

Fuel to Electricity via Solid Electrolyte Fuel Cells

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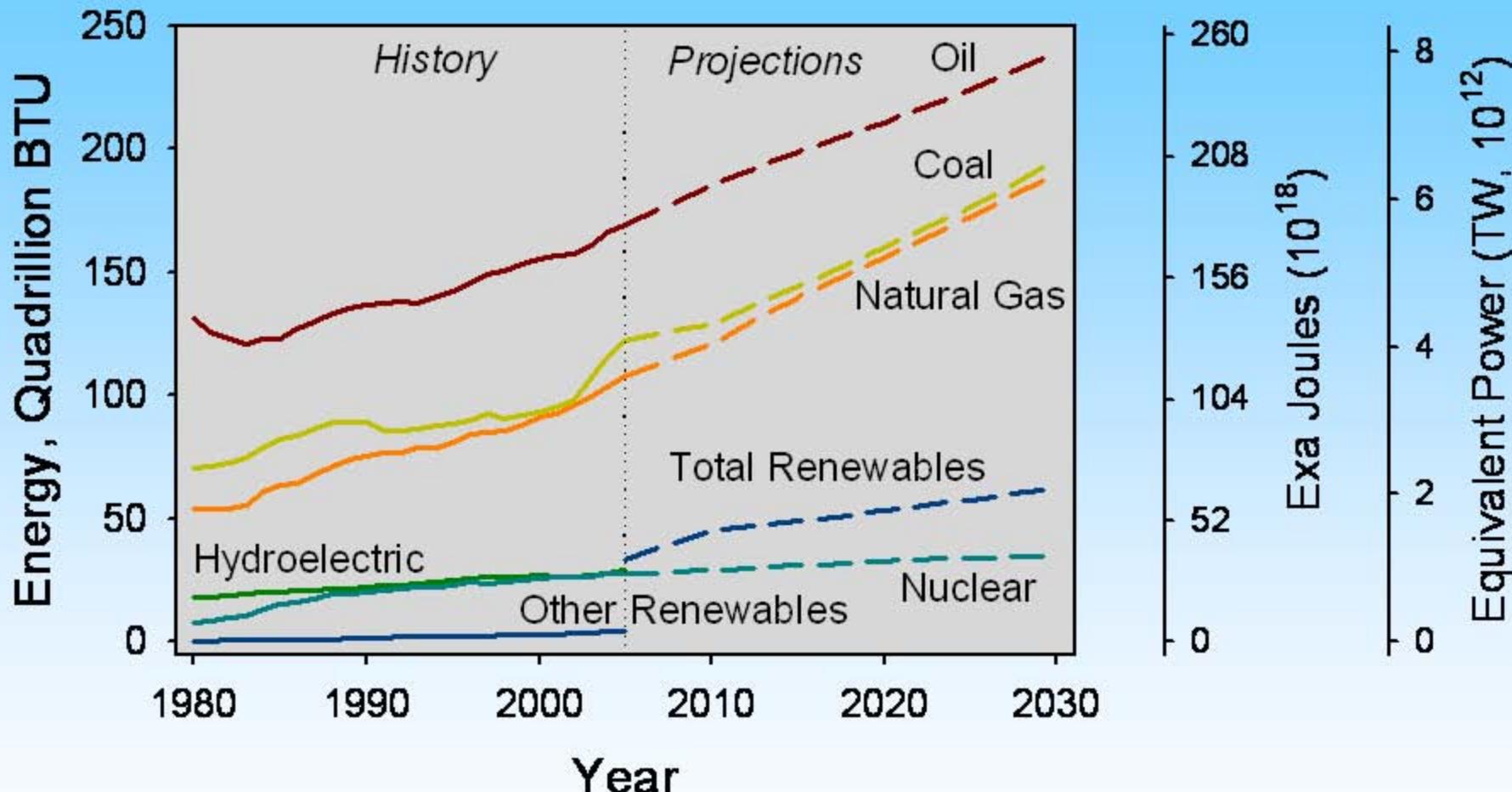


Contents

- The Problem of Energy
 - *Growing consumption*
 - *Consequences*
 - *Sustainable energy resources*
- Fuel Cell Technology Overview
 - *Principle of operation*
 - *Types of fuel cells and their characteristics*
- Selected (Caltech) Advances
 - *New category of fuel cells based on new proton conducting electrolytes*
 - *New component material (cathode) for high power output from solid oxide fuel cells*



World Energy Consumption



2005 totals:

490 Q-Btu, 515 EJ, 16TW

} 86% fossil

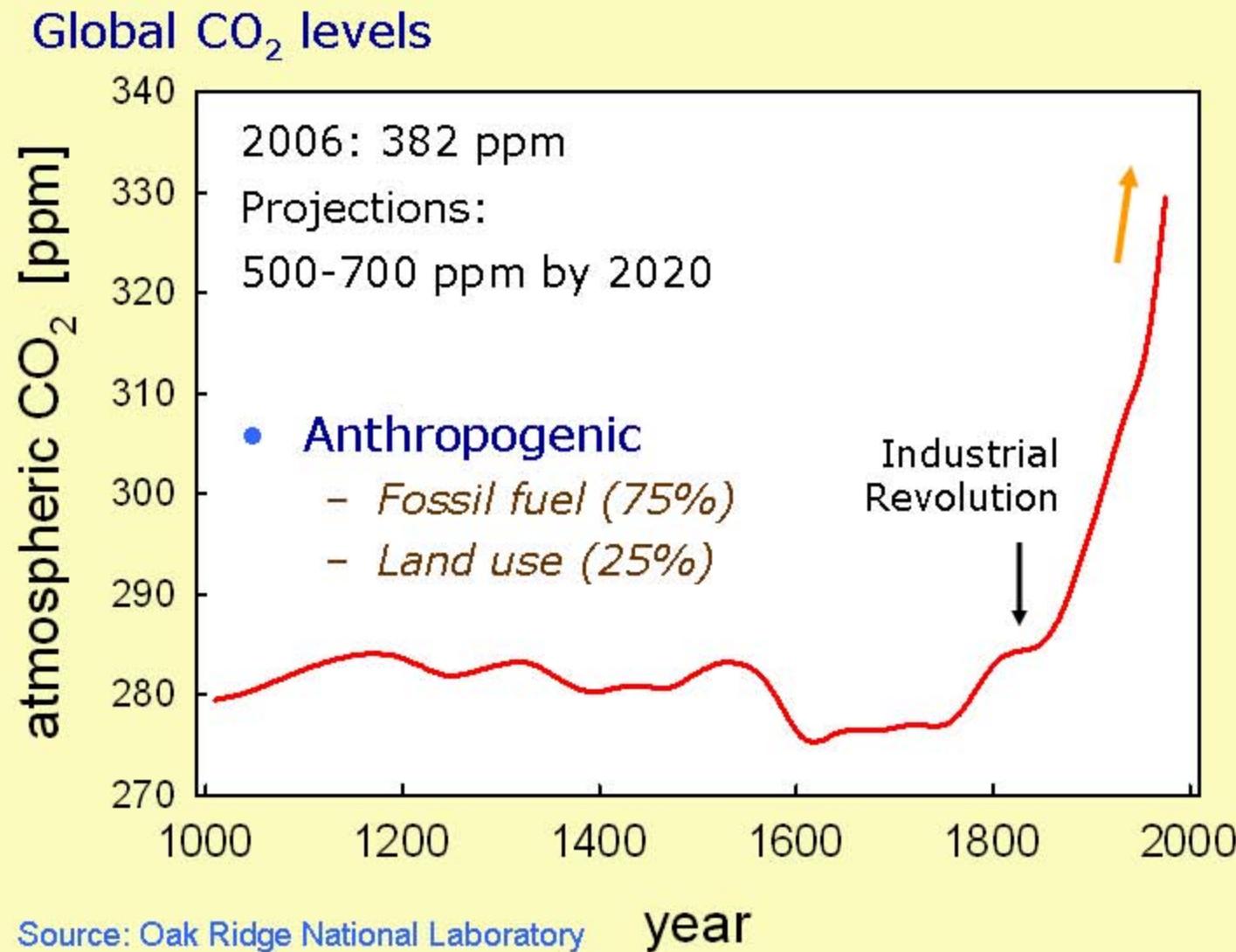
2030 projections:

720 Q-Btu, 760 EJ, 24TW

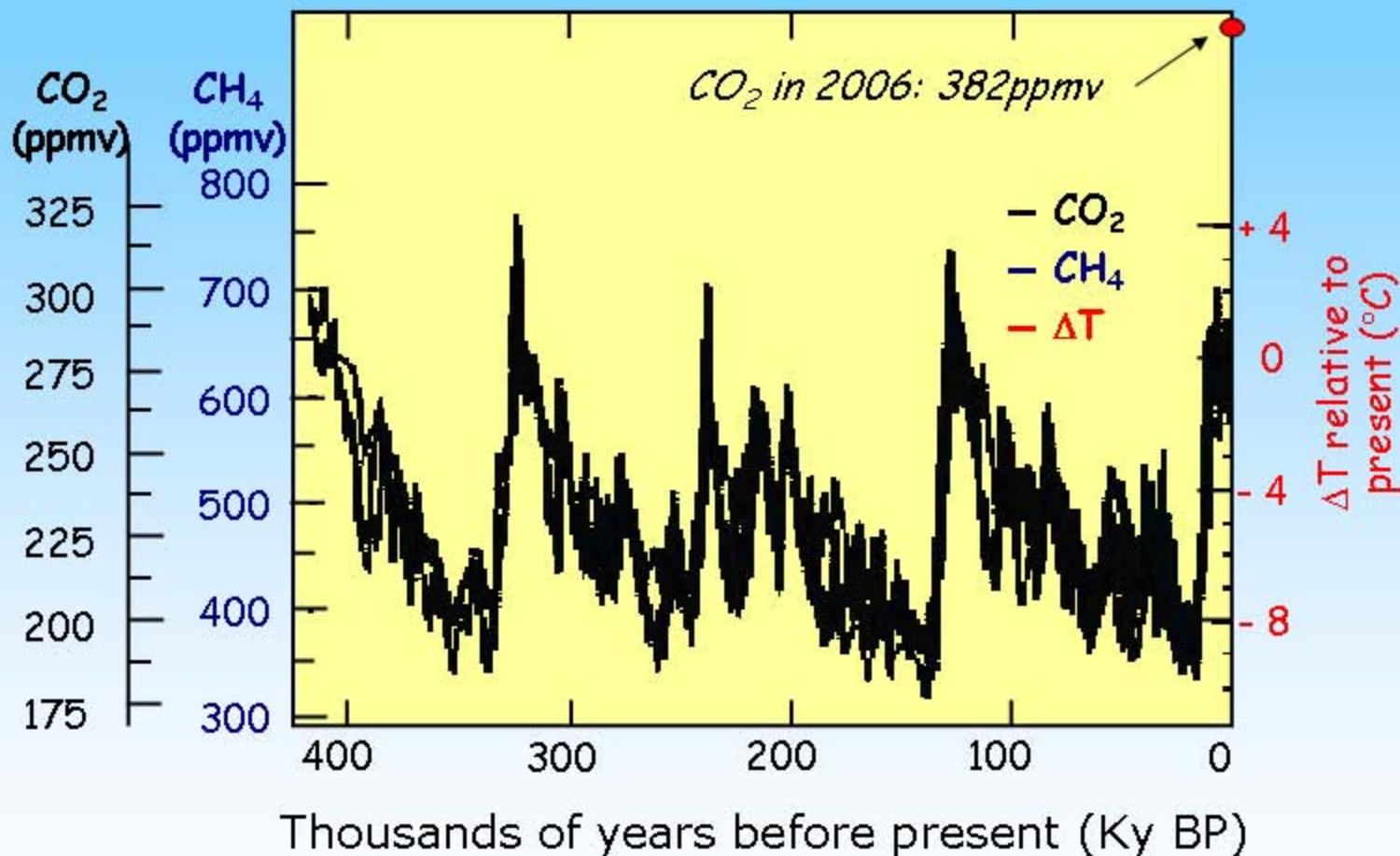
} 81%



Environmental Outlook



Environmental Outlook



Intergovernmental Panel on Climate Change, 2001; <http://www.ipcc.ch>
N. Oreskes, Science 306, 1686, 2004; D. A. Stainforth et al, Nature 433, 403, 2005

The Energy Solution

Solar

1.2×10^5 TW at Earth surface
600 TW practical

The need:

~ 20 TW by 2050

Wind

2-4 TW extractable

Tide/Ocean Currents

2 TW gross

Geothermal

12 TW gross over land
small fraction recoverable

Nuclear

Waste disposal
60 yr uranium supply



Biomass

5-7 TW gross
all cultivatable
land not used
for food

Hydroelectric

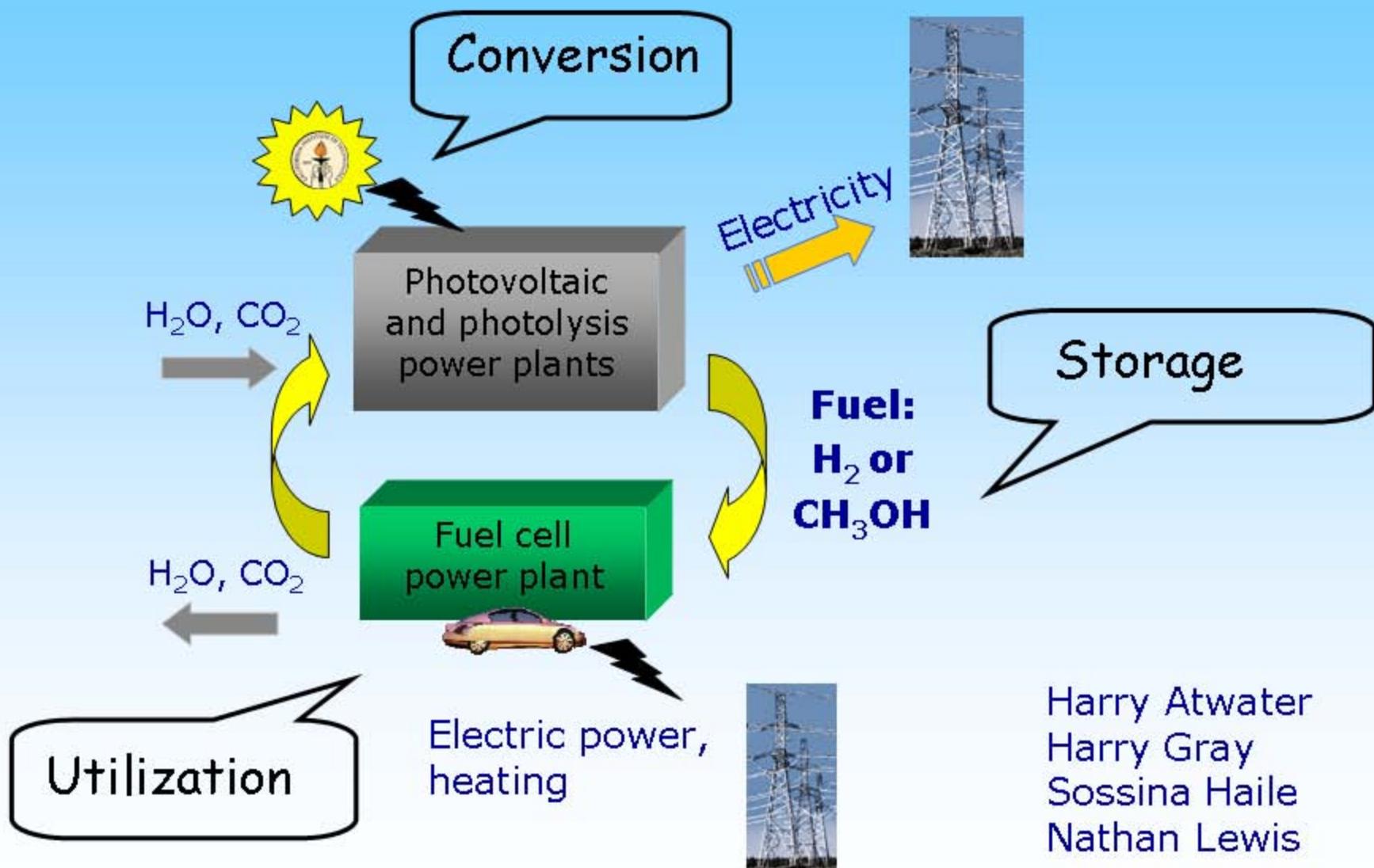
4.6 TW gross
1.6 TW technically feasible
0.9 TW economically feasible
0.6 TW installed capacity

Fossil with sequestration

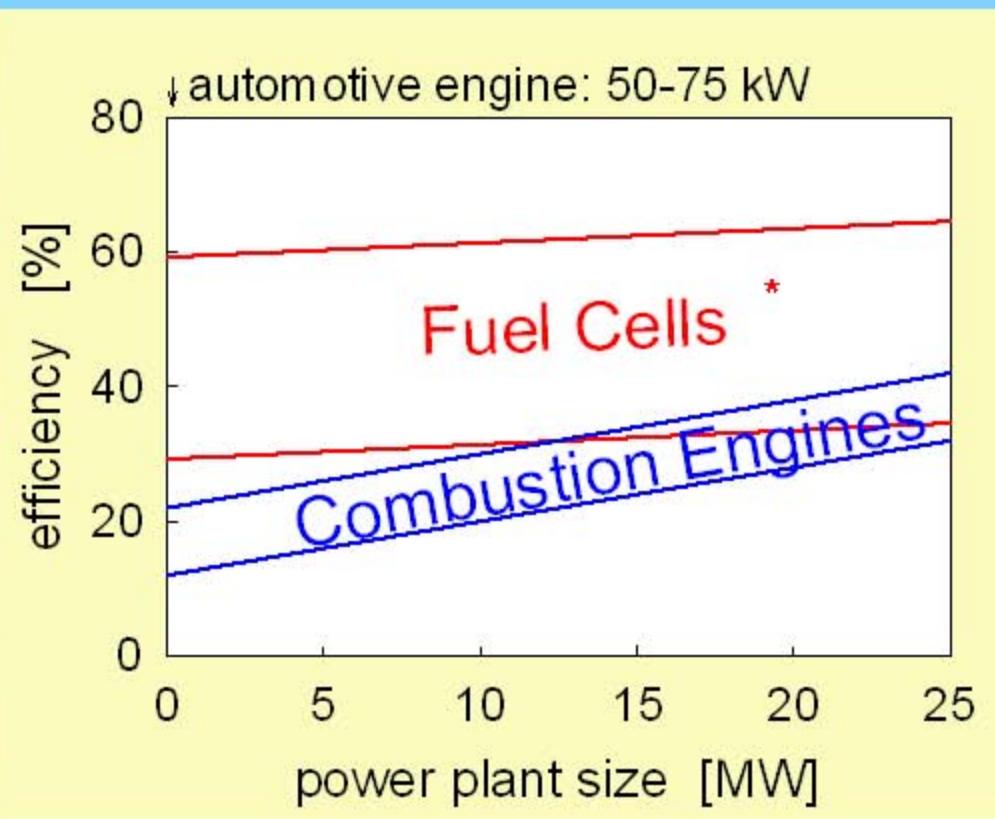
1% / yr leakage -> lost in 100 yrs



Caltech Center for Sustainable Energy Research



Fuel Cells: Part of the Solution?

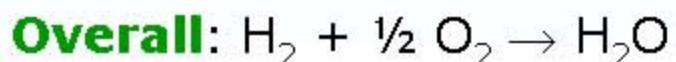
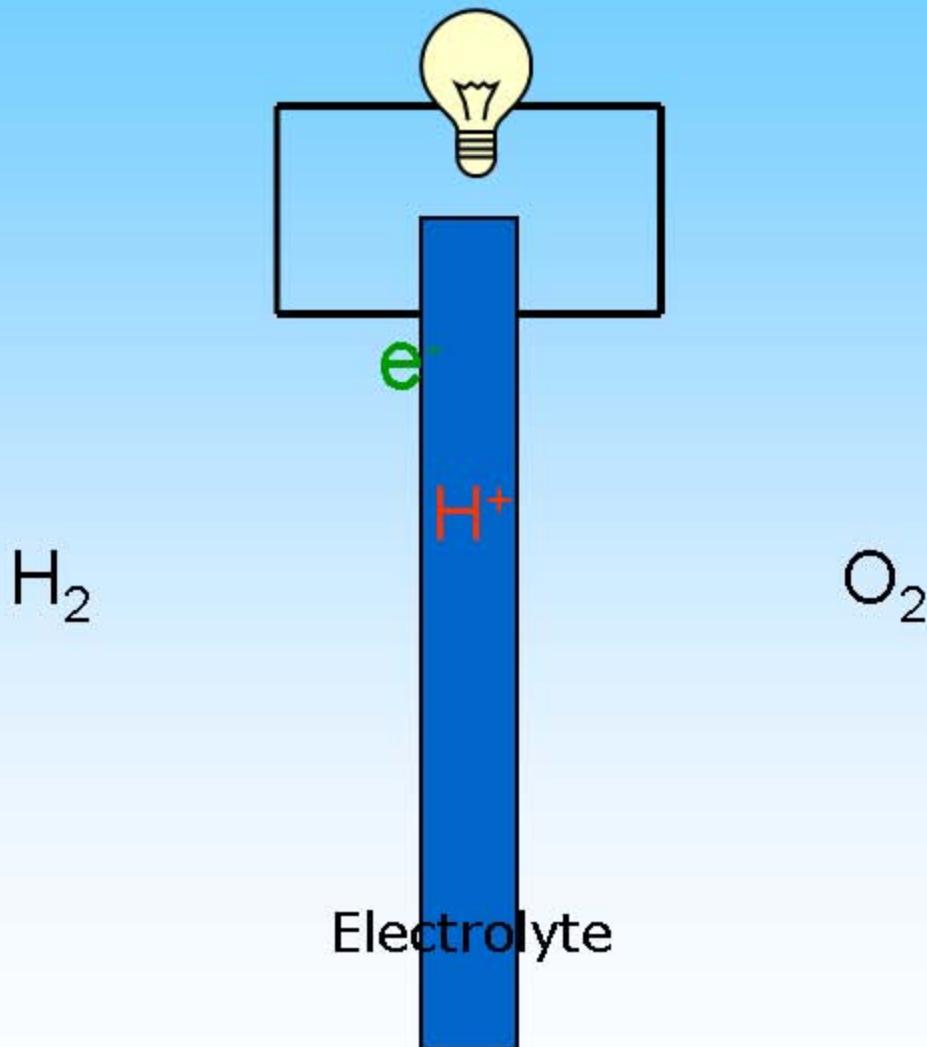


- High efficiency
 - *low CO₂ emissions*
- Size independent
- Various applications
 - *stationary*
 - *automotive*
 - *portable electronics*
- Controlled reactions
 - *"Zero Emissions"*
- Operable on hydrogen
 - *(if suitably produced)*

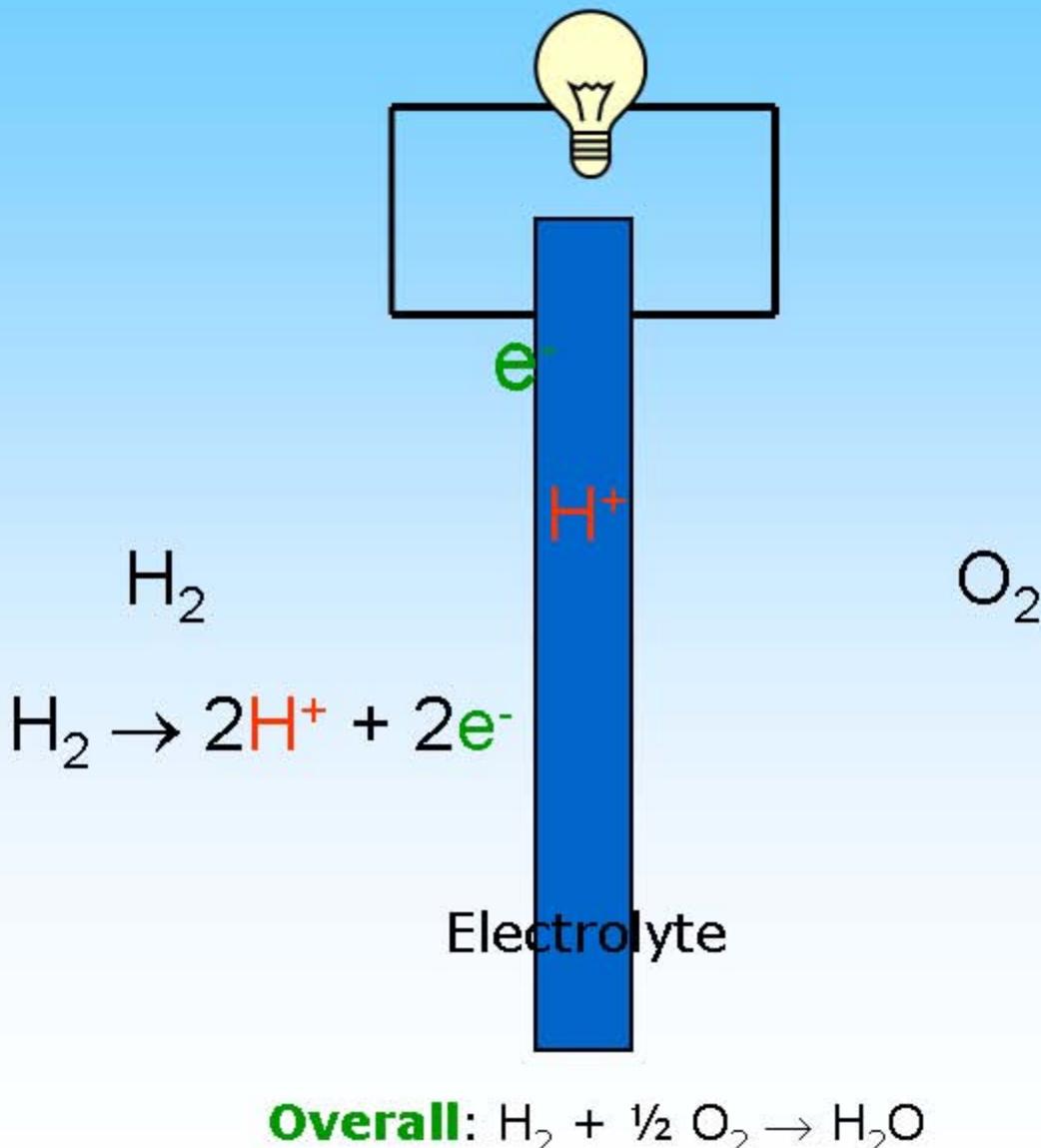
*Can be as high as 80-90% with co-generation



Fuel Cell: Principle of Operation

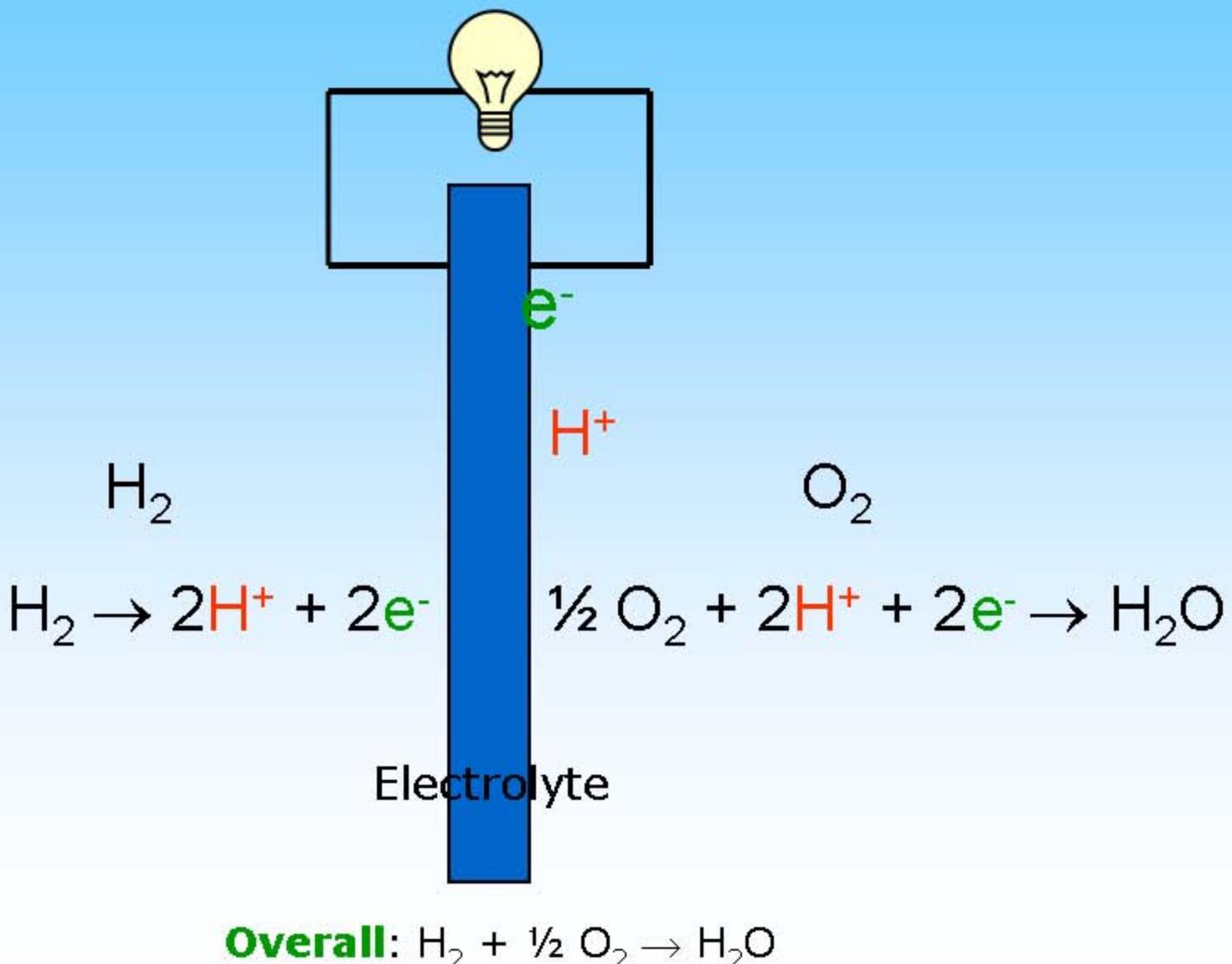


Fuel Cell: Principle of Operation

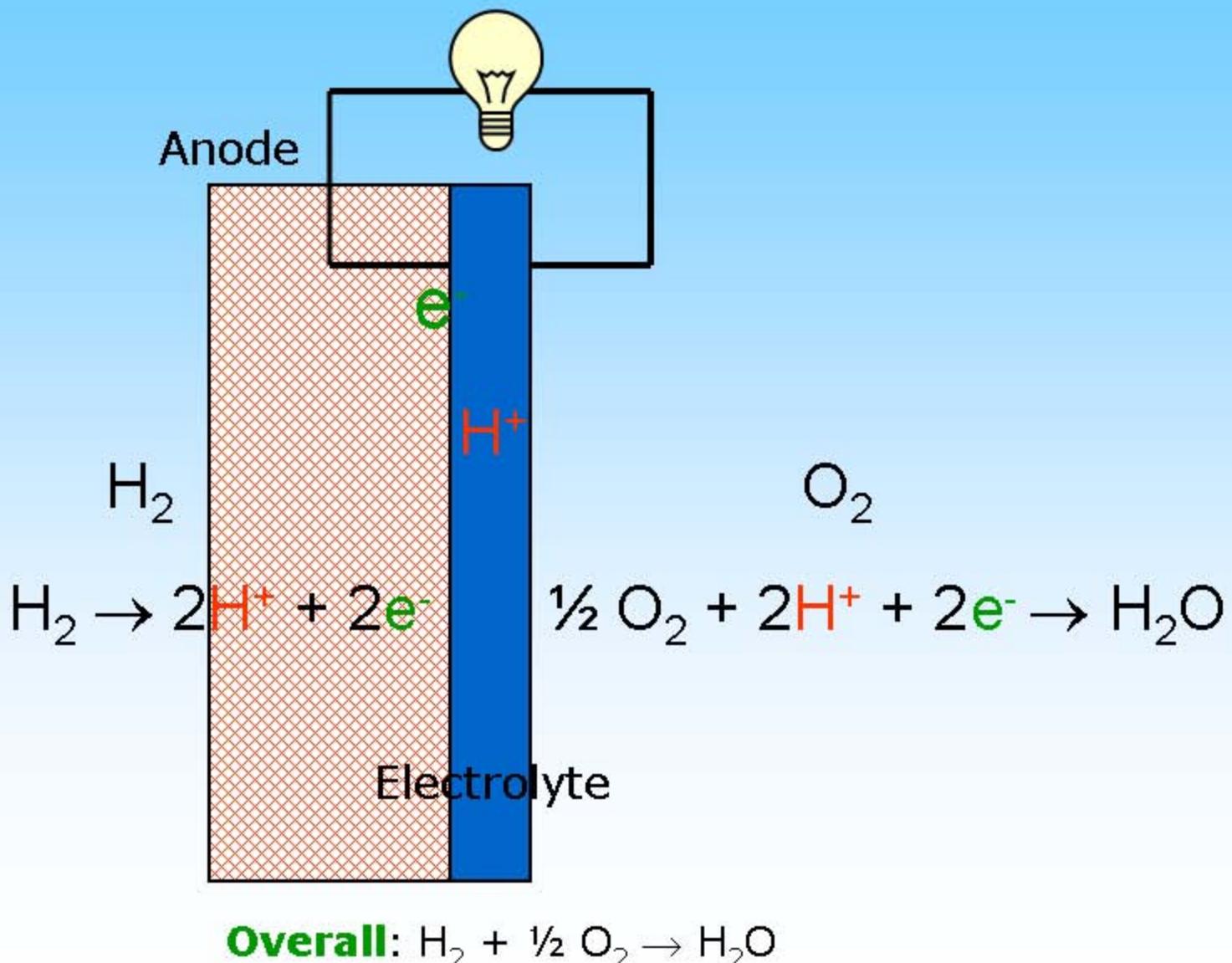


Towards a Sustainable Energy Future

Fuel Cell: Principle of Operation

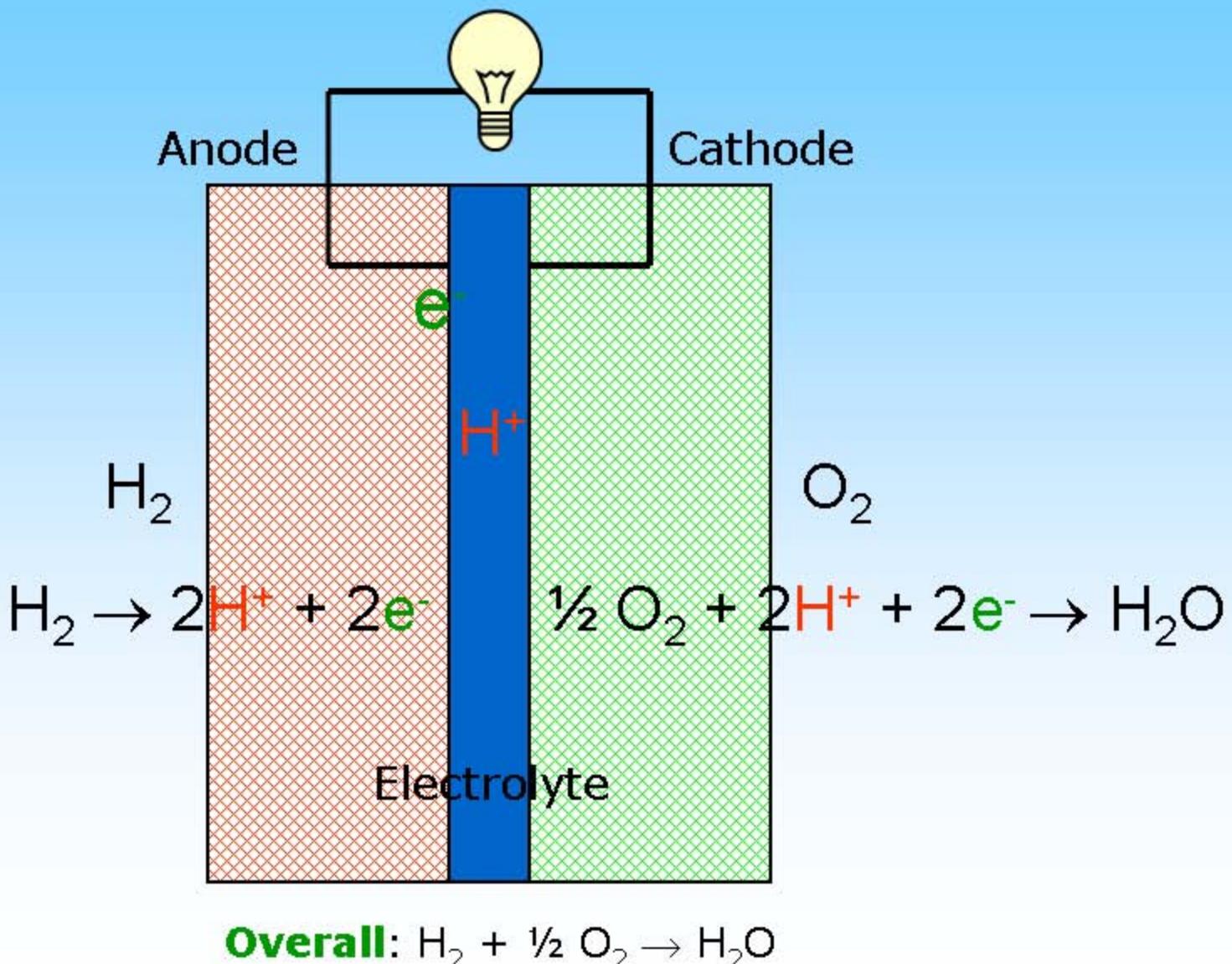


Fuel Cell: Principle of Operation



Towards a Sustainable Energy Future

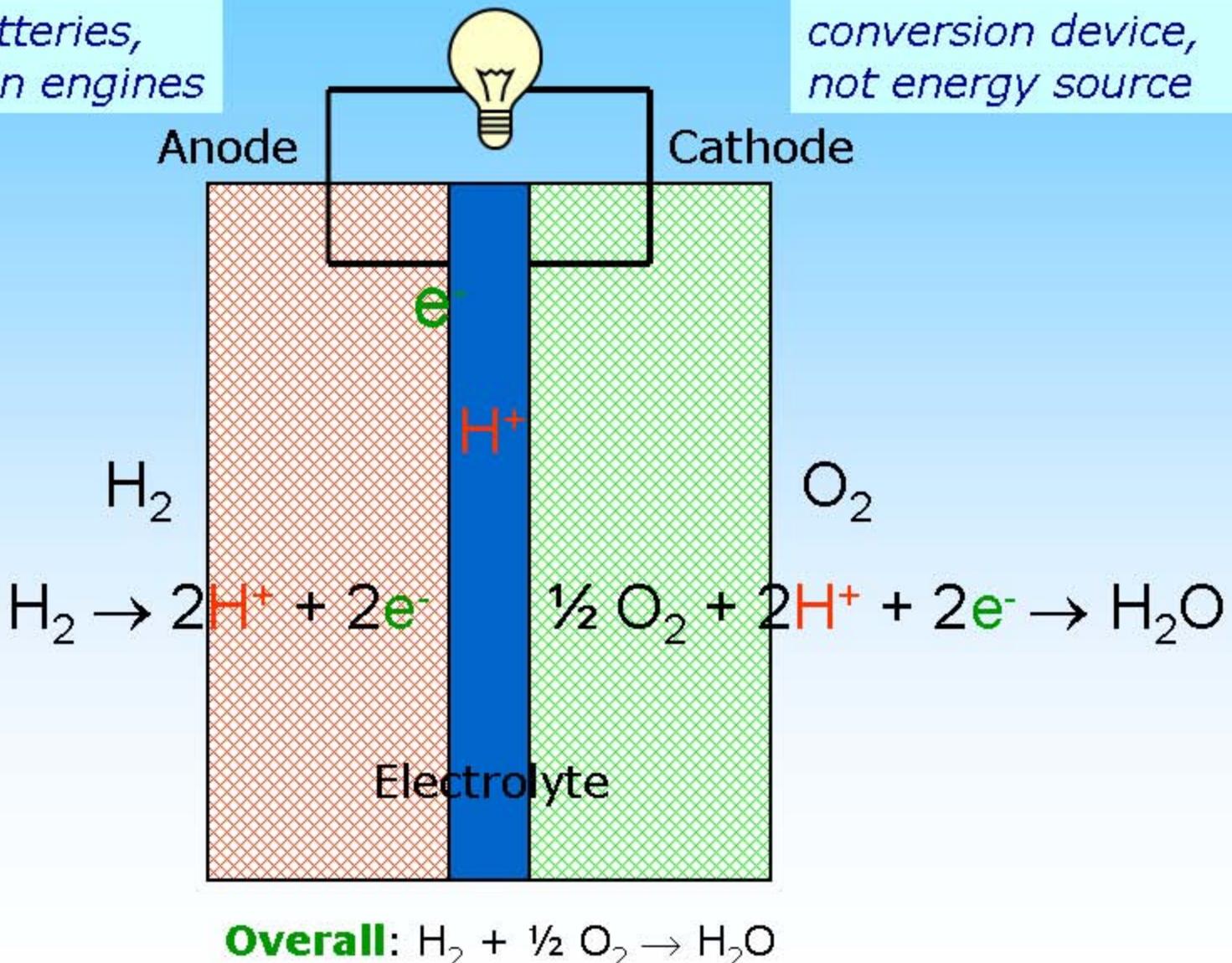
Fuel Cell: Principle of Operation



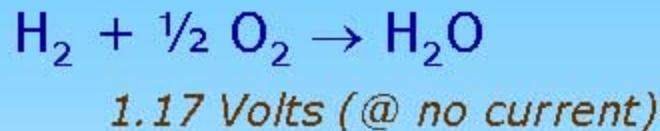
Fuel Cell: Principle of Operation

*best of batteries,
combustion engines*

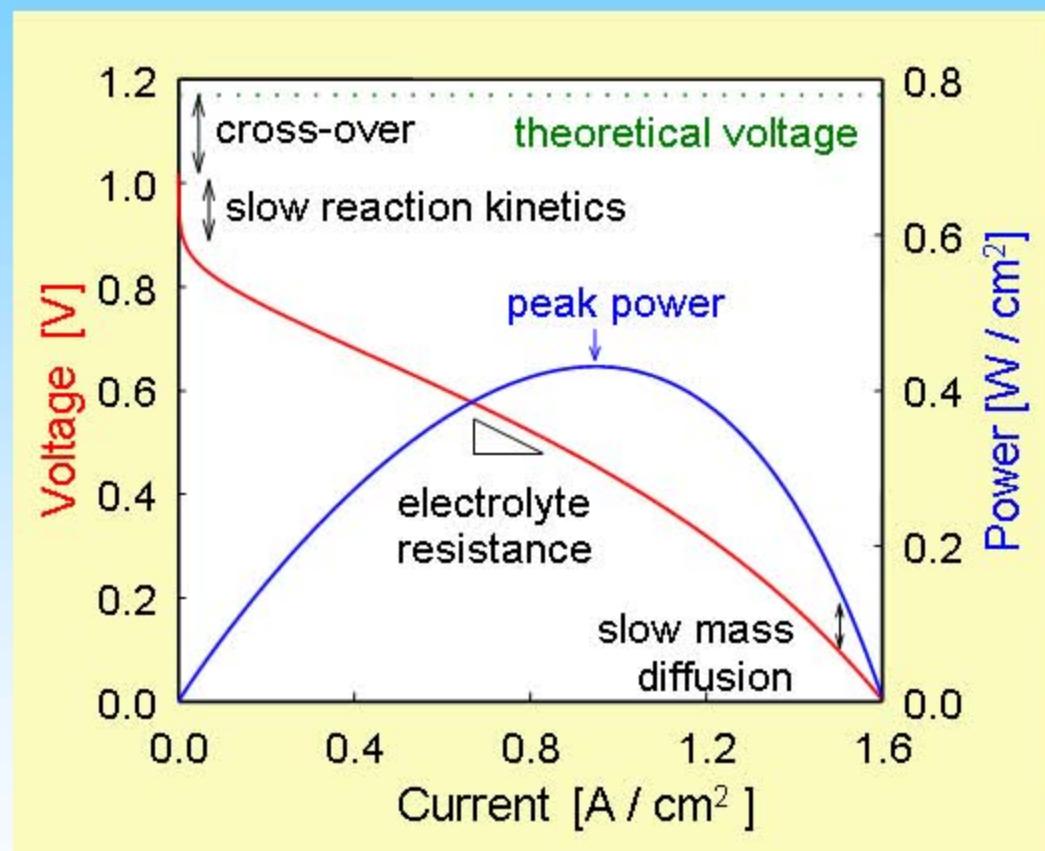
*conversion device,
not energy source*



Fuel Cell Performance

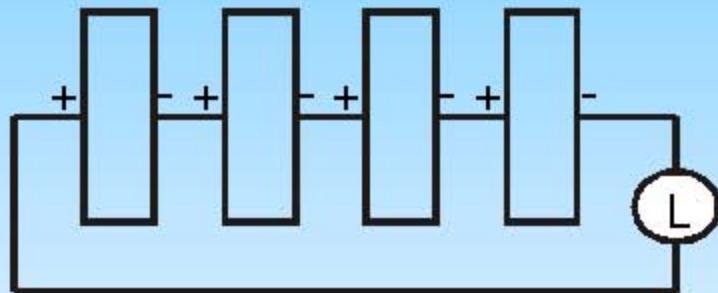


- voltage losses
 - fuel cross-over
 - reaction kinetics
 - electrolyte resistance
 - slow mass diffusion
- power = I*V
- peak efficiency at low I
- peak power at mid I



From a Single Cell to a Fuel Cell Stack

- Multiple cells
- Connect in series: $V = nV_o$



- Connect in parallel: $I = nI_o$
- Requires gas flows to each
- Thermal management
- Greater system complexity than batteries



Fuel Cell Types

Types differentiated by **electrolyte**, temperature of operation

Type	PEM	AFC	PAFC	MCFC	SOFC
°C	90-110	100-250	150-220	500-700	700-1000
Fuel	$H_2 + H_2O$	H_2	H_2	$HC + CO$	$HC + CO$
Electrolyte Ion	Nafion $H_3O^+ \downarrow$	KOH $OH^- \uparrow$	H_3PO_4 $H^+ \downarrow$	Na_2CO_3 $CO_3^{2-} \uparrow$	$Y-ZrO_2$ $O^{2-} \uparrow$
Oxidant	O_2	$O_2 + H_2O$	O_2	$O_2 + CO_2$	O_2

← Easy thermal cycling → Fuel flexibility, efficiency

Most substantial recent investments and development activity



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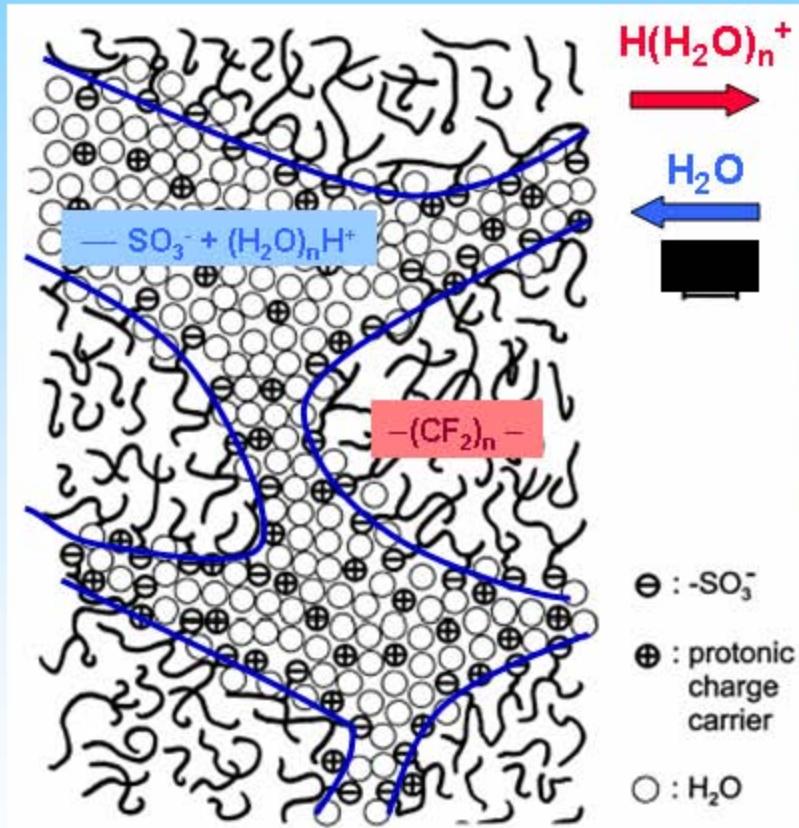
Easy thermal cycling Fuel flexibility, efficiency

Most substantial recent investments and development activity



Ambient Temperature Fuel Cells

Proton Exchange Membrane or Polymer Electrolyte Membrane



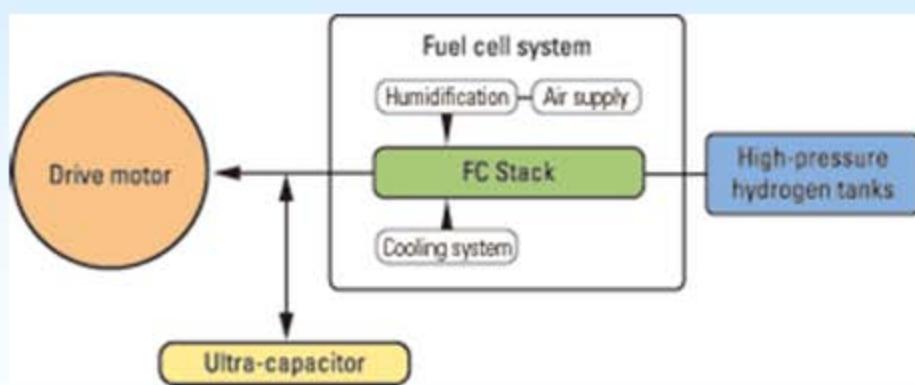
Kreuer, J. Membr. Sci. 2 (2001) 185.

Nafion (Dupont)

- saturate with H_2O
 - *inverse micelle structure*
 - $\text{H}(\text{H}_2\text{O})_n^+$ ion transport
-
- ✓ High conductivity
 - ✓ Flexible, high strength
 - ✗ Requires humidification & water management
 - ✗ Operation below 90°C
 - Limits catalytic activity
 - ✗ Permeable to methanol
 - ✗ Permeable to O_2, H_2



Development Activities



- Honda FCX Clarity
 - Leasing in summer 2008
 - H_2 available markets (LA)
- 86 kW PEM fuel cell
- 68 mpg equivalent
 - $1.5 \times$ gas-electric hybrid
- 270 mile range
- 5,000 psi H_2 tank
 - approx 4 kg H_2
- Lithium-ion battery pack
 - Replaces ultra-caps

Some Fundamental Challenges

- Polymer conductivity scales with water content
- Methanol cross-over scales with water content
- Acidic water in polymer dissolves catalysts
 - *Coarsens fine particles*
 - *Causes Ru cross-over (used for methanol oxidation)*
- Ambient temperature operation requires Pt
 - *DOE target: 1 g/kW (0.75 g/hp)*
 - *125 hp engine \Rightarrow 100g Pt $\Rightarrow \$5,028$*
 - *93% of US Pt is imported, 80% of world reserves in SA*
 - *Converting all registered US vehicles (~ 250 million)*
 - *Need: 25 million kg Pt*
 - *Reserves: proven ~ 7 million kg; inferred ~ 32 million kg*
 - *DOE longterm target: 0.2 g/kW*

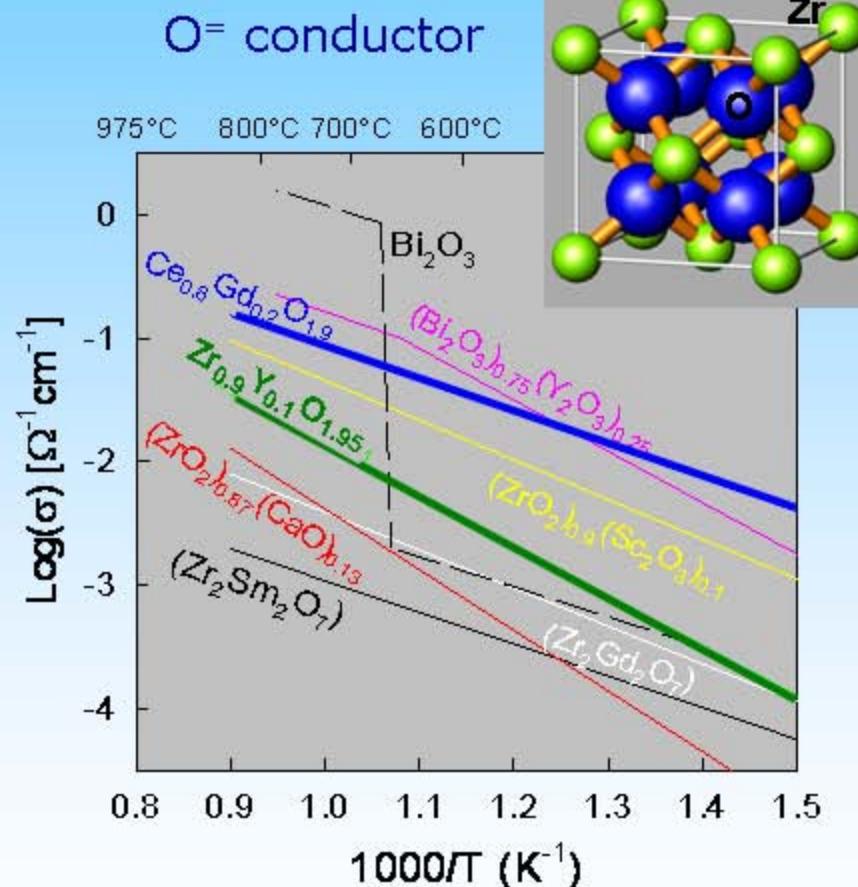


Solid Oxide Fuel Cells

(La,Sr)MnO₃ | YSZ | Ni-YSZ
cathode | electrolyte | anode

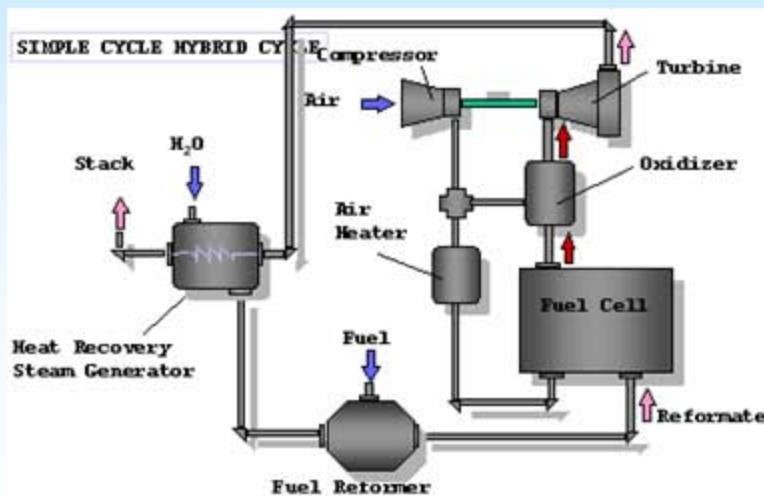
- Anode or electrolyte supported
- 800 – 1000 °C operation
- Fuel flexible, efficient
- But...
 - Costly (*manufacture*)
 - Poor thermal cyclability

Goal: reduced temperature operation, 500 – 800 °C



Demonstration Activities

Siemens-Westinghouse Project at Natl Fuel Cell Res Ctr



"HYBRID" 220 kW Hybrid

- Solid Oxide Fuel Cell + Micro Turbine Generator
- 180 kW SOFC
- 40 kW Microturbine
- Installed 2000
- Operated > 1,500 hr
- Fuel-to-electricity
 - 53% demonstrated
 - 60-70% future
- Natural gas (100 psi)



Fuel Cell Types

Types differentiated by **electrolyte**, temperature of operation

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Fuel flexibility, efficiency Easy thermal cycling



Fuel Cell Types

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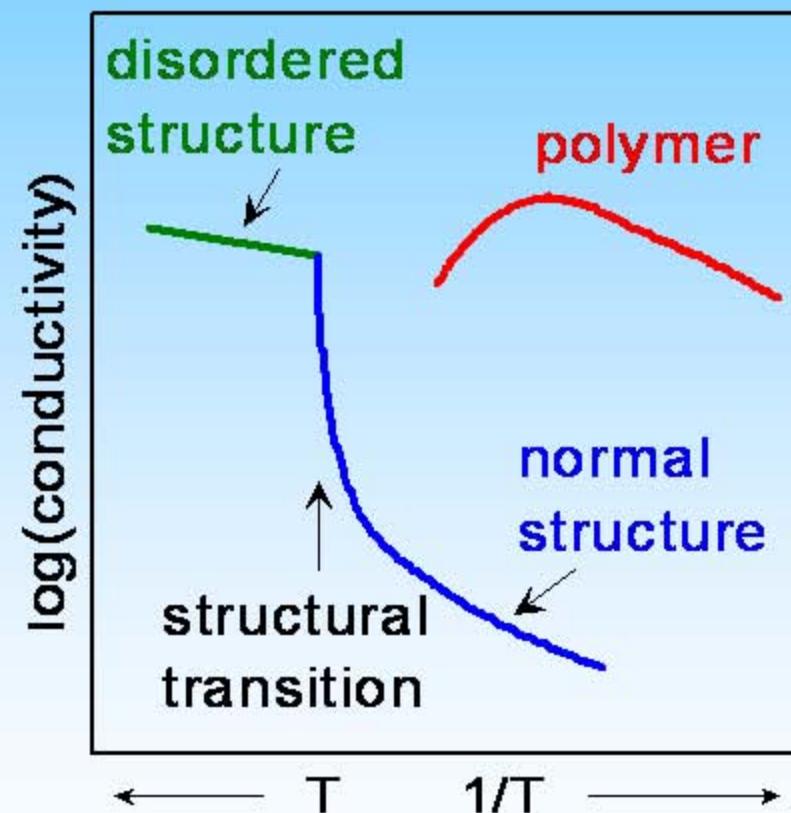
Fuel flexibility, efficiency → ← **Easy thermal cycling**

Target regime

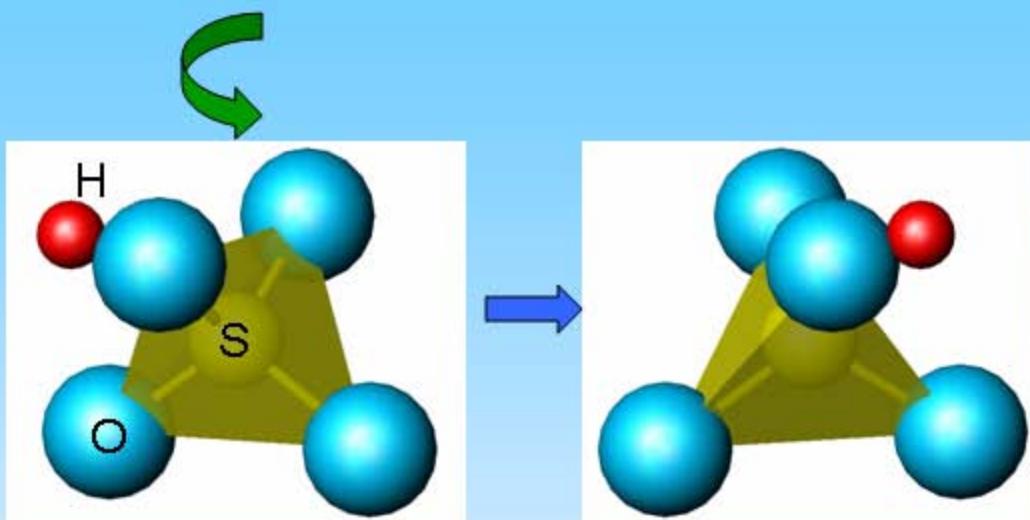


New Electrolytes: Solid Acids

- Chemical intermediates between normal salts and normal acids: “acid salts”
 $\frac{1}{2}(\text{Cs}_2\text{SO}_4) + \frac{1}{2}(\text{H}_2\text{SO}_4) \rightarrow \text{CsHSO}_4$
- Physically similar to salts
- Structural disorder at ‘warm’ temperatures
- Properties
 - ✓ Direct H^+ transport
 - ✓ Humidity insensitive
 - ✓ Impermeable
 - ✗ Water soluble!! Brittle



Proton Transport Mechanism

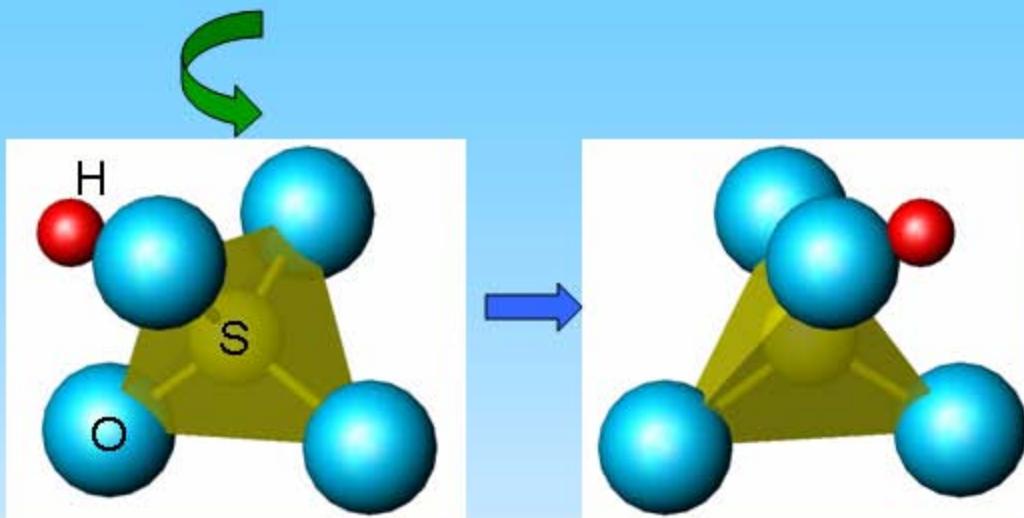


Sulfate group
reorientation

10^{-11} seconds

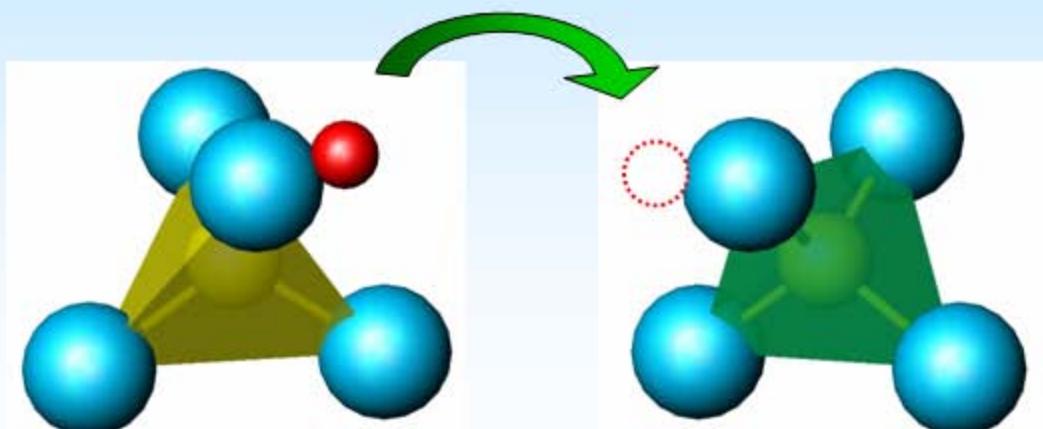


Proton Transport Mechanism



Sulfate group
reorientation

10^{-11} seconds



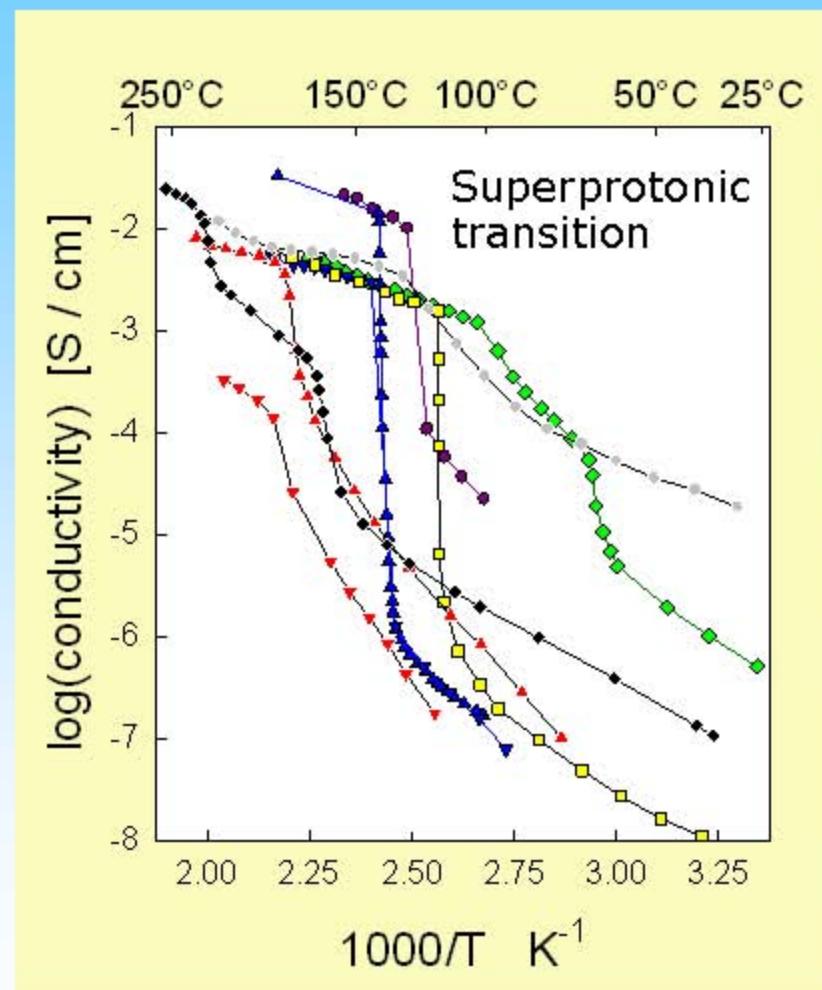
Proton transfer

10^{-9} seconds



Conductivity of Solid Acids

- CsHSO_4 [Baranov, 1982]
- CsHSeO_4 [Baranov, 1982]
- $(\text{NH}_4)_3\text{H}(\text{SO}_4)_2$
[Ramasastri, 1981]
- $\text{Rb}_3\text{H}(\text{SeO}_4)_2$
[Pawlowski, 1988]
- $\text{Cs}_2(\text{HSO}_4)(\text{H}_2\text{PO}_4)$
[Chisholm & Haile, 2000]
- $\beta\text{-Cs}_3(\text{HSO}_4)_2(\text{H}_2\text{PO}_4)$
[Haile et al., 1997]
- $\text{K}_3\text{H}(\text{SO}_4)_2$
[Chisholm & Haile, 2001]



But sulfates and selenates are unstable under reducing conditions...



CsH_2PO_4 as a Fuel Cell Electrolyte

- Expected to have chemical stability
 - $3\text{CsH}_2\text{PO}_4 + 11\text{H}_2 \rightarrow \text{Cs}_3\text{PO}_4 + 3\text{H}_3\text{P} + 8\text{H}_2\text{O}$
 - $dG(rxn) \gg 0$
- But does it have high conductivity?
- Does it have sufficient thermal stability?
- Literature dispute
 - *High conductivity on heating due to H_2O loss*
 - *High conductivity due to transition to a cubic phase*

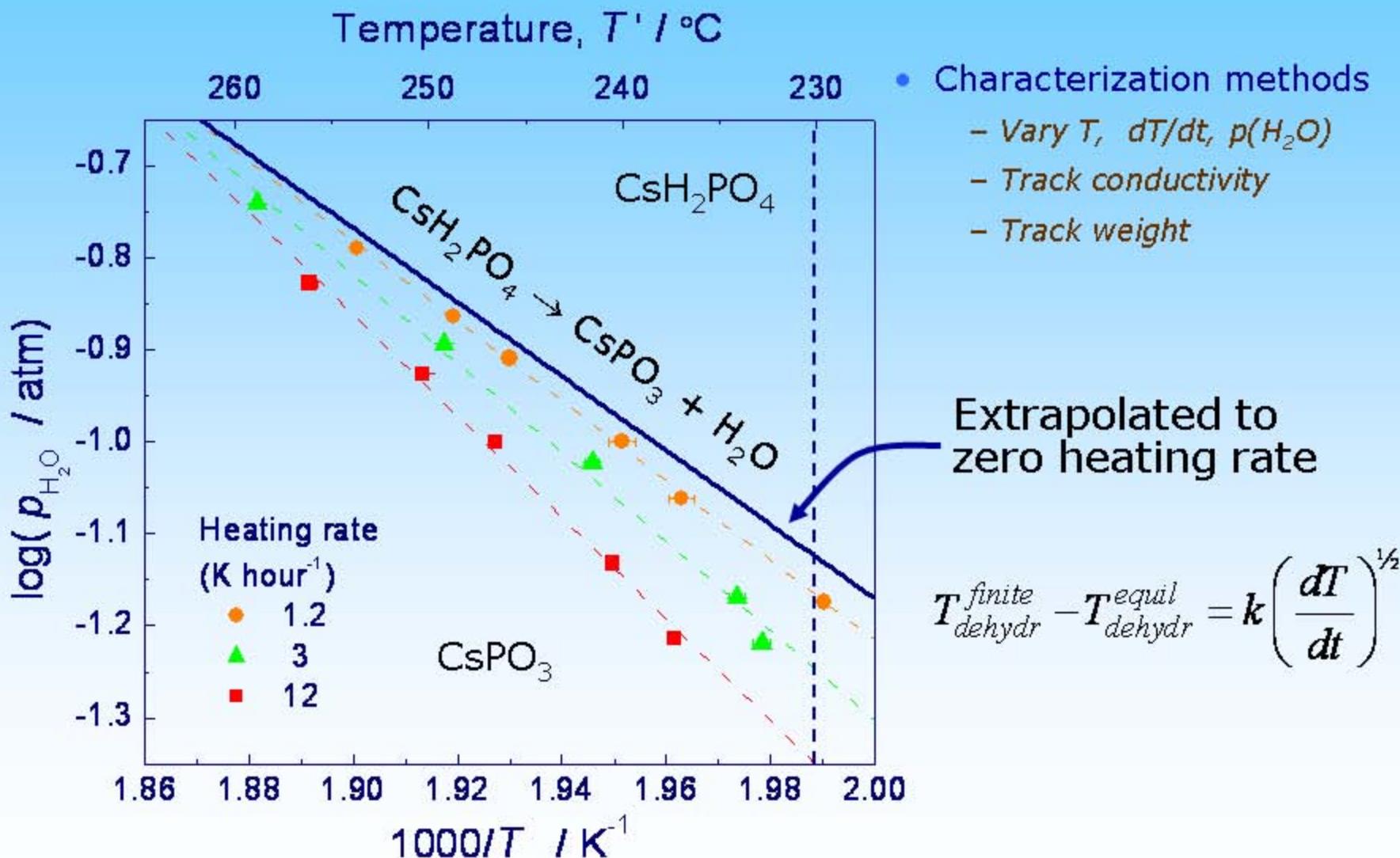


The Controversy

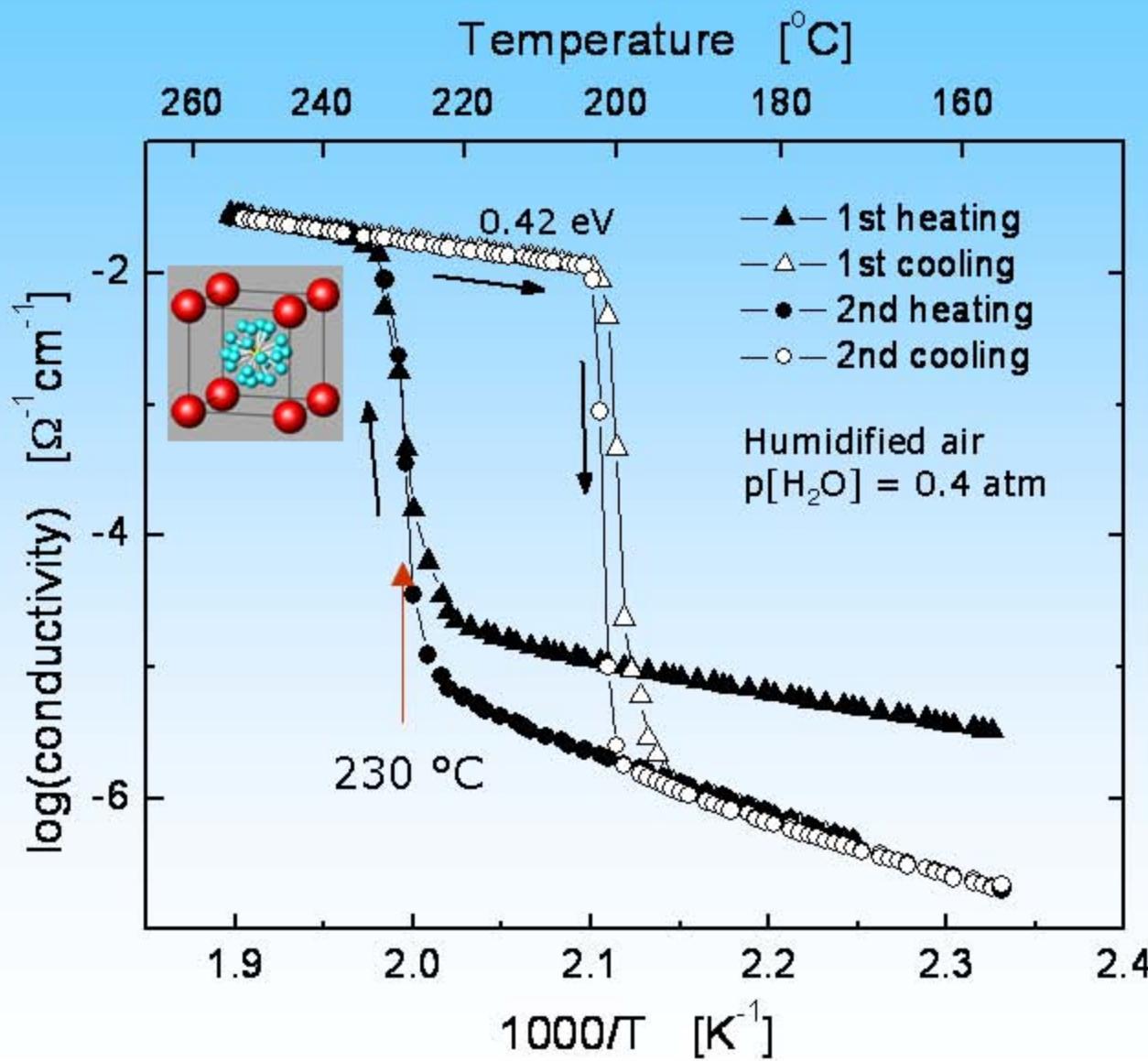
A. I. Baranov et al	Frequency Dielectric-Dispersion in the Ferroelectric and Superionic Phases of CsH_2PO_4 .	1988
W. Bronowska	X-Ray Study of the High-Temperature Phase-Transition of CsH_2PO_4 Crystals.	1990
F. Romain et al	Raman-Study of the High-Temperature Phase-Transition in CsH_2PO_4	1991
R. A. Vargas et al.	Phase-Behavior of RbH_2PO_4 and CsH_2PO_4 in the Fast-Ion Regime	1993
A. Preisinger et al.	The Phase Transition of CsH_2PO_4 (CDP) at 505 K	1994
K. S. Lee	Hidden Nature of the High-Temperature Phase Transitions in Crystals of KH_2PO_4 -Type: A Physical Change?	1996
Y. Luspin et al	Discontinuities in the Elastic Properties of CsH_2PO_4 at the Superionic Transition	1997
E. Ortiz et al	On the High-Temperature Phase Transitions of CsH_2PO_4 : a Polymorphic Transition? A Transition to a Superprotic Conducting Phase?	1999
E. Ortiz et al	On the High-Temperature Phase Transitions of Some KDP-Family Compounds: a Structural Phase Transition? A Transition to a Bulk-High Proton Conducting Phase?	1999
W. Bronowska	Does the Structural Superionic Phase Transition at 231 Degrees C in CsH_2PO_4 Really Not Exist	2001
K. S. Lee	Surface Transformation of Hydrogen-Bonded Crystals at High-Temperatures and Topochemical Nature	2002
J. Otomo et al	Protonic Conduction of CsH_2PO_4 and Its Composite With Silica in Dry and Humid Atmospheres.	2003
D. A. Boysen et al	High-Temperature Behavior of CsH_2PO_4 Under Both Ambient and High Pressure Conditions.	2003
J. H. Park et al	Physical Properties of CsH_2PO_4 Crystal at High Temperatures	2003
D. A. Boysen et al	High-Performance Solid Acid Fuel Cells Through Humidity Stabilization.	2004
J. H. Park	Possible Origin of the Proton Conduction Mechanism of CsH_2PO_4 Crystals at High Temperatures	2004
K. Yamada et al	Superprotic Conductor CsH_2PO_4 Studied by H-1, P-31 NMR and X-Ray Diffraction	2004
J. Otomo et al	Effect of Water Vapor on Proton Conduction of Cesium Dihydrogen Phosphate and Application to Intermediate Temperature Fuel Cells	2005



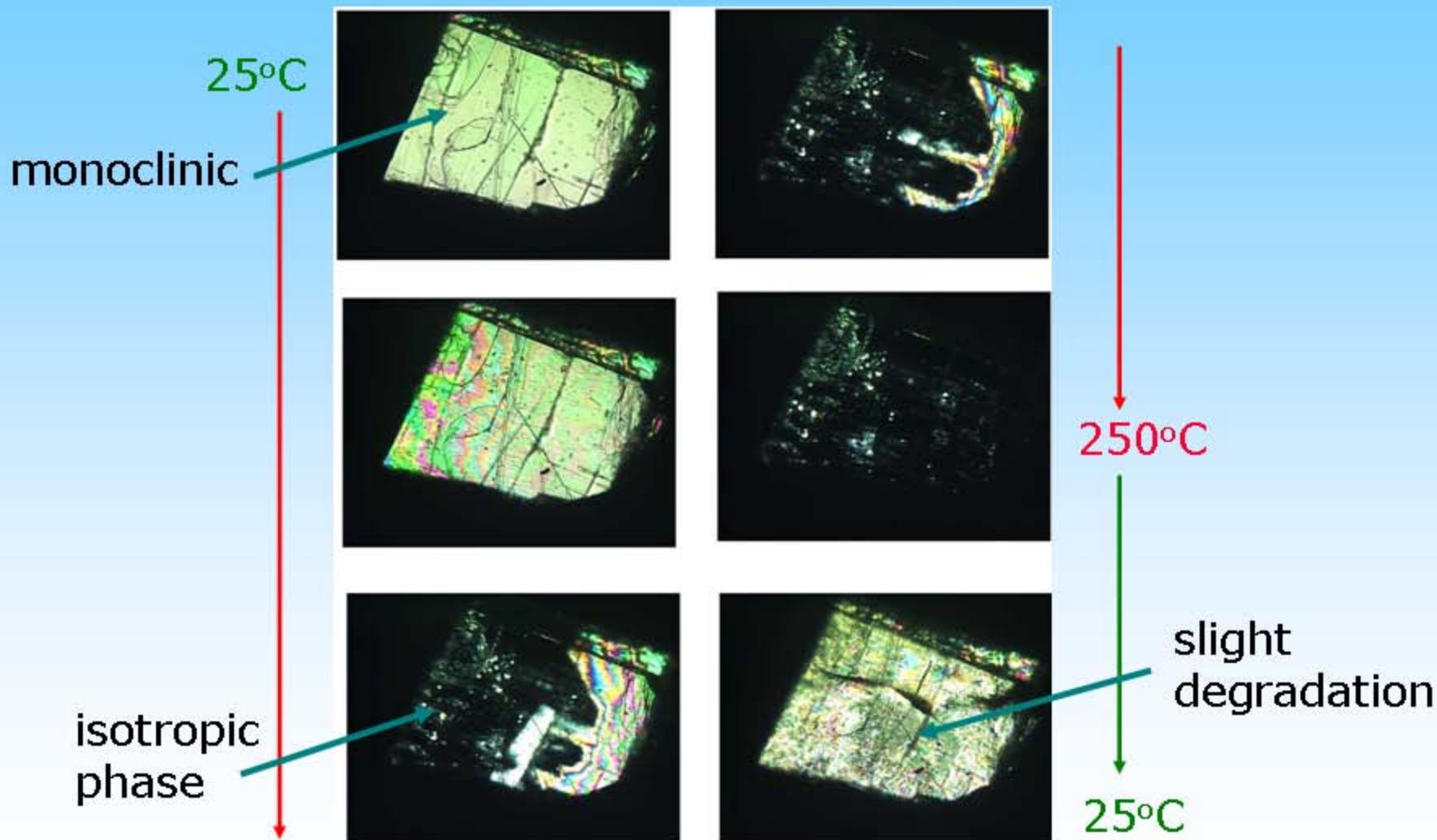
Equilibrium Dehydration



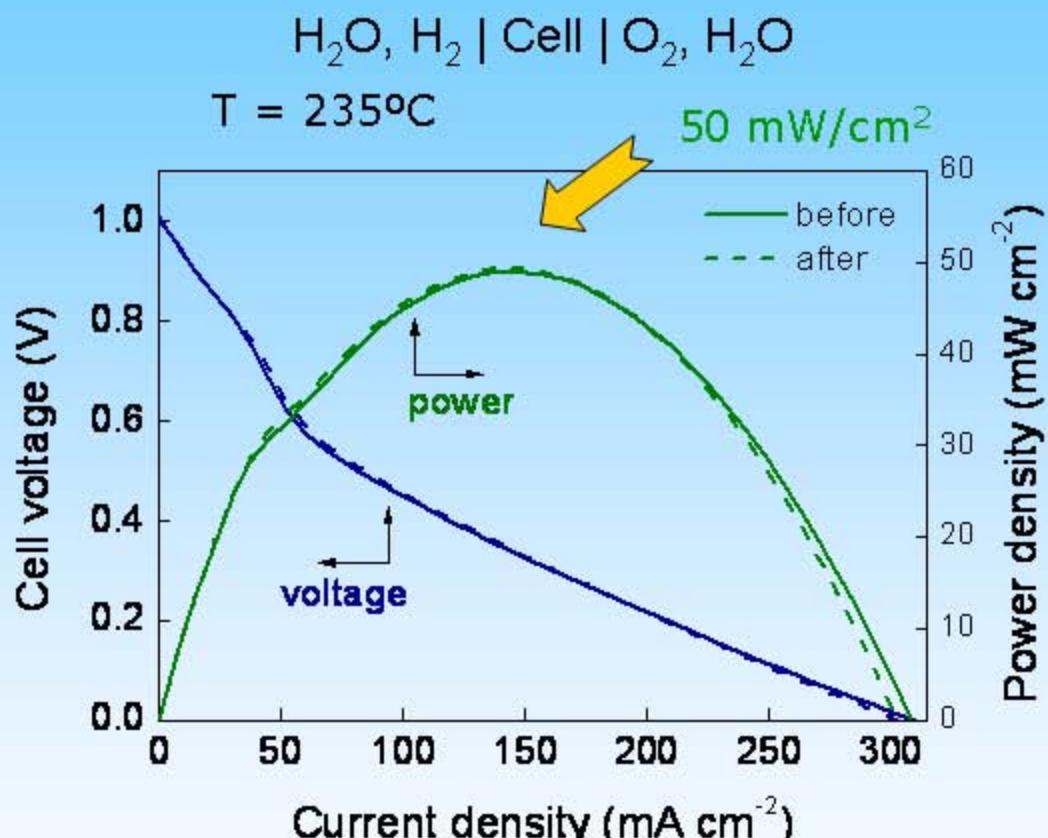
Conductivity of CsH_2PO_4



Optical Microscopy



Proof of Principle



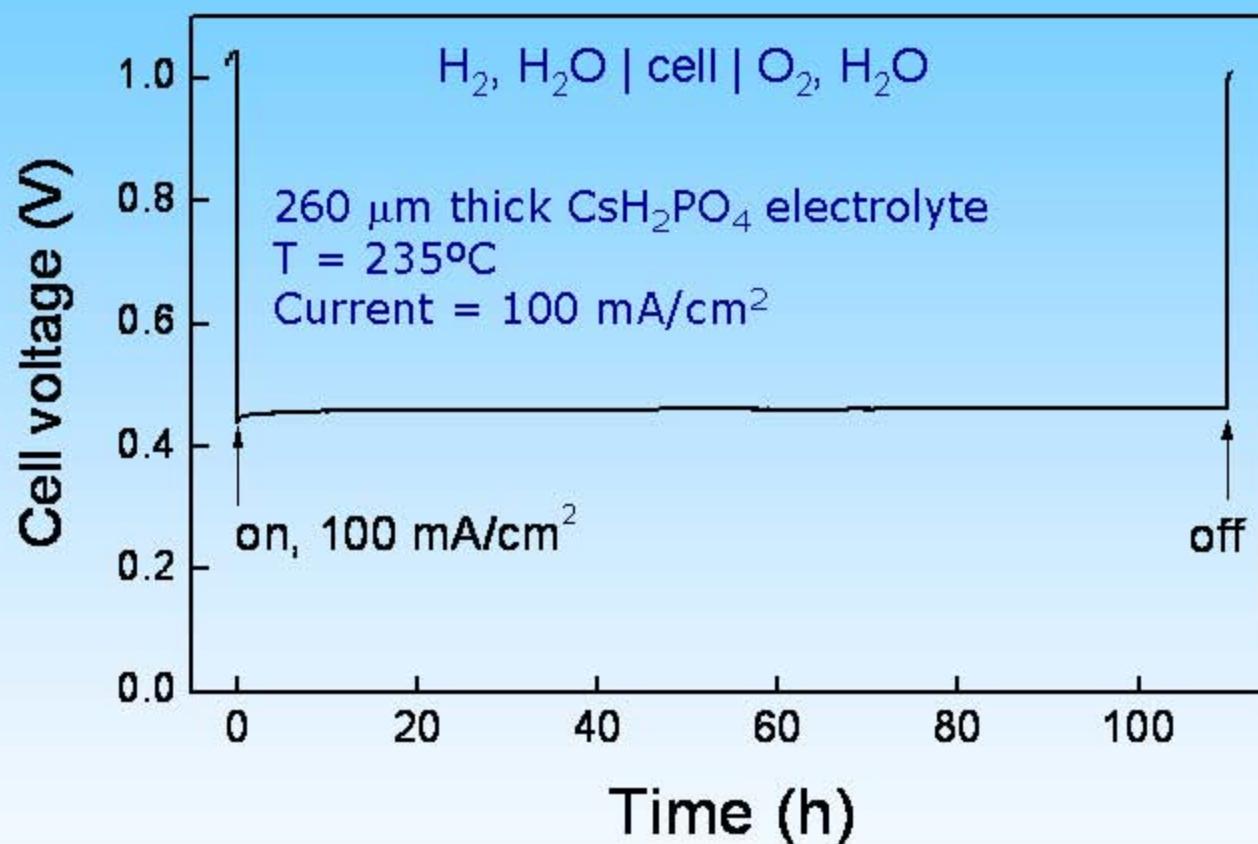
Compared to polymers

- ✓ High open circuit voltage
 - Theoretical: 1.15V
 - Measured: 1.00 V
 - Polymers: 0.8-0.9 V
- ✗ Power density
 - Polymers: > 1 W/cm 2
- Platinum content
 - Polymers: $\sim 0.1 \text{ mg/cm}^2$

D. A. Boysen, T. Uda, C. R.I. Chisholm and S. M. Haile, *Science* 303, 68-70 (2004)



Fuel Cell Longevity: Stable Performance



- CsH_2PO_4 – **no** degradation in 110 hr measurement
- $CsHSO_4$ – functions for only ~ 30 mins (recoverable degradation)



Impact

S. M. Haile, D. A. Boysen, C. R. I. Chisholm and R. B. Merle,
 "Solid Acids as Fuel Cell Electrolytes," *Nature* 410, 910-913 (2001).

The promise of protonics

The promise of protonics

news and views

Fuel cells seem a good alternative to dirty and wasteful combustion. But known electrolytes — the crucial component — all have flaws. A new solid-state proton conductor solves.

Fuel cells convert chemical energy directly to electrical energy through oxidation and reduction, but materials problems often limit their great potential. One of the most serious is the electrolyte — a material that conducts ions. It has to be aqueous to allow protons and electrons to move and to conduct the reaction products. The most common fuel cells use these acids as H₃O⁺, H⁺ and OH⁻.

A solid electrolyte is a promising because it allows ever more efficient power conversion. It can also serve as a proton conductor for solid-state fuel cells. In 2000, experts at the University of California, Berkeley, reported that proton-conducting solid-state protonic conductors (solid-state PCFCs) are promising for stationary power installations and auxiliary power units in vehicles. The problem with these materials is that they must operate at temperatures need to be solved. On page 910 of this week's *Nature* (see article by S. M. Haile et al., this page), researchers at the University of California, Berkeley, report a new solid-state proton conductor that operates stably between 100°C and 200°C.

To the surprise of the engineers who developed protonic conductors that can do protonic fuel cells by state-of-the-art proton-conducting polymer electrolytes (PECEs), protonic electrolytes had until now been considered too slow. They had added, but did not fully consider the implications of this limitation. This is one of the many times that people become too sure of their own ways, but mostly not on their 100°C mark. However, before long, instead of additional material studies, there will be a huge push toward new performances that are both faster, more reliable and more durable (and, perhaps, more cost-effective). That's something very important about science.

In this issue, the Berkeley group reports that the fuel cell powered by their solid-state proton conductor can operate at 150°C and 100% relative humidity, which is currently being investigated to increase the operating temperature range.

Given the positive results obtained at intermediate temperatures, it is natural to ask whether the same proton conductor can operate at higher temperatures. The answer is yes. At 200°C, the proton conductor can operate at a higher temperature than most of the oxygen ion-conducting solid electrolytes. It is not surprising that the proton conductor is more stable at 200°C. In addition, the proton conductor has a lower activation energy of about 140 kJ/mol, which the proton conductor needs to achieve these high temperatures.

In this high-temperature, solid electrolyte system, phase separation of CaTiO₃ and Ca_{0.9}Zr_{0.1}O₃ occurs, while solid acids such as H₃O⁺ and Cl⁻(H₃O⁺) interpenetrate with each other and are strongly bonded to the two materials, thus they become separate, so that the solid acid can move from one side to the other. And with these protonic solid acids the fuel cell can operate at the theoretical 100%, which is needed for many applications. The PECEs will be used in the first time.

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Some Like It Medium Hot

ScienceNOW - 2001/4051

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Some Like It Medium Hot

Some Like It Medium Hot

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Some Like It Medium Hot

Just right. Fuel cells might someday power automobiles cleanly and efficiently, but only if they can run within a reasonable temperature range.

The key fuel cell component that determines its operating temperature is the electrolyte, a layer of solid acid (such as H₃O⁺) and a porous scaffold that conducts charged atoms from one side of the cell to the other. Most electrolytes are made of either a proton conductor or a related material called solid acids. Among the best candidates are the two proton conductors that the Berkeley team developed to operate at 150°C: a proton conductor based on a thin layer of solid acid and another based on solid acid dispersed throughout a thin layer of solid electrolyte. These materials had never been put to work in a fuel cell.

High-temperature solid electrolytes are good for liquid cells, but the temperature range of operation for solid electrolytes is rather very high (above 100°C) or rather low (below 100°C). The high-temperature electrolytes are not yet really practical for fuel-cell applications such as automobile-size fuel cells. Low-temperature fuel cells, on the other hand, are not as flexible in the fuel they can use, and much of the energy they release is wasted prior to electrical operation. Better performance could be achieved from fuel cells operating at intermediate temperatures. Recently, a team at Caltech led by Gianna Masi demonstrated that small proton electrolytes, based on a solid acid, may operate at temperatures in the intermediate range when used in a fuel cell.

Water, water everywhere

The basic design of a fuel cell is illustrated in the diagram. Two electrodes — the anode and cathode — are separated by an electrolyte. A fuel such as molecular hydrogen or methanol is spontaneously oxidized by a catalyst at the anode; molecular oxygen is reduced at the cathode. The two half-reactions are completed by the flow of ions.

<http://www.physicstoday.org/print/54/6/7p22.html>

Solid Acids Show Promise...

Physics Today July 2001

Physics Today online

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Search & Discovery

July Articles:

Solid Acids Show Potential for Fuel Cell Electrolytes

Solid acids can have high proton conductivity. Recent experiments demonstrate that they may be sufficiently stable to form the core of next-generation fuel cells.

In the quest for alternative sources of energy, one active area of exploration is fuel cells. These devices use the same ion migration reaction as batteries, but by spatially separating the reactants, fuel cells convert chemical energy directly into electrical energy instead of generating heat as an intermediate (see the review by Steven Gottesman and Patrick O'Neil in Physics Today, November 1994, page 5-2). So far, fuel cells have the potential to be a clean and efficient means of electrical energy production.

Magnetic Resonance Imaging

Medical Ultrasound

Electrokinetic Remediation

Electrokinetic Remediation

Ion Beams in a Radiation Source

Industrial Robotics

Electrokinetic Remediation

Electrokinetic Remediation

References

Some Like It Medium Hot

ScienceNow

Physics Today

July 2001

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Nature: News & Views

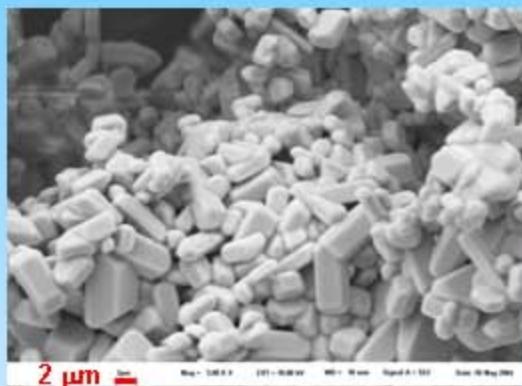
Science Now Magazine

Towards a Sustainable Energy Future

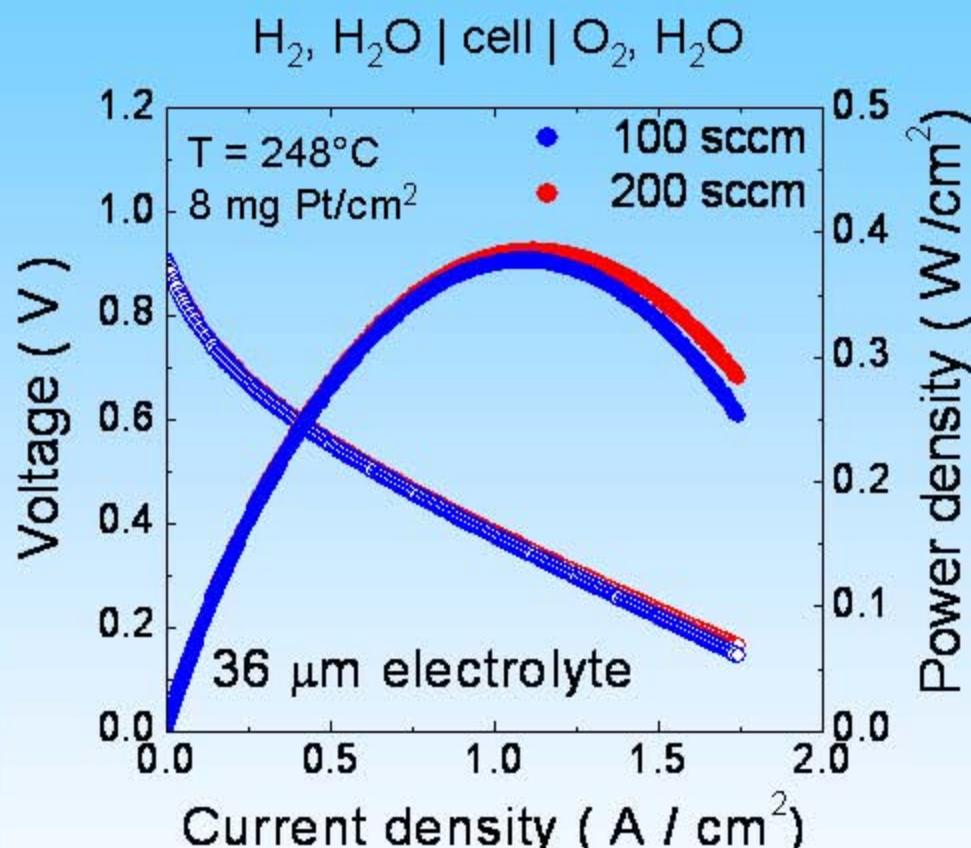
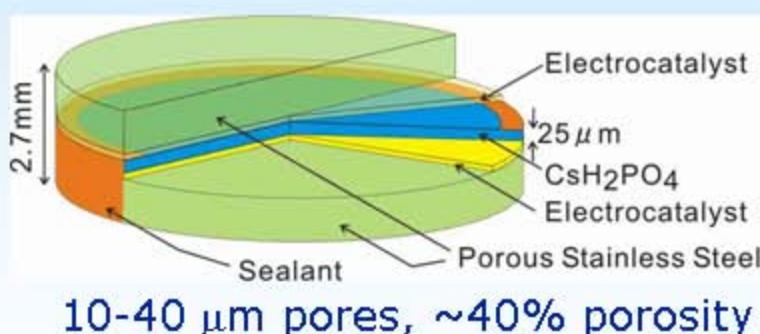
Physics Today Online

Fuel Cell Operation

Fine CsH_2PO_4



Slurry deposit



T. Uda & S.M. Haile, *Electrochim & Solid State Lett.* **8** (2005) A245-A246

Open circuit voltage: 0.9-1.0 V Peak power density: 285-415 mW/cm²



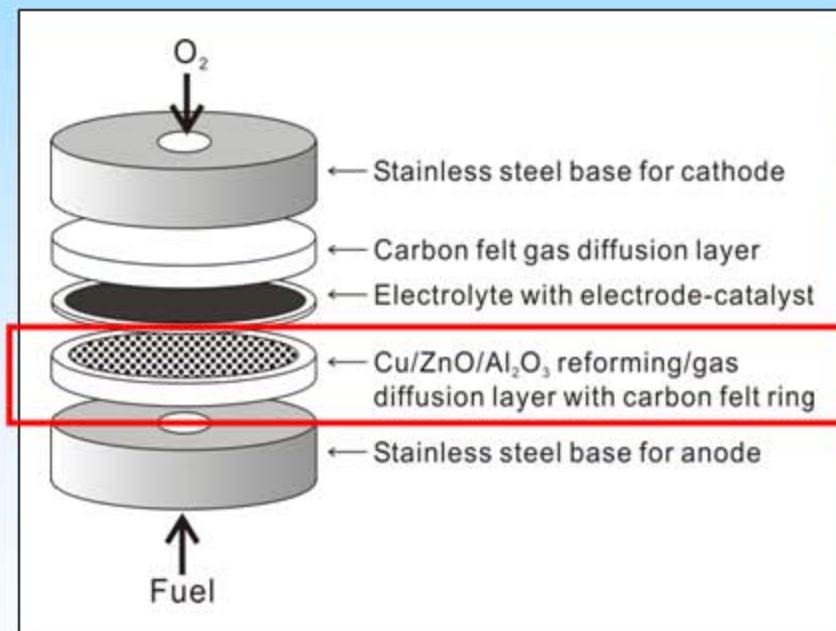
Towards a Sustainable Energy Future

'Direct' Alcohol Fuel Cells

Methanol in proton exchange membrane fuel cells



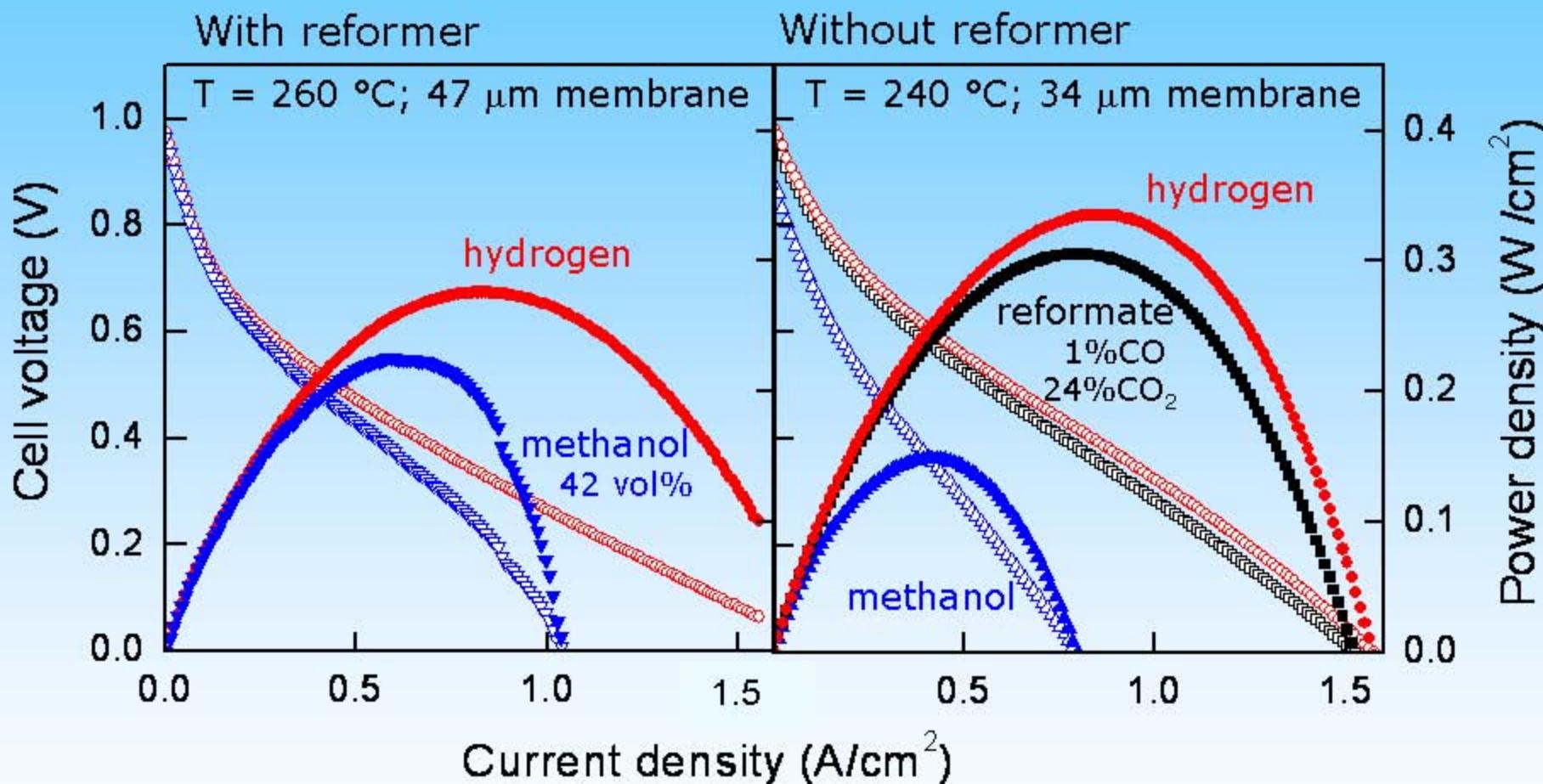
- SAFCS ideal thermal match
 - Reforming rxn: 200 – 300°C
 - Electrolyte: 240 – 280°C
 - Steam reforming: endothermic
 - Fuel cell rxns: exothermic
- Integrated design
 - Incorporate alcohol reforming catalyst in anode chamber



T. Uda et al., *Electrochim & Solid State Lett.* **9** (2006) A261-A264



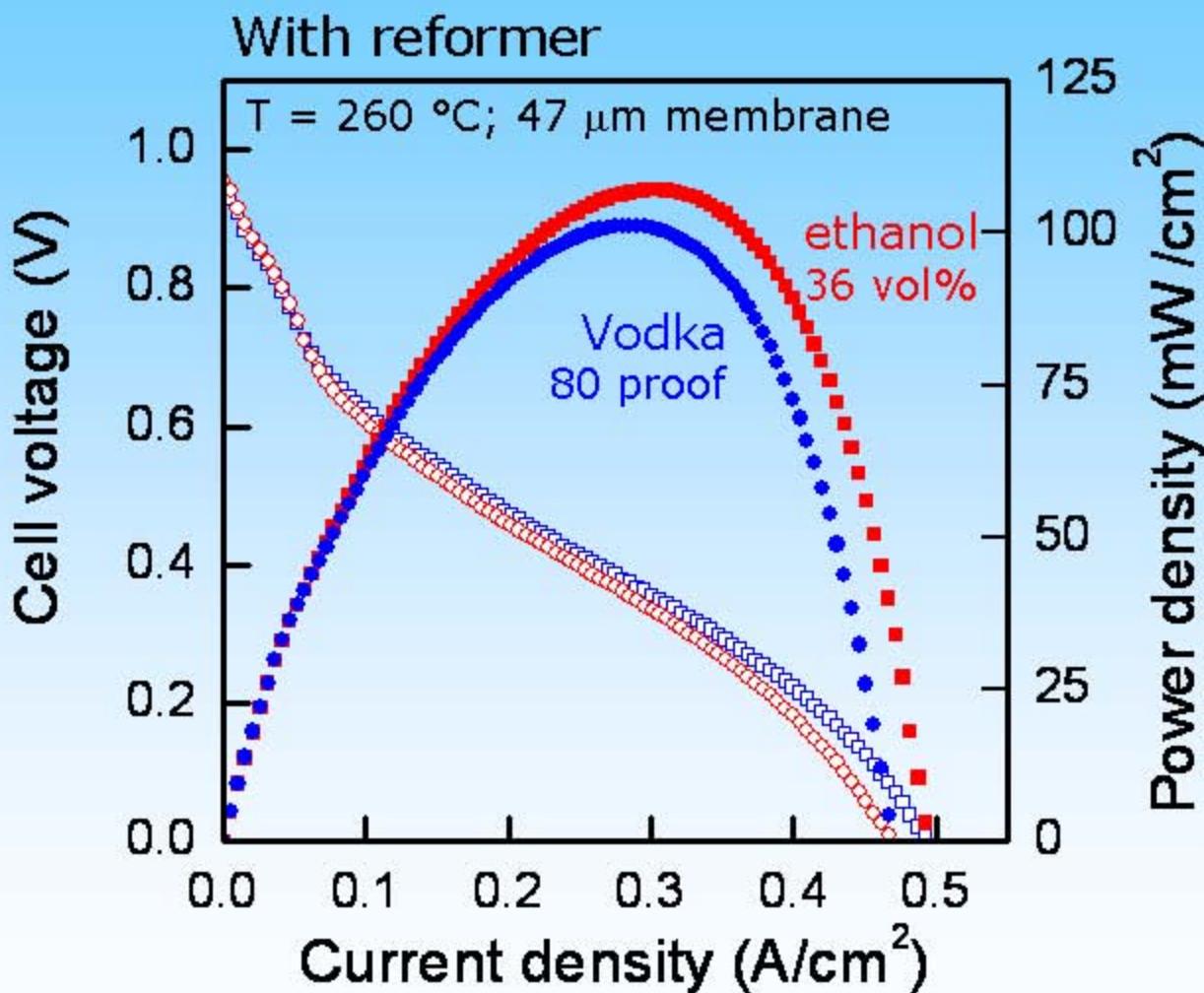
'Direct' Methanol Fuel Cells



- Methanol power $\sim 85\%$ H₂ power
- For polymer fuel cells $\sim 10\%$
- Reformate power $\sim 90\%$ H₂ power
- Methanol power $\sim 45\%$ H₂ power



'Direct' Alcohol Fuel Cells



- Ethanol power $\sim 40\%$ H_2 power



From Breakthrough to Product

2001



1 cm² of fuel cell area
36 mg Pt for 10 mW
43 g Pt for 60 W bulb
~ \$2,163 in Pt

Calum



Dane



2007



1 mg Pt for 200 mW
2.5 g Pt for 60 W bulb
~ \$126 in Pt



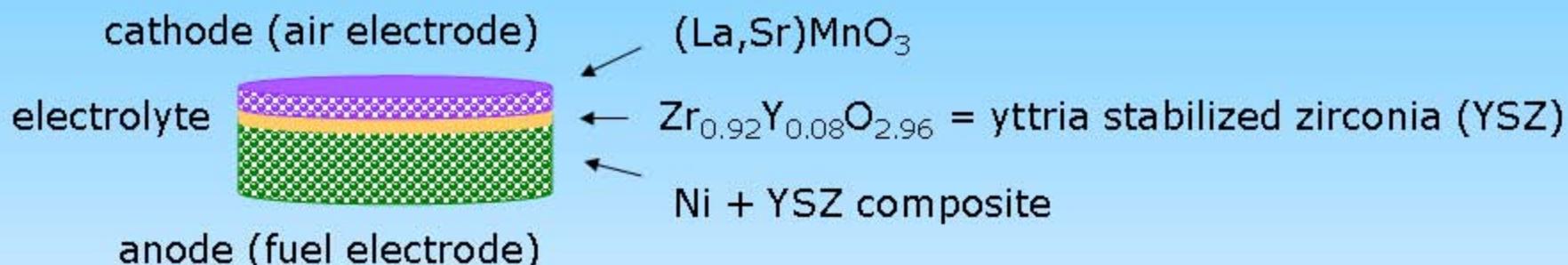
Tom Friedman talking to his wife
on an SAFC powered cell phone



Towards a Sustainable Energy Future

State-of-the-Art SOFCs

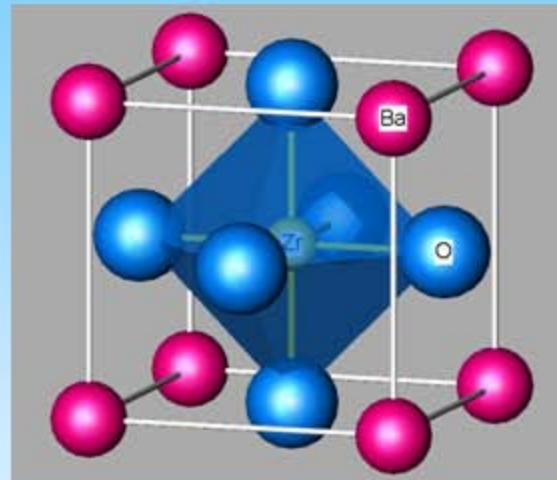
Component Materials



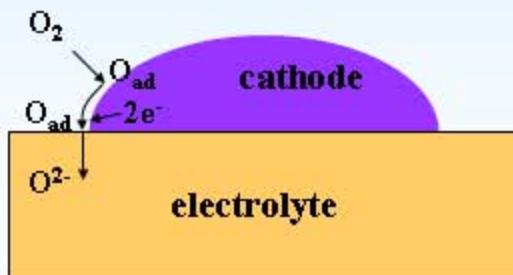
- Cathode typically exhibits highest losses
 - Prepared as thinnest component
 - Murky literature on impact of cathode composition on O_2 electroreduction rates
 - General but not detailed mechanistic understanding
 - DOE has an SOFC 'cathode working group'

Solid Oxide Fuel Cell Cathodes

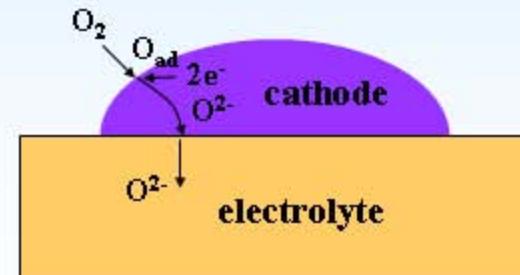
- Traditional cathodes
 - $A^{3+}B^{3+}O_3$ perovskites
 - Poor O^{2-} transport
 - Limited reaction sites
- Our approach
 - High O^{2-} flux materials
 - Extended reaction sites
 - $A^{2+}B^{4+}O_3$ perovskites



'triple-point' path

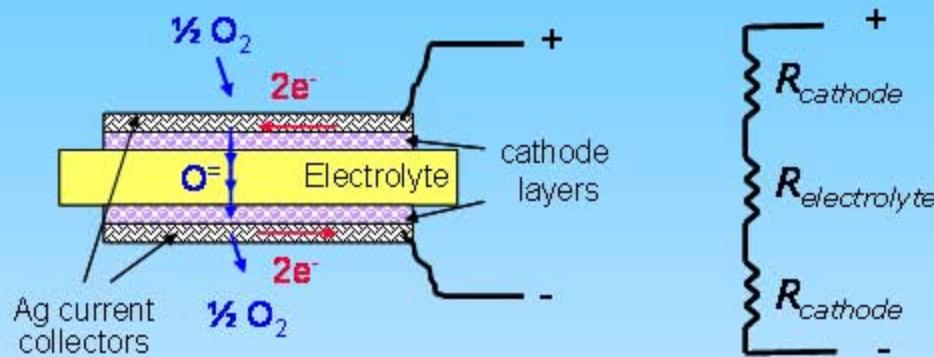


electrode bulk path



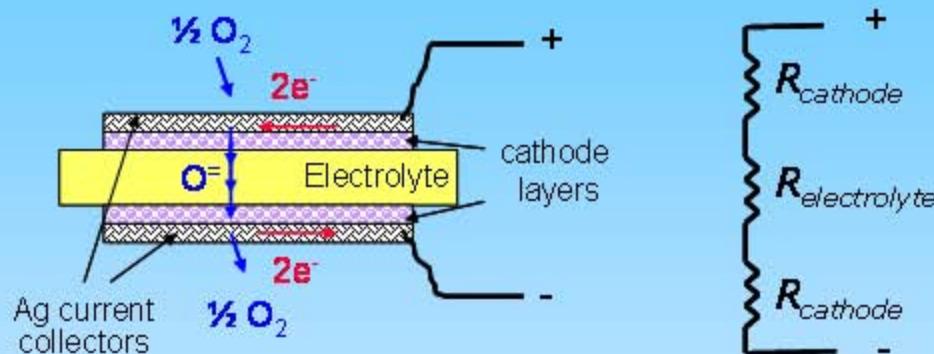
Cathode Electrocatalysis

- Symmetric cell resistance measurements

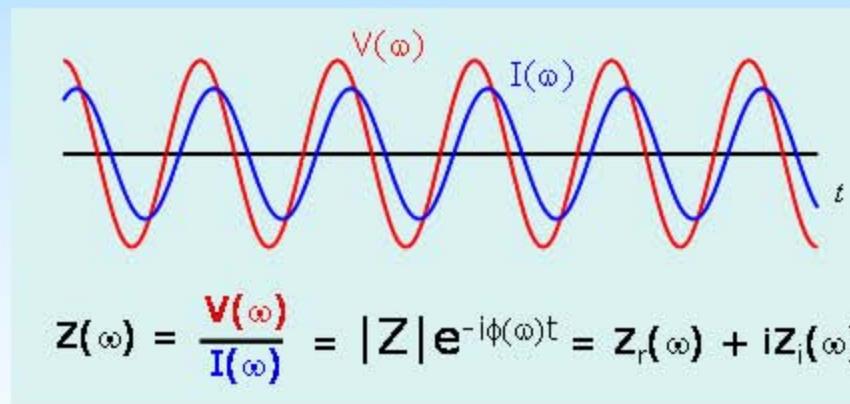


Cathode Electrocatalysis

- Symmetric cell resistance measurements

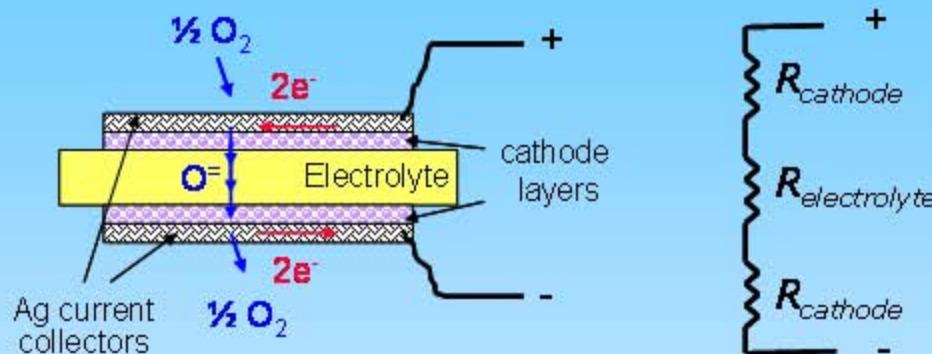


- A.C. Impedance Spectroscopy

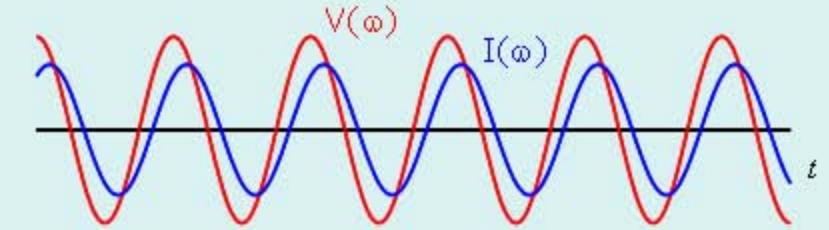
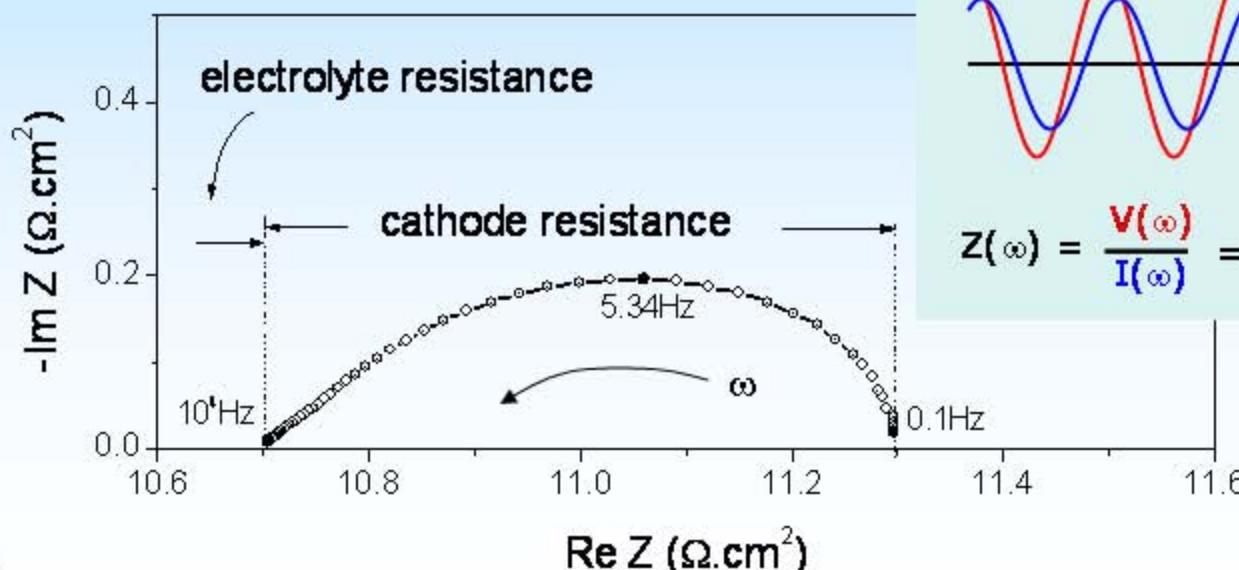


Cathode Electrocatalysis

- Symmetric cell resistance measurements

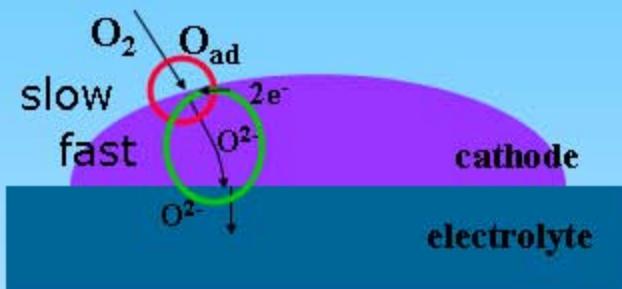
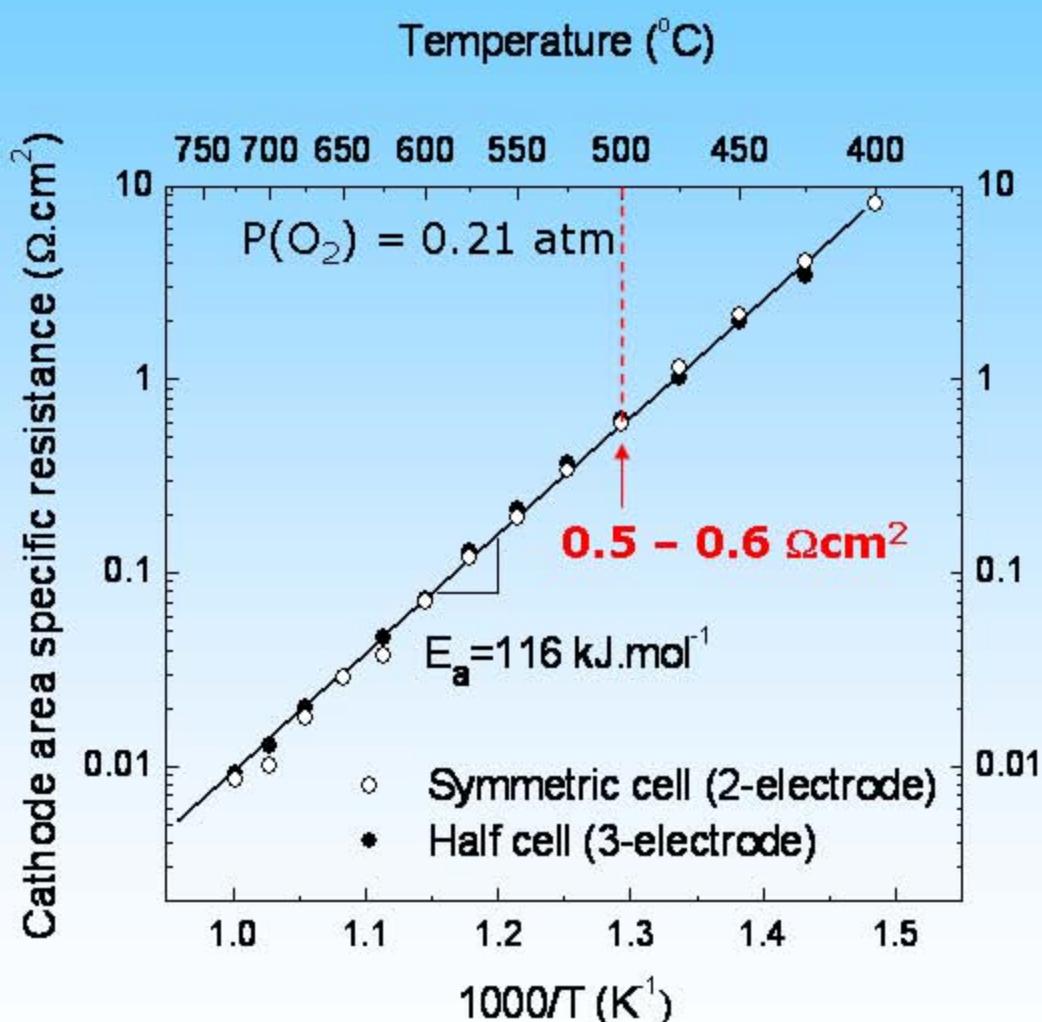


- A.C. Impedance Spectroscopy



$$Z(\omega) = \frac{V(\omega)}{I(\omega)} = |Z| e^{-i\phi(\omega)t} = Z_r(\omega) + iZ_i(\omega)$$

Cathode Electrocatalysis



E_a same as oxygen surface exchange ($113 \text{ kJ} \cdot \text{mol}^{-1}$)

Bulk diffusion is fast ($46 \text{ kJ} \cdot \text{mol}^{-1}$)

Other 'advanced' cathodes
 $(\text{PrSm})\text{CoO}_3$: $5.5 \Omega \text{cm}^2$
 $(\text{LaSr})(\text{CoFe})\text{O}_3$: $48 \Omega \text{cm}^2$

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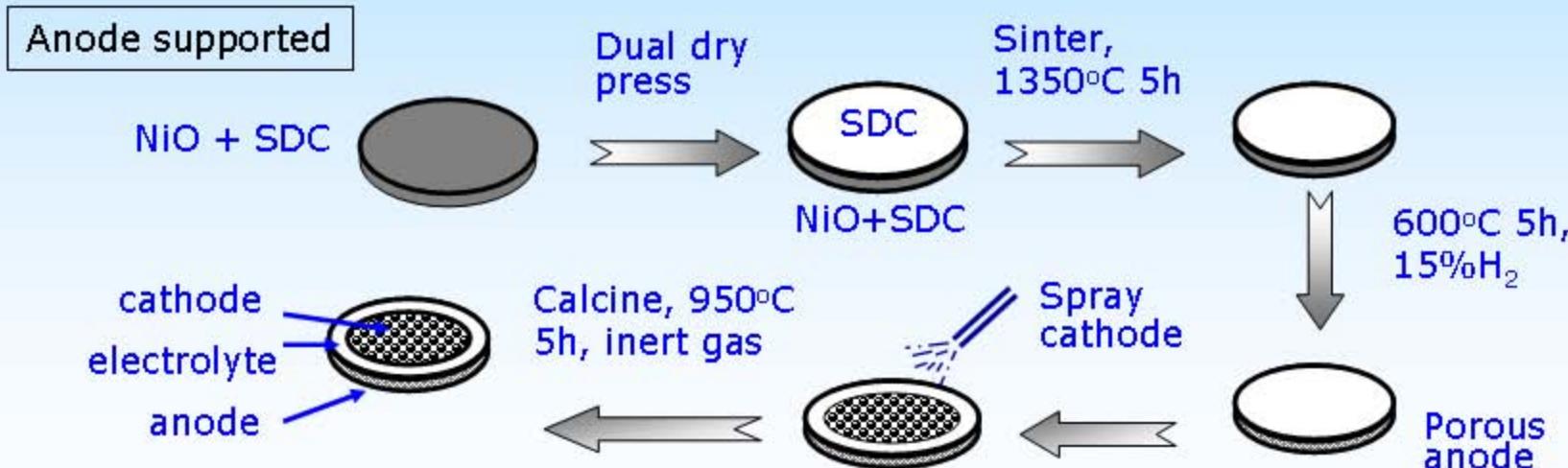


Fuel Cell Realization

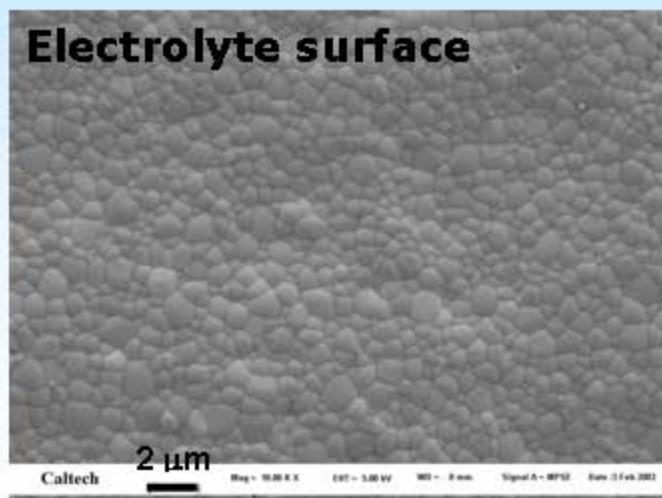
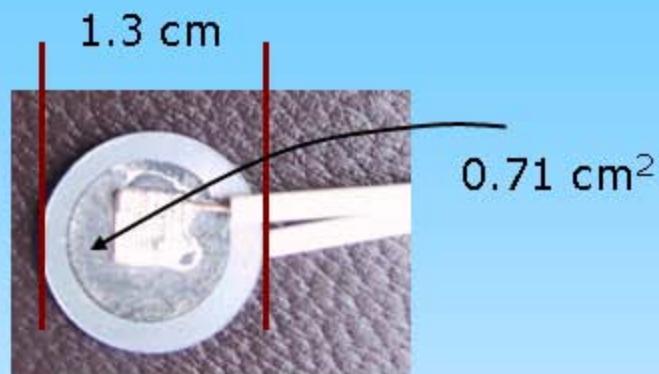
Component	Material
Electrolyte	Sm-CeO ₂ [SDC]
Anode	SDC-NiO [SDC-Ni]
Cathode	Many types

- Characteristics

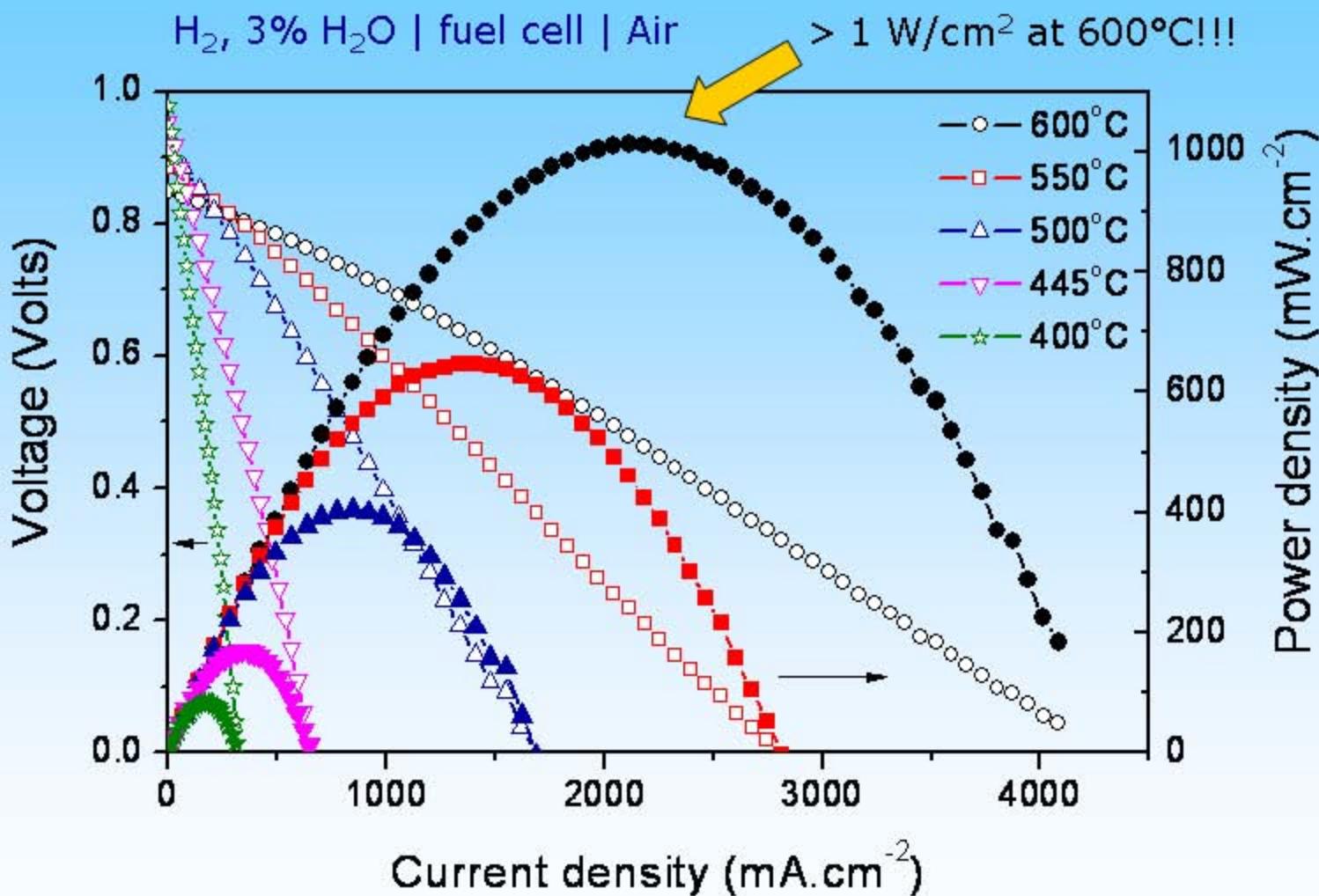
- Anode supported, thin electrolyte
- Careful matching of sintering rates
- Bilayer suited to cathode screening



Typical Fuel Cell Structures



Fuel Cell Power Output

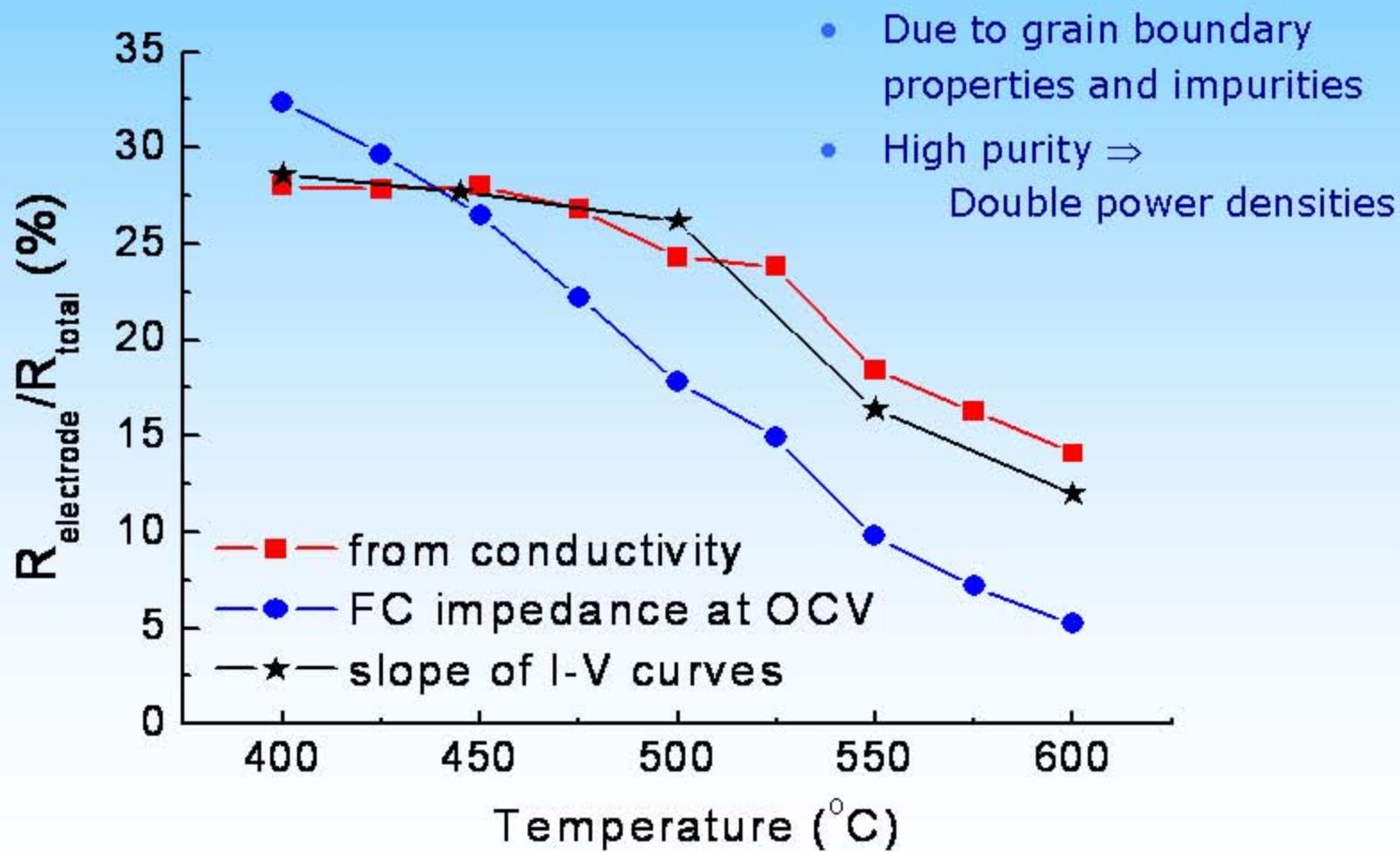


Comparison: literature cathode material $\Rightarrow 350 \text{ mW/cm}^2 \text{ at } 600^\circ\text{C}$



Sources of Polarization Losses

Electrolyte contributes 85-95% of polarization losses at 600°C!



Impact

Cooler Material Boosts Fuel Cells

TRNmag.com
The Latest Technology Research News

Cooler material boosts fuel cells

By Jennifer Peery, Technology Research News

Finding a way to cool down fuel cells for solid oxide fuel cells, which now require temperatures of 800 to 1,000 degrees Celsius to use fuel other than pure hydrogen, is a key step toward widespread adoption of fuel cells.

Solid oxide is one of the basic types of fuel cells, and is a promising type for municipal, home and mobile electricity generation.

Researchers from the California Institute of Technology have devised a way to cool down fuel cells to temperatures as low as 500 to 700 degrees Celsius. This temperature range is hot enough to support a variety of fuels, but low enough that the fuel cell components need not be made from costly high-temperature materials, said Sossina Haile, an associate professor of materials science and chemical engineering at the California Institute of Technology.

The method promises to lower the cost of fuel cells, which could spur broader adoption of the technology.

Fuel cells extract chemical energy from fuel rather than burning it like combustion engines. Like batteries, fuel cells contain a pair of electrodes, and supply a flow of electrons by pushing electrons from the anode to the cathode. This happens when oxygen reacts with electrons at the cathode to form oxygen ions, which then migrate through the electrolyte to the anode where they react with fuel to produce water and release electrons. Some fuels also produce carbon dioxide at this step.

The researchers' fuel cell looks much like existing cells, said Haile. "It's like developing a recipe for a cake that bakes at 150 degrees Fahrenheit rather than 325 degrees Fahrenheit," she said. "The oven still looks pretty much the same, but it's a lot cheaper because it doesn't have to withstand such high temperatures."

Until the researchers' new cathode, all known cathode materials have been effective only at temperatures near 1,000 degrees Celsius at catalyzing, or speeding up, the reaction of the oxygen gas molecule with electrons to form negatively-charged oxygen ions, said Haile.

Haile's research colleague Zongping Shao developed the material, made from barium, strontium, cobalt, iron and oxygen, and dubbed BSCF, for a different application – oxygen purification membranes.

It was natural that the researchers test the material as a fuel cell cathode because some of the properties that make the material useful as an oxygen purification membrane also tend to make it good as a fuel cell cathode, said Haile.

But the chemical formula was different enough from typical fuel cell cathodes

R&D FOCUS

Energy shuttle exploits nanocatalysis

SOFC cathode is hot stuff at lower temperatures

Next generation of fuel cells addresses major design problem

Archives | Charts | Companies/Links | Conferences | How | Types of Fuel Cells | The Basics | Fuel Cell #

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Publication Date: 07-17-2004

Source: Science Letter

For several years now the U.S. Department of Energy (DOE) has been urging the fuel cell community to solve a major problem in the design of solid oxide fuel cells (SOFCs): heat. Such fuel cells could someday provide reliable power for homes and industry, dramatically cutting greenhouse gas emissions as well as other pollutants.

But SOFCs run hot, at temperatures as high as 1,000 degrees C (about 1,800 degrees F). They're efficient at such temperatures, but only a few costly materials can withstand the heat. Using such materials makes them expensive, and is the reason for the push for lower temperatures by the DOE.

Sossina Haile, an associate professor of materials science and chemical engineering at the California Institute of Technology, is an expert in fuel cells, and she has been whittling away at the heat problem for years. Now she and her colleagues have not only solved the problem, they've smashed it. They brought the temperature down to about 600 degrees C (1,100 degrees F), while achieving more power output than others are achieving at the higher temperatures - about 1 watt per square centimeter per fuel cell area.

They accomplished this by changing the chemical composition of one component of a fuel cell cathode. The cathode is where air is fed in to the fuel cell, and it's where the oxygen is electrochemically reduced to oxygen ions. The oxygen ions then migrate across the electrolyte (it conducts electricity), to react with fuel at the anode, another fuel cell component. The electrochemical reduction of oxygen is an essential step in the fuel cell's process of generating power. But the problem with running solid oxide fuel cells at 500-700 degrees C is that the cathode becomes inactive when temperature is less than about 600 degrees C.

Haile and postdoctoral scholar Zongping Shao's insight was to switch out the conventional cathode and replace it with a compound that has a long chemical formula guaranteed to strike fear into the hearts of every undergraduate, but is abbreviated as "BSCF".

What BSCF can do that standard cathodes can't is to allow the oxygen to diffuse through it very rapidly. "In conventional cathodes, the oxygen diffuses slowly, so that even if the electrochemical reaction is fast, the oxygen ions are slow in getting to the electrolyte," said Haile. "In BSCF the electrochemical reaction is fast and the oxygen ion transport is fast. You have the best combination properties." This combination is what gives the very high power outputs from Haile's fuel cells.



Tech Research News

Towards a Sustainable Energy Future

R & D Focus

Fuel Cell Works

Summary & Conclusions

- Sustainable energy is the 'grand challenge' of the 21st century
 - *Solutions must meet the need, not the hype*
 - *Fuel cells can play an important role*
- Solid acid fuel cells
 - *Radical alternatives to state-of-the-art*
 - *Viability demonstrated; spin-off company established*
- Solid oxide fuel cells
 - *Promising alternative cathode discovered*
- Still plenty of need for fundamental research

"The stone age didn't end because we ran out of stones."

-Anonymous



The People

- Current Students



Chatr



Ayako



Mary



Drew



Mikhail



Kenji



Áron



Evan



Tae-Sik



William



Justin

- Current Post-docs

- Former, who contributed to results



Calum



Tetsuya



Dane



Zongping



Wei



Yoshi



Jianhua



Marion



Ali



Eric



Teruyuki