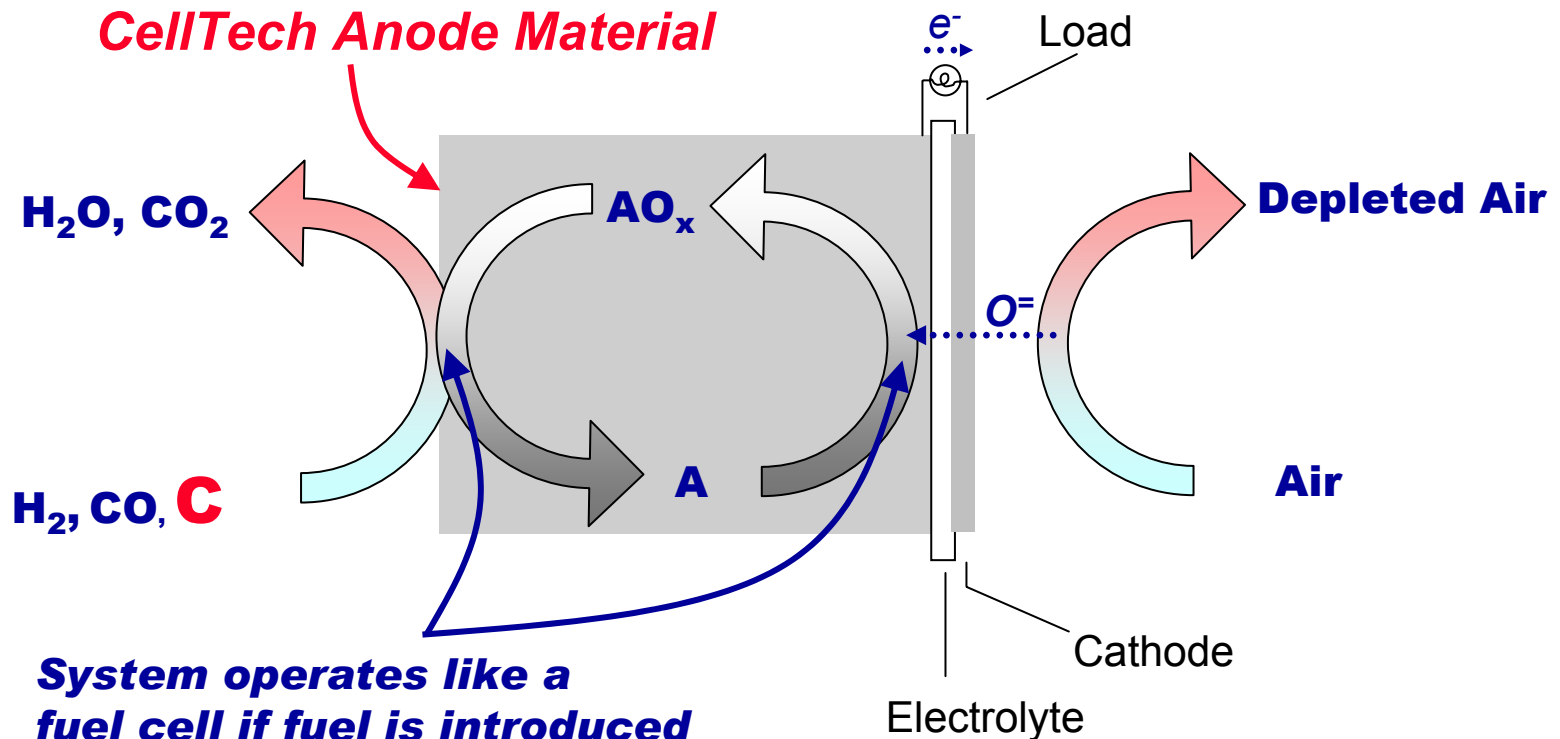


How CellTech's Fuel Cells Work (Electrical Charging in Battery Mode)

CellTech Anode Material

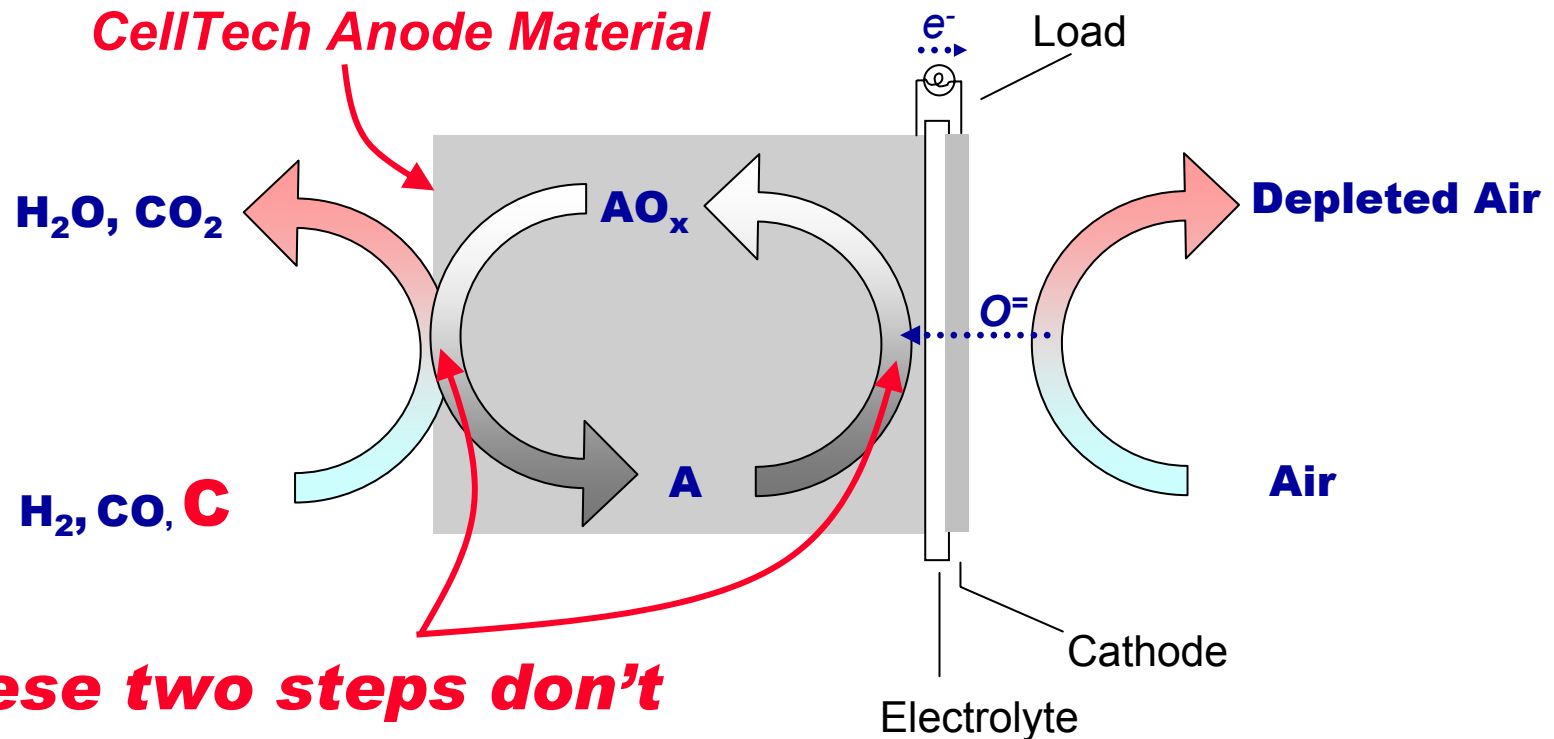


How CellTech's Fuel Cells Work (Fuel Cell Mode)



System operates like a fuel cell if fuel is introduced while the cell is delivering power

How CellTech's Fuel Cells Work (Fuel Cell Mode)

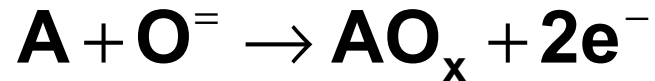


These two steps don't need to happen at the same time or at the same rate!

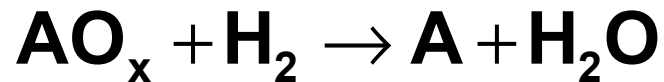
How CellTech Fuel Cells Work (cont.)

“Two-Step” Chemistry:

Step 1



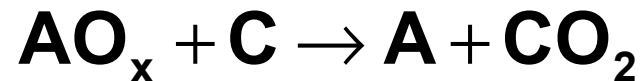
Step 2



-or-



-or-



Technical Advantages - Robustness

- System behaves like a battery
 - **Superior Load Following:** system can go from zero to full output in less than 0.0001 seconds
 - **Peaking Capability:** The system can deliver significantly more power than its rated capacity for short durations
 - Series-Parallel stacks with high cell count leads to fault tolerance
 - Fuel supply can be shut off for short durations
- System tends to remove impurities from the active area of the cell:
 - Most impurities (e.g. sulfur and higher hydrocarbons) form gaseous oxides that leave the cell

Commercial Advantages - Low \$/kWhr

- Simple system with low capital costs:
 - *Elimination of steam injectors, catalytic reformers, and shift reactors reduces both BOM costs and assembly costs*
 - *Battery-like performance eliminates the need for the external battery pack and complex fuel controls that are necessary for load following*
- Highly efficient system with low operating costs:
 - *System is expected to have equal or greater efficiency than any other SOFC (40%+ for natural gas and 60%+ for carbon)*
 - *High quality waste heat will lead to even higher efficiencies when used in hybrid or co-generation applications*

Why the Direct Carbon Conversion

Energy Security---The Most Abundant Fossil Fuel

US coal 25% world reserve

Charcoals from wood and biomass

Carbon blacks & cokes from oils

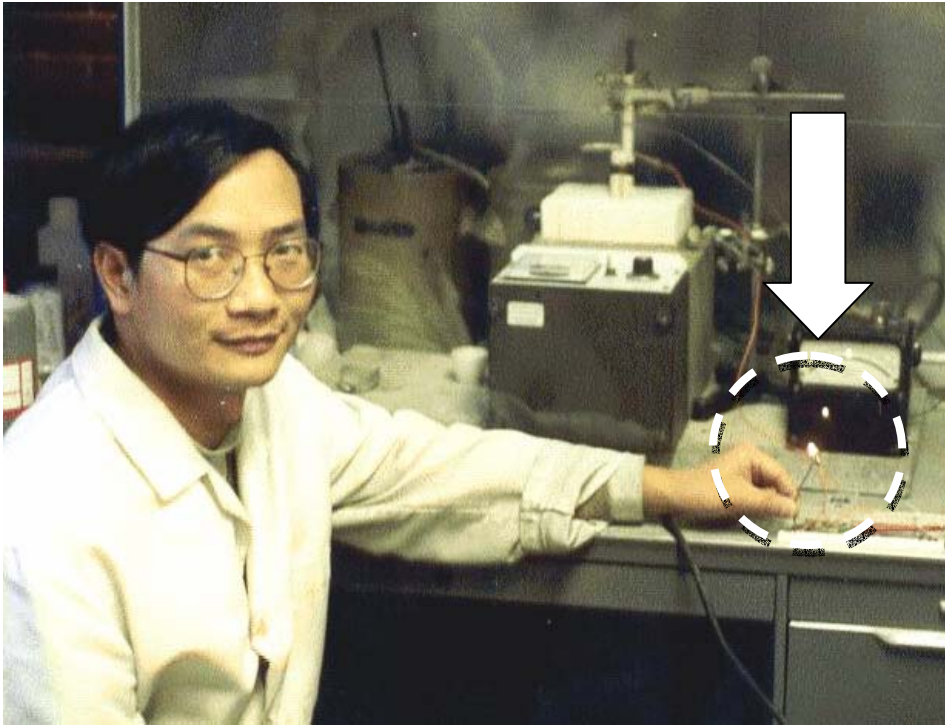
CO₂ Emission---Fuel Efficiency

60-70% (as measured at load) vs. 35-40%
coal firing plants

Performance---One of the Highest Energy Density

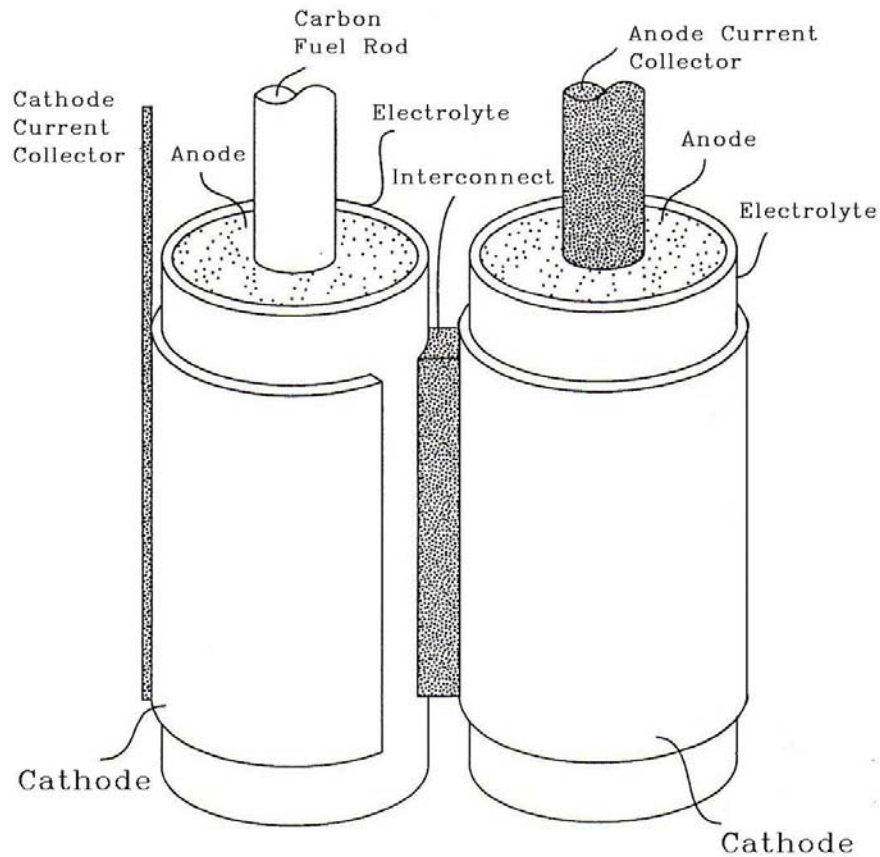


The Discovery



- July, 1998, the first 2-cell direct carbon stack made and tested
- Stack runs for 2 weeks
- Fuels used during experiment:
 - *Carbon blacks*
 - *Graphite powders*
 - *Unprocessed Coal with 20% ash*

2-Cell Direct Carbon Conversion Stack



CellTech **Direct Carbon:** Potential Markets and Applications

- Battery
 - *Highest energy density*
- Back-up Power
 - *Solid fuel powered generator for use in backup and auxiliary power applications*
- Primary Power
 - *Solid fuel-powered generator for use in primary DG applications*
 - *Solid fuel powered CHP system*

CellTech Direct Carbon: As Battery

The highest energy density and long lasting battery



9.2 kW.hr/kg

21 kW.hr/liter

Potential Applications:

A few watts up to thousands watts

Robotic

Military

Auxiliary Powers for boats, RVs, small planes



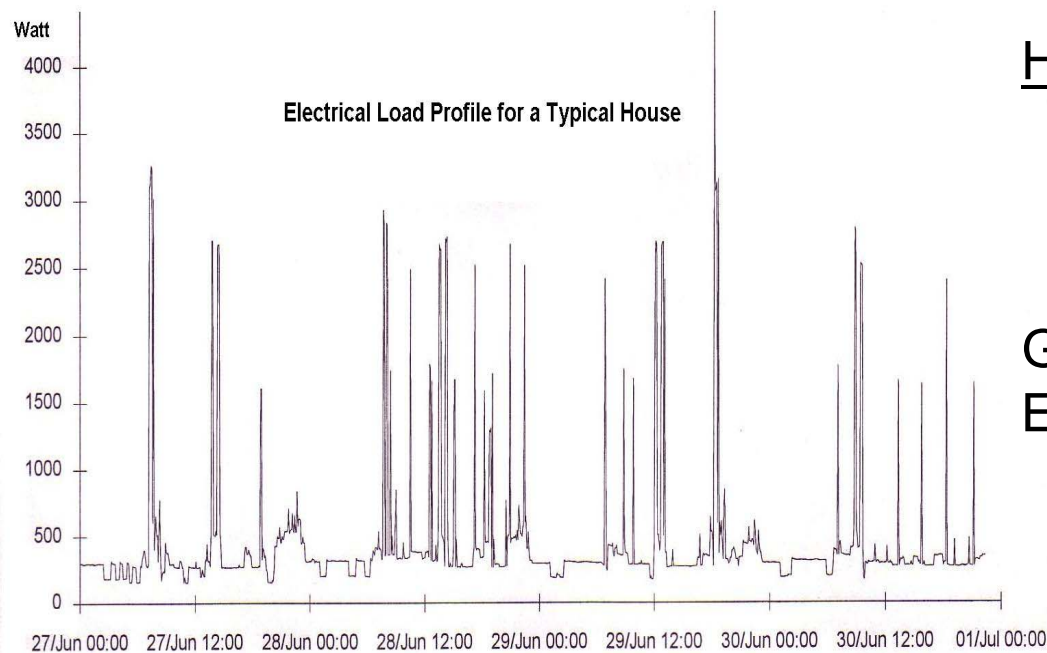
CellTech Direct Carbon: As Backup Powers

- Instant load following
- Short term burst power
- Long term sustaining power
- Kept hot

Backups for Electric Grid, elevators, computer and communication centers, hospitals

CellTech Direct Carbon: As CHP & Co-Gen

Combined Heat and Power (CHP) for Residential



Heat to Electric Power ratio

5:1 summer

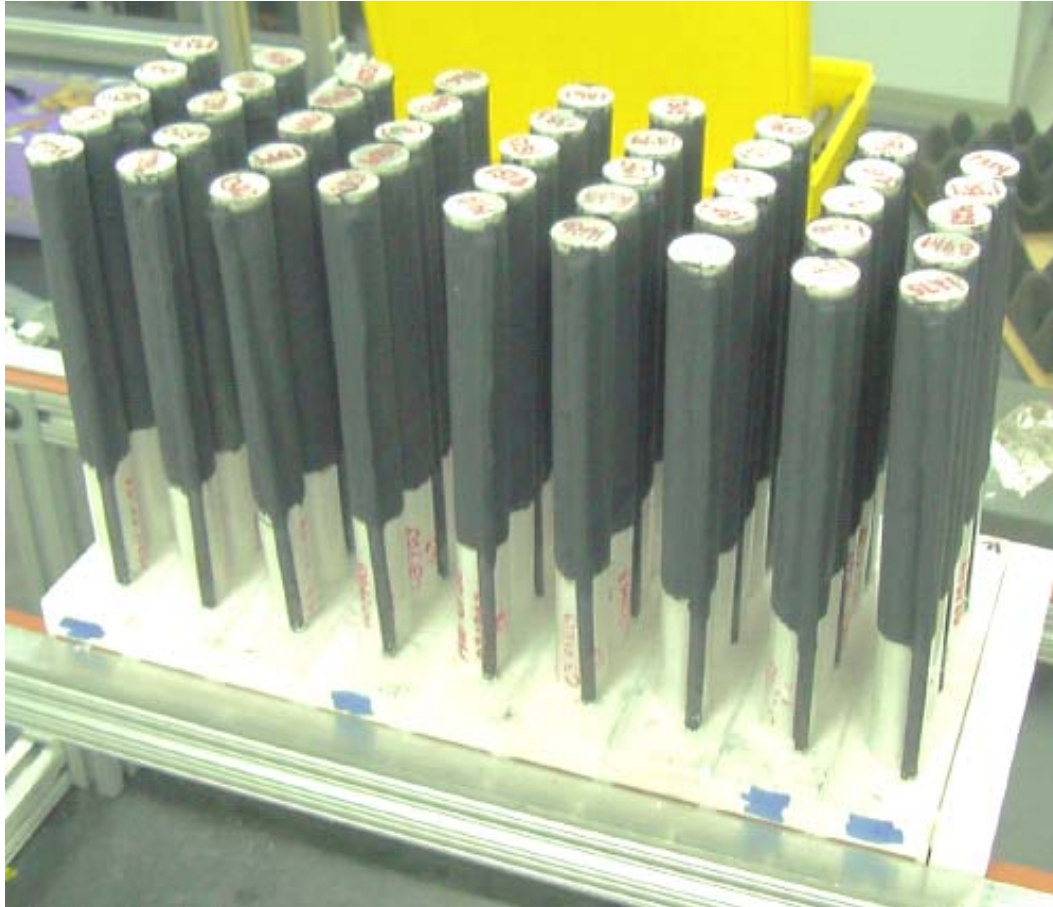
10:1 winter

Goal: Combined Fuel
Efficiency >90%

Status of CellTech's Direct Carbon Conversion Technology

- Fundamentals verified and key inventions made
- Pure carbon-fueled cells demonstrated
- Substantial purification development required for use of un-processed coal
- Private investment is possible
- **Public support is the key**

Current Cell and Stack Configuration



- *Tubular cells connected in series-parallel arrays*
- *External cathode*

Relative DG Performances

	\$/Watt	Electrical Efficiency	Load Following	Low-Maintenance	Multifuel Capability	Small Scale	Large Scale
CellTech	\$1	40%-50%	✓	✓	✓	✓	✓
Conventional Fuel Cells:							
SOFCs	\$1.5+	40%-50%		●	(limited)	●	●
PEMFCs	?	30%-40%				●	?
MCFCs	\$1-\$2	40%-50%		?	(limited)		●
PAFCs	\$2+	30%-45%					●
Other D.G.:							
Microturbines	\$0.80	25%-35%	(limited)	●	●		●
IC Engines	\$0.30	10%-35%	●		●	●	●

CellTech's Technology Development Plan for NG unit

Cell Technology Development

1 kW Alpha
Development

▼ - 1 kW Alpha Demo

▼ - Series B Round

5 kW Beta Dev.
& Field Testing

5 kW Commercialization

Manufacturing Scale-up

2001

2002

2003

2004

2005

2006 - 2010

CellTech's 1 kW Alpha Prototype (to be completed this fall)

1. 1 kW, 120VAC output
2. 30% DC electrical efficiency
(@ 1 kW AC output)
3. Self-contained, "productized" unit
4. *Natural gas fuel*



Direct Carbon Conversion:

The realization of a 150 Year Old Dream!

Thank You!

