Fuel Cells and the Emerging Hydrogen Energy Economy

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Overview

- The Promise of Fuel Cells
  - *What fuel cells are and are not*
- Types of Fuel Cells
- Fuel Cell Applications
- Availability of Fuel Cell Power Systems
- Economics of Fuel Cell Power Systems
- Summary

The Promise of Fuel Cells

What fuel cells are and are not

- Fuel cells are *not:*
  - … a panacea for the future
  - … more efficient than all other technologies
  - … free of pollutants and greenhouse gases
  - … the solution to all our energy and environmental concerns

The Promise of Fuel Cells

What fuel cells are and are not

- **Fuel cells *are:***
  - ***… An important part of a balanced future energy policy***
  - ***… A viable alternative to batteries, ICEs and other energy technologies in many applications***
  - ***… More efficient than conventional energy technologies in specific applications***
  - ***… A technology whose time has come***

Types of Fuel Cells

Seven major fuel cell technologies

- **Polymer Electrolyte Membrane (PEM)**
- **Direct Methanol**
- **Alkali**
- **Metal-air**
- **Phosphoric Acid**
- **Molten Carbonate**
- **Solid Oxide**

Fuel Cell Applications

- Handheld applications
- Portable power
- Small-scale distributed power
- Large-scale distributed power
- Transportation, mobility & utility

Fuel Cell Applications

Handheld applications

- **Metal-air fuel cells**
- **Direct methanol fuel cells**
  - **Cell phones**
  - **Lap top computers**
  - **PDAs, calculators**
  - **Diagnostic equipment**
  - **Power tools**
    - ☞ **President George W. Bush speaking on a cell phone powered by an *MTI MicroFuel Cells* direct methanol fuel cell**

Fuel Cell Applications

Portable power

- **Polymer electrolyte membrane**
- **Metal-Air fuel cells**
- **Alkali fuel cells**
  - **Remote applications**
  - **Recreational use**
  - **Emergency response**
  - **Backup power**

Metallic Power 1.6 kW zinc-air fuel cell

Fuel Cell Applications

Small-scale distributed power

- **Polymer electrolyte membrane**
- **Metal-air fuel cells**
- **Solid oxide fuel cells**
  - **Residential**
  - **Small Commercial**
  - **Back up or primary power**
  - **Grid parallel**
  - **Grid independent**
  - **Pipeline NG or LPG operation**

Global Thermoelectric 800W SOFC stack

Fuel Cell Applications

Large-scale distributed power

- **Solid oxide**
- **Molten carbonate**
- **Phosphoric acid**

  - **Large commercial & industrial applications**
  - **Back up or primary power**
  - **Premium power**
  - **Natural gas, LPG or digester gas**
  - **Biomass under development**

Fuel Cell Applications

Transportation & mobility

- **Polymer electrolyte membrane**
- **Alkali fuel cells**
- **Metal air fuel cells**
- **Solid oxide fuel cells**
  - **Automobiles**
  - **Public transportation**
  - **Hotel power (trucks and trains)**
  - **Utility vehicles**
  - **Personal mobility vehicles**

Fuel Cell Availability

Commercially available fuel cells

- **PEM fuel cells**
  - Small distributed power/cogen
  - Portable power
- **Phosphoric acid fuel cells**
  - Commercial/industrial DPG/cogen/renewable
- **Molten carbonate fuel cells**
  - 250 kW– 2 MW scale DPG/cogen/combined cycle
  - Renewables on the horizon

Fuel Cell Availability

PEM fuel cells

- **Plug Power**
  - **4.5 kWe back up power/cogen**
  - **NG operation**
- **Ballard/Coleman Powermate**
  - **1 kW backup/portable system**
  - **Hydrogen operation**
- **Avista Laboratories**
  - **100, 500 W, 1 kW**
  - **Hydrogen operation**

Fuel Cell Availability

PEM fuel cells

- **Plug Power GenSys**
  - **Residential/light commercial**

- **4.5 kWe/6.7 kWth**
- **Backup power**
- **Grid parallel or independent**
- **NG (hydrogen)**
- **1- and 2-year warrantees**

Fuel Cell Availability

PEM fuel cells

- **Coleman Powermate**
  - **Ballard PEM fuel cell**
  - **1 kWe**
  - **120 VAC**
  - **Transportable**
  - **Requires hydrogen**
  - **Industrial only**

Fuel Cell Availability

PEM fuel cells

- Avista Labs
  - Independence 1000
  - Commercial/industrial only
  - 48 VDC output
  - Premium power

Fuel Cell Availability

Phosphoric acid fuel cells

- **UTC Fuel Cells**
  - **200 kW industrial operation**
  - **900,000 Btu/hr cogen heat**
  - **Shown in digester gas application**

Fuel Cell Availability

Molten carbonate fuel cell

- **Fuel Cell Energy**

- **250 kW, 1 MW, 2 MW units available**
- **47 – 50 % efficient**
- **Cogen heat available at > 400 °C**
- **Renewable fuel systems under development**

Fuel Cell Economics

Hardware costs

- PEM Fuel Cells
  - $6,000/kW hydrogen only
  - $11,000/kW NG (fuel processor) with cogen
    - $13,800/kW installed
    - Expected to drop to $4,500/kW in 2004
- PAFC
  - $4,000/kW NG with cogen
    - $5,200/kW installed
- MCFC
  - $4,000/kW NG with cogen
    - $4,700/kW installed

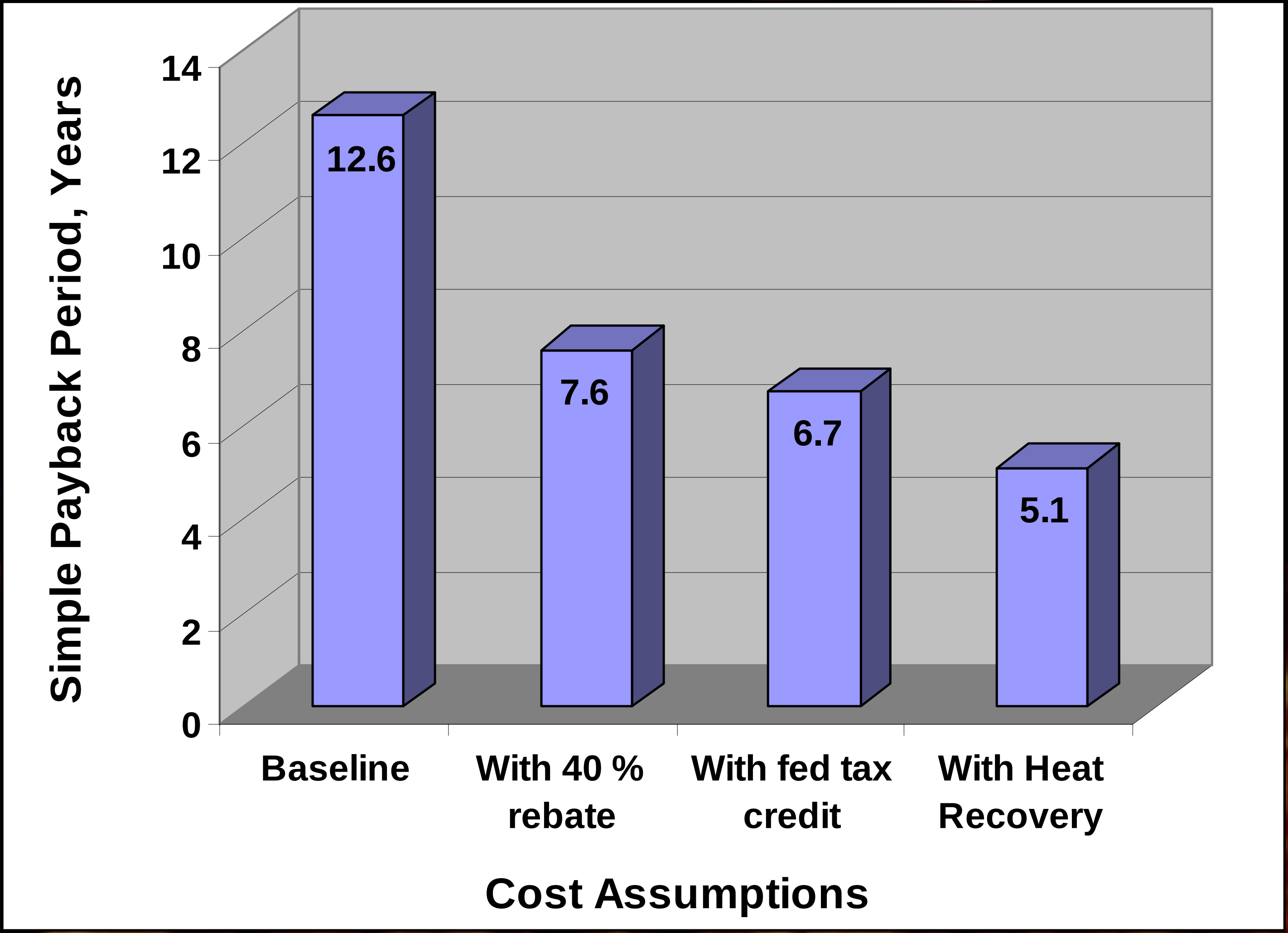
Fuel Cell Economics

Rebate programs

- California
  - Various state and local programs offering up to $4,500/kW (50 %) for renewable fuel sources, $2,500/kW (40 %) for NG and LPG operation
- DoD Climate Change Fuel Cell Program
  - $1,000/kW (33 %)
- Federal Business Tax Credit (S.461)
  - $1,000/kW

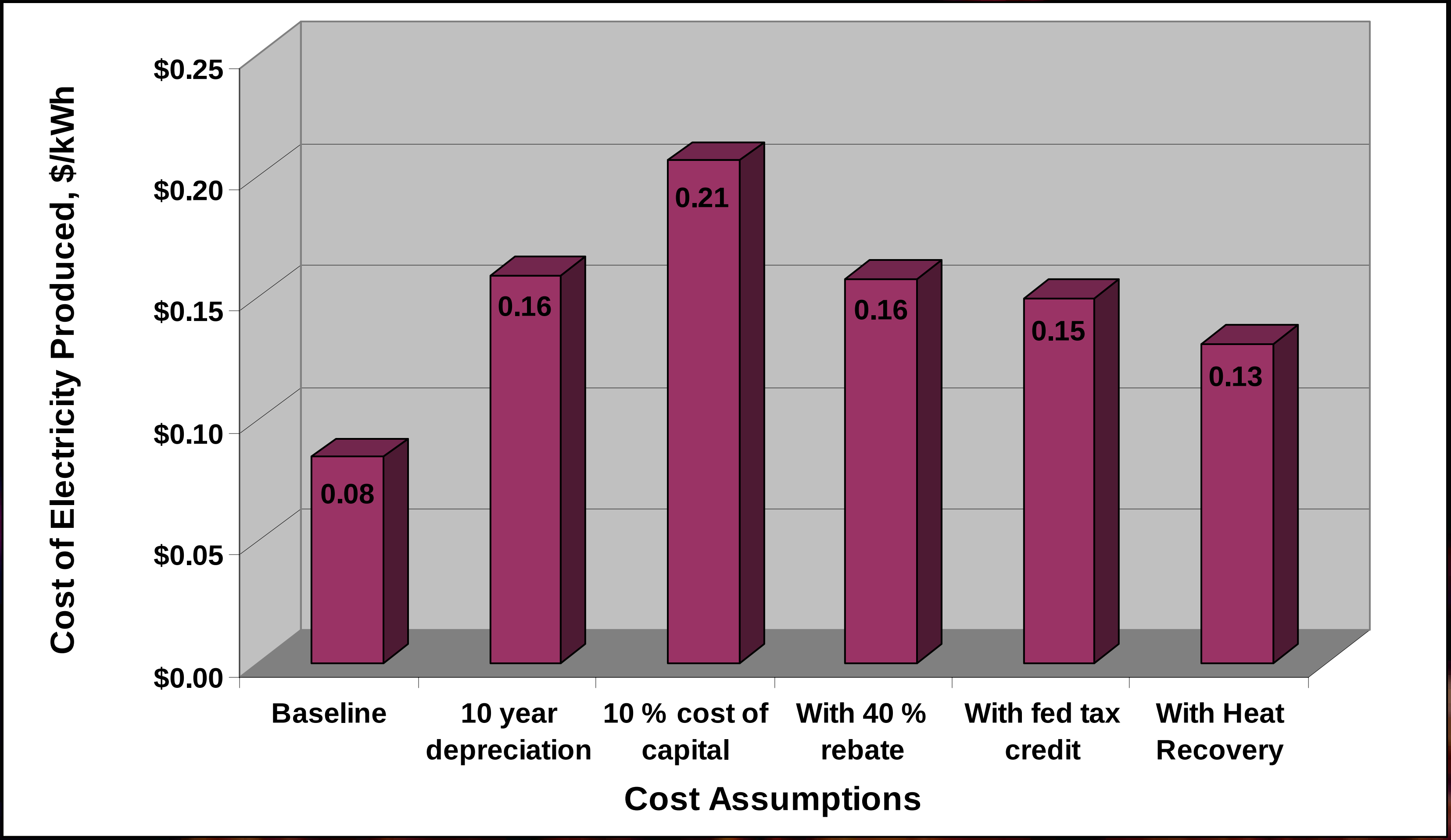
Fuel Cell Economics

Example case - PAFC



Fuel Cell Economics

Example case - PAFC



Summary

- Fuel cell technology is available today
- Economics are very site specific
  - Rely heavily on rebates, tax credits
- Value beyond simple power more difficult to quantify
  - Cost of outages
  - Value of “security of supply”

California Hydrogen Business Council

www.ch2bc.org

Addendum

Introduction to Fuel Cells

- **Fuel Cells 101**
  - **Science & Technology of Fuel Cells**
- **Fuel cells 102**
  - **Types of Fuel Cells**
  - **Major Distinctions**

Fuel Cells 101

Science and technology of fuel cells

- **History of Fuel Cells**
  - **Invented in 1839 by Sir William Grove**
    - **Known then as the *gas voltaic battery***
    - **The term *fuel cell* was proposed by Mond and Langer in 1889**
  - **Later revived for space programs**
  - **Evolved into seven major commercially viable technologies**
    - **Several other technologies waiting in the wings**

Fuel Cells 101

Science and technology of fuel cells

- **Fuel Cell Science**
  - Fuel and oxidant combined to produce electric current
  - Fuel delivered at the anode
  - Oxidant delivered at the cathode
  - Hydrogen-oxygen fuel cell has the simplest chemical system

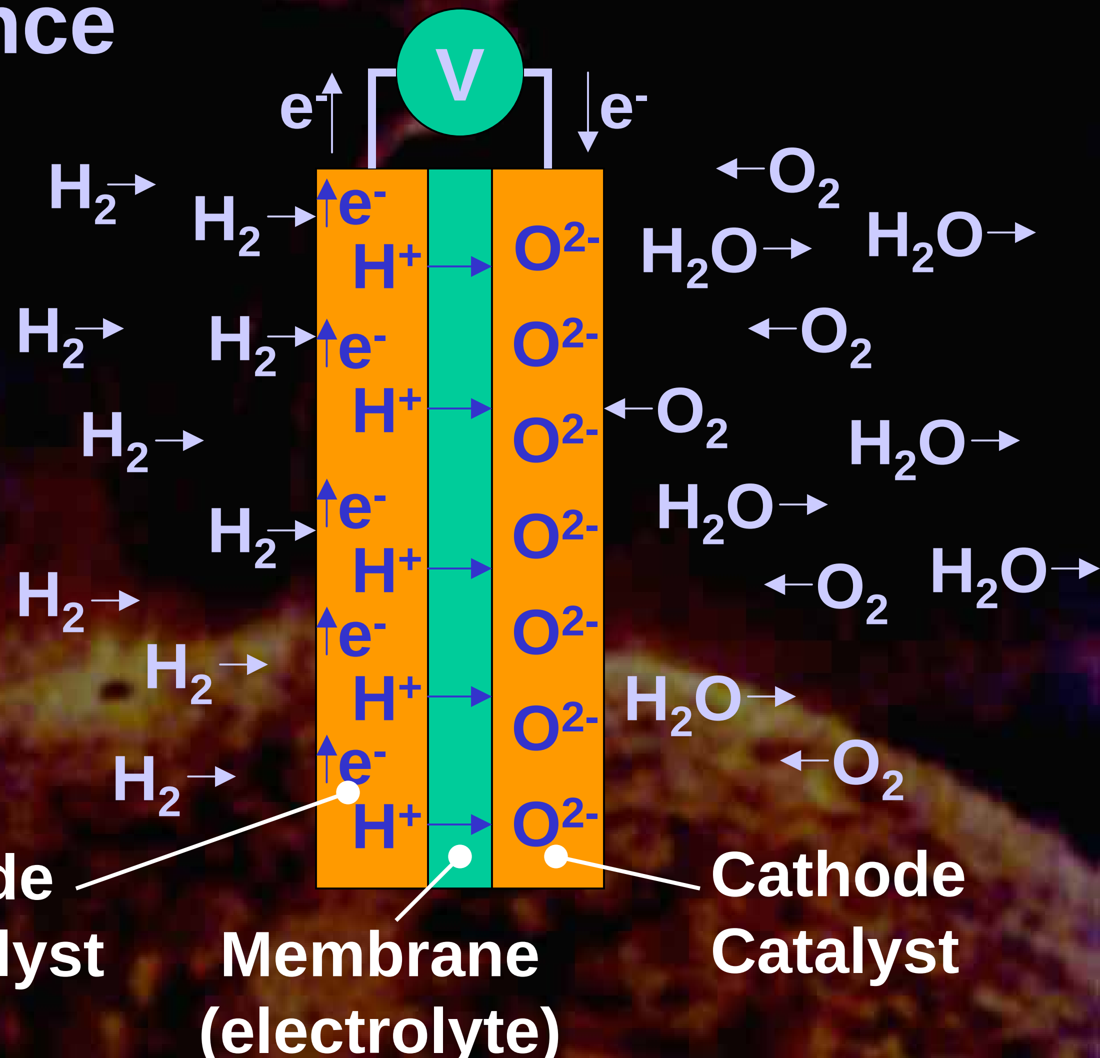
Anode reaction:	$H_2 \rightarrow 2\ H^+ + 2\ e^-$
Cathode reactions:	$\frac{1}{2}\ O_2 + 2\ e^- \rightarrow O^{2-}$ $O^{2-} + 2\ H^+ \rightarrow H_2O$

Fuel Cells 101

Science and technology of fuel cells

• Fuel Cell Science

1) Hydrogen reacts at the anode to produce protons and free electrons
2) Electrons are conducted across the “load” between the anode and cathode
3) Protons are conducted across the electrolyte
4) Oxygen molecules react with electrons to form oxide anions on the cathode
5) Protons and oxide anions react to form water vapor



Fuel Cells 102

Types of fuel cells and their major distinctions

- **Types of fuel cells**
  - **Ways of classifying fuel cells**
- **Major distinctions**
  - **Temperature**
  - **Electrolyte**
  - **Fuel type**

Fuel Cells 102

Types of fuel cells and their major distinctions

- **Ways of Classifying Fuel Cells**
  - **Temperature**
    - **Low, intermediate, high**
  - **Electrolyte**
    - **Solid, liquid**
    - **Acidic, basic**
  - **Fuel**
    - **Hydrogen**
    - **Syngas (internally reforming)**
    - **Metallic**

Fuel Cells 102

Types of fuel cells and their major distinctions

- **Low temperature (< 100 °C)**
  - **PEM**
  - **Direct Methanol**
  - **Alkali**
  - **Metallic**
- **Intermediate temperature (100 – 250 °C)**
  - **Phosphoric acid**
  - **Alkali**
- **High temperature (up to 1000 °C)**
  - **Molten carbonate**
  - **Solid oxide**

Fuel Cells 102

Types of fuel cells and their major distinctions

- **Solid electrolyte**
  - **Solid oxide**
  - **PEM**
  - **Direct Methanol**
- **Liquid electrolyte**
  - **Metallic**
  - **Phosphoric acid**
  - **Molten carbonate**
  - **Alkali**

Fuel Cells 102

Types of fuel cells and their major distinctions

- **Acid electrolyte**
  - PEM, Direct Methanol, Phosphoric Acid
  - Proton is charge carrier
- **Basic electrolyte**
  - Alkali, Molten carbonate, Metallic, Solid oxide
  - Anionic charge carrier
    - OH^-, CO_3^{2-}, OH^-, O^{2-}, respectively

Fuel Cells 102

Types of fuel cells and their major distinctions

- **Fuel Type**
  - **Metallic**
    - **Aluminum, zinc**
  - **Hydrogen**
    - **PEM, Alkali, Phosphoric acid**
  - **Syngas**
    - **Molten carbonate, Solid oxide**
  - **Alcohol**
    - **Direct methanol**