

Regenerative Hydrogen/Halogen Fuel Cells for Peak Shaving and Load Leveling Applications

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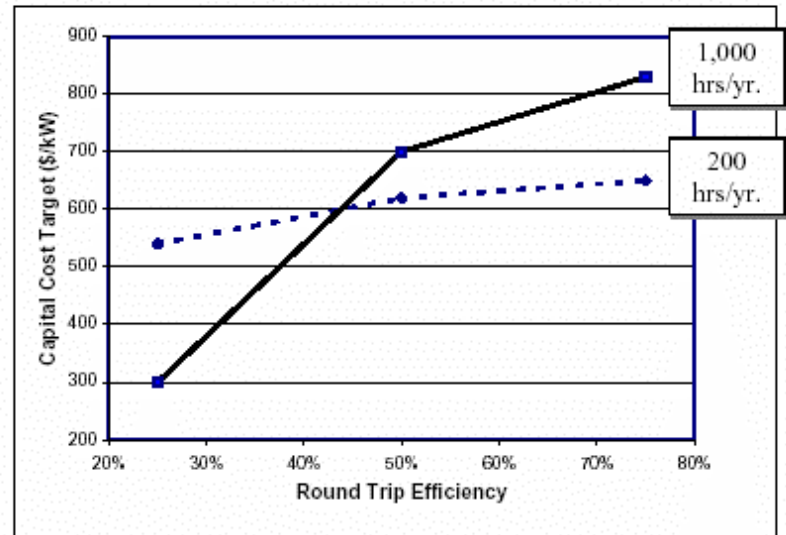
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Energy Storage Overview

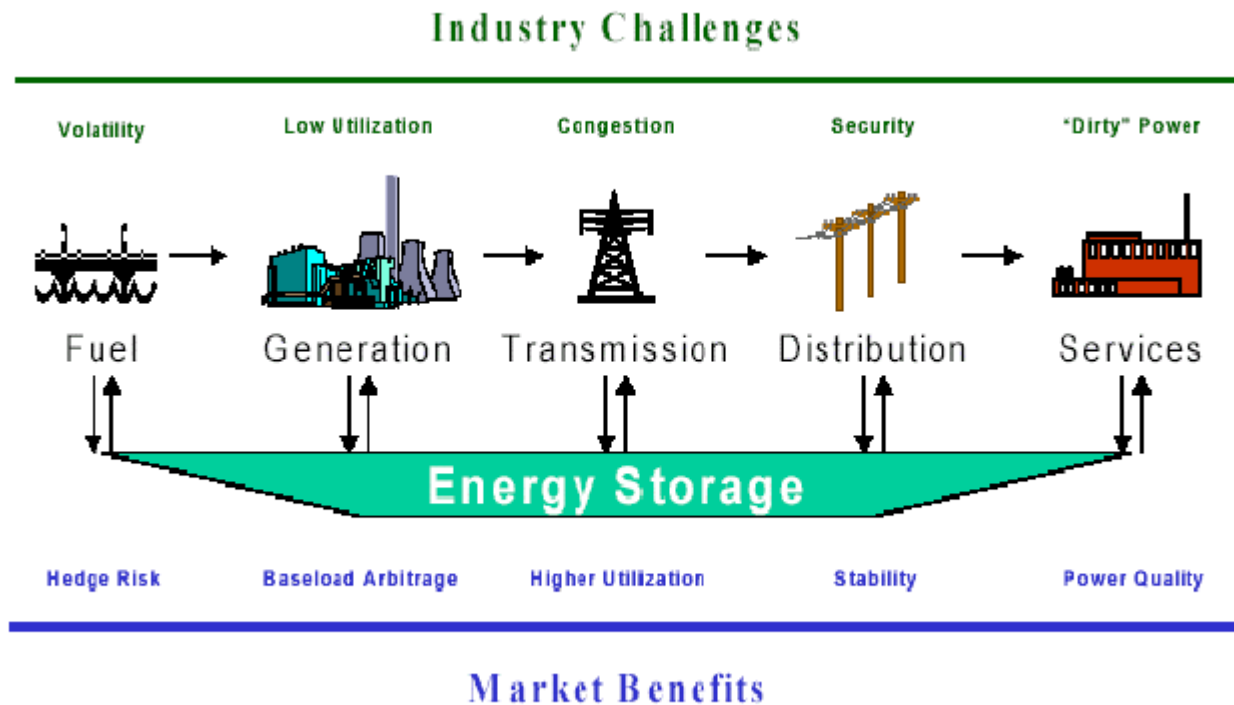
- Energy Storage has a Critical Role to Play in our Nation's Electricity Infrastructure
 - Securing and Assuring our Critical Assets
 - Raising the Value of Renewables to the Market
 - Balancing Peak Demands With Generation and Transmission Infrastructure Capability

Energy Storage Value, an Illustration

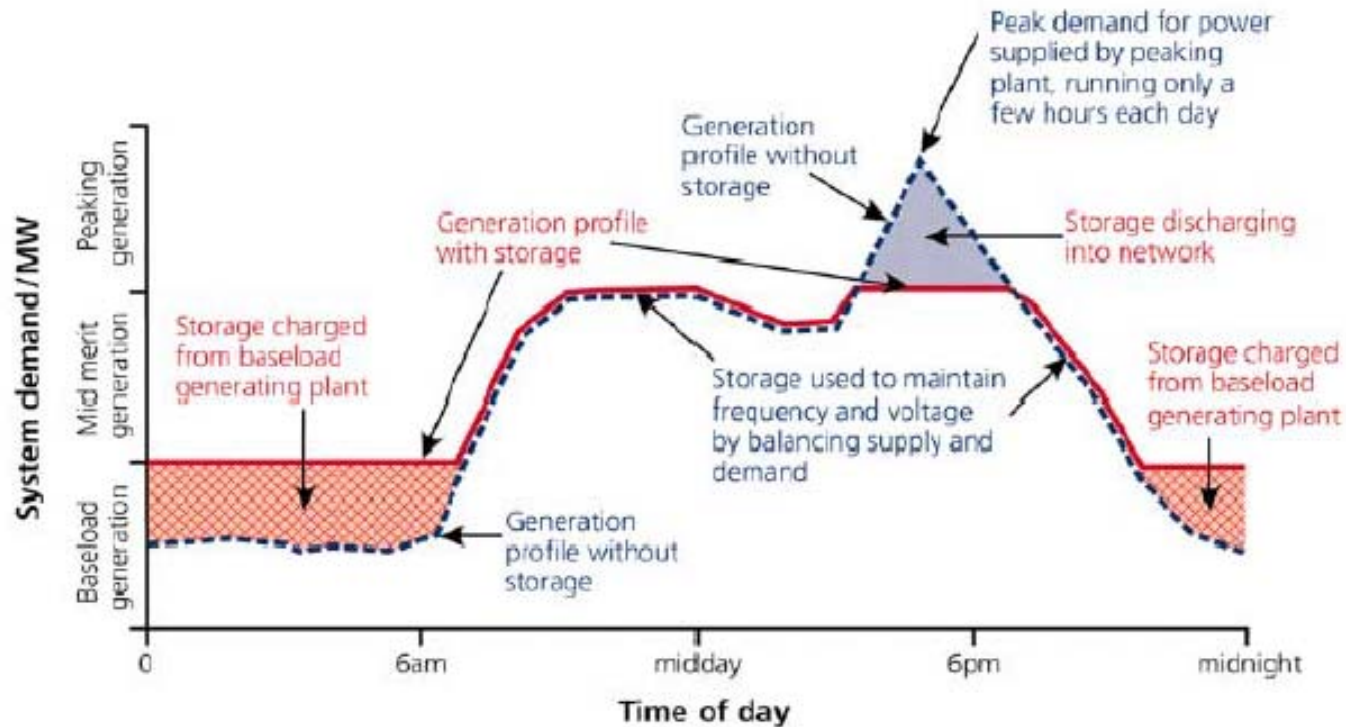


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Benefits of Energy Storage



Load Profile of a Large-Scale Energy Storage System



Reproduced from Anthony Price, Regenesys

Technology Choices For Energy Storage Applications

Technology	Life	Reliability	Overall Cost	Efficiency	Response	Energy Stored
Flywheels	?	•	?	?	o	Hours
Batteries	•	•	•	o	o	Hours
Fuel Cell/Electrolysis (Hydrogen/Oxygen)	•	•	o	•	o	Days
SMES	•	?	?	?	o	Minutes
Pumped Hydro	o	o	o	o	⊗	Years
Hydrogen/Halogen Regenerative Fuel Cell	•	•	o	o	o	Days

o Excellent

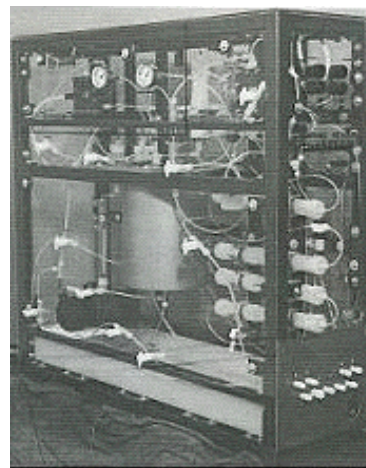
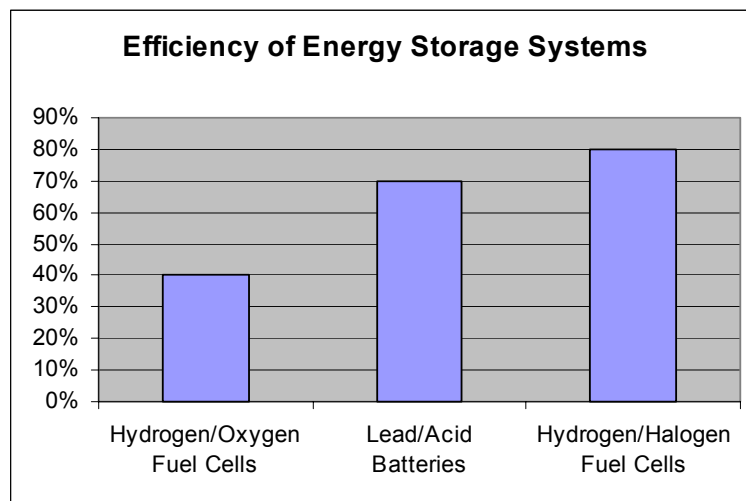
• Average

⊗ Poor



Background – Hydrogen/Halogen Regenerative Fuel Cells

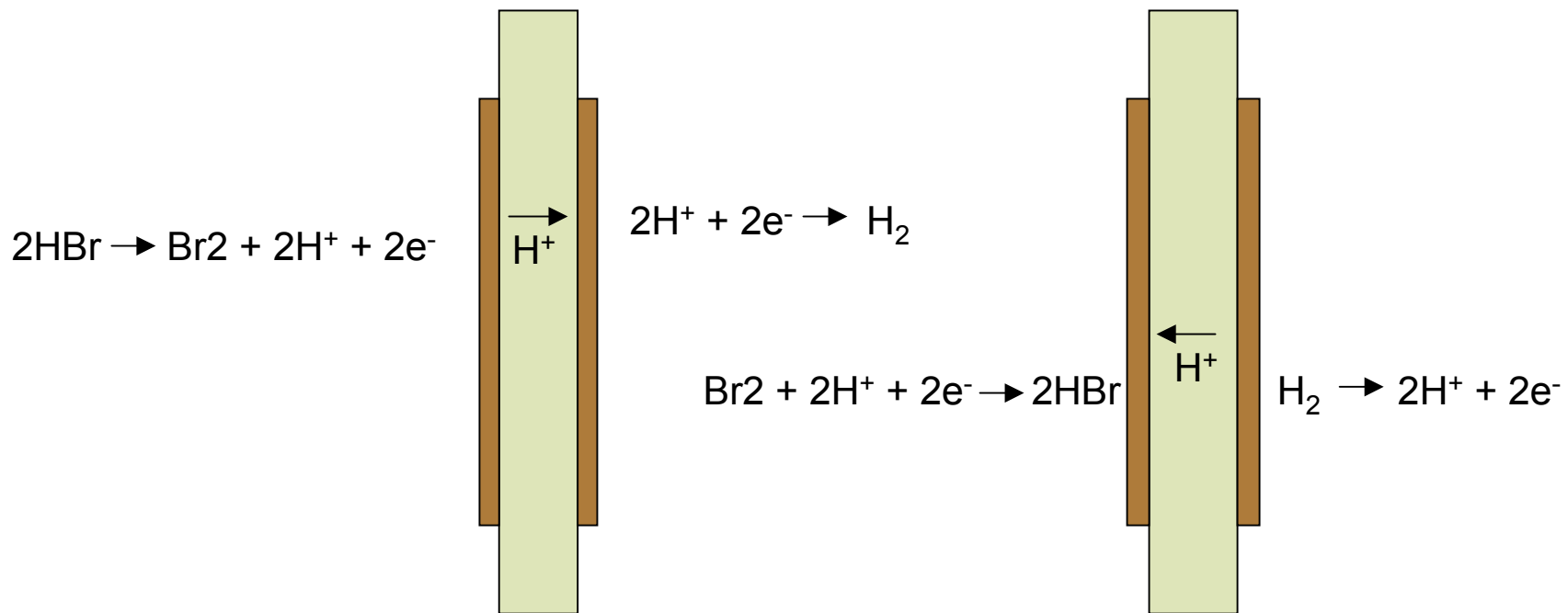
- PEM Hydrogen/Oxygen Fuel Cells Originally Developed for Space Applications
- New Applications Demanded More Efficient Systems (1970's – 1980's)
 - MX/Deep Base
 - Portable Power
 - Utility-Based Energy Storage
- Hydrogen/Halogen Fuel Cell Designs Leveraged Technology Developed in the NASA Programs and Commercial Chlor-Alkali Applications
 - H₂/Cl₂
 - H₂/Br₂



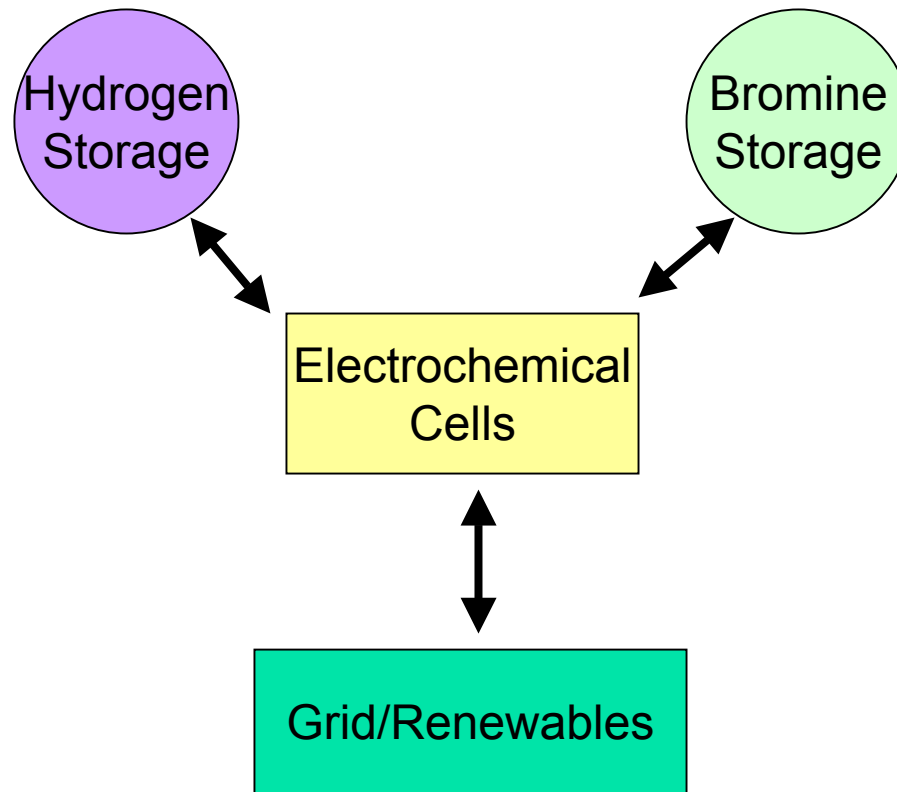
Hydrogen Bromine Regenerative Fuel Cell Electrochemistry

Charge Mode

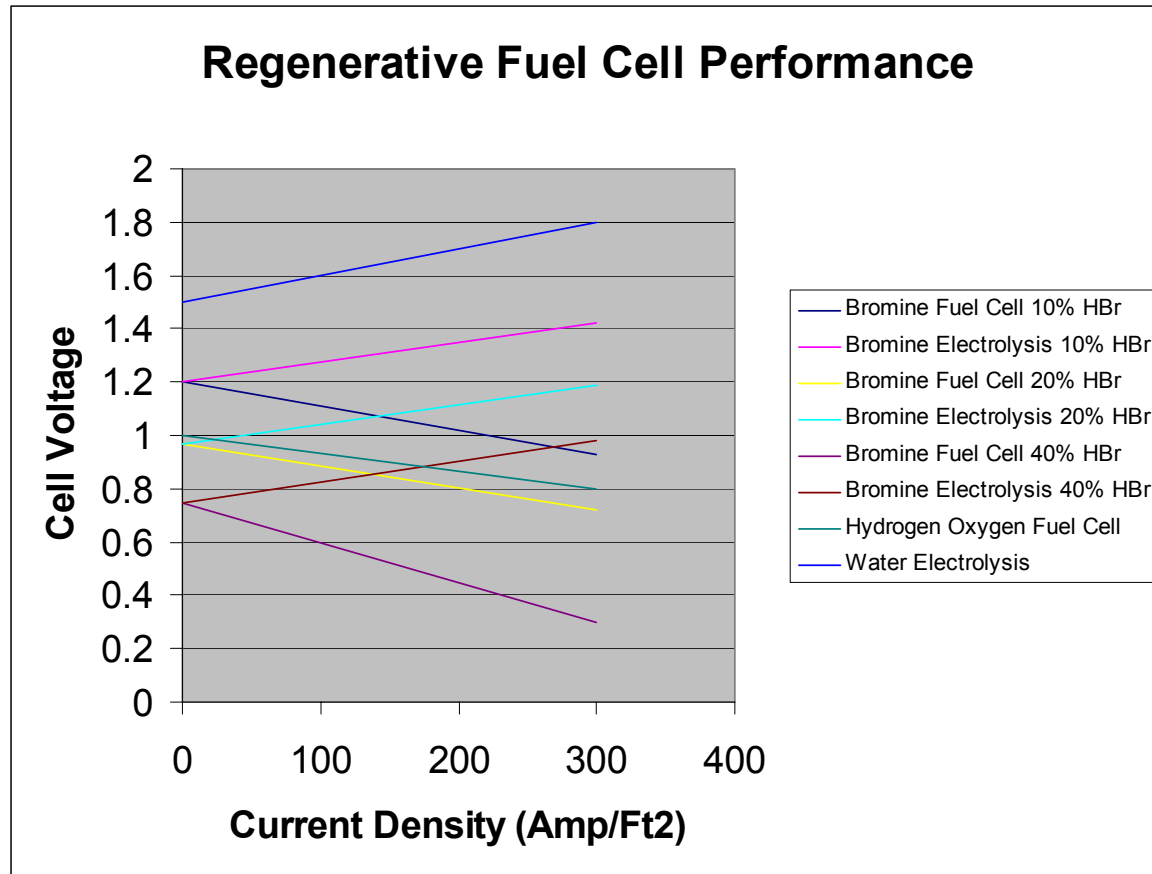
Discharge Mode



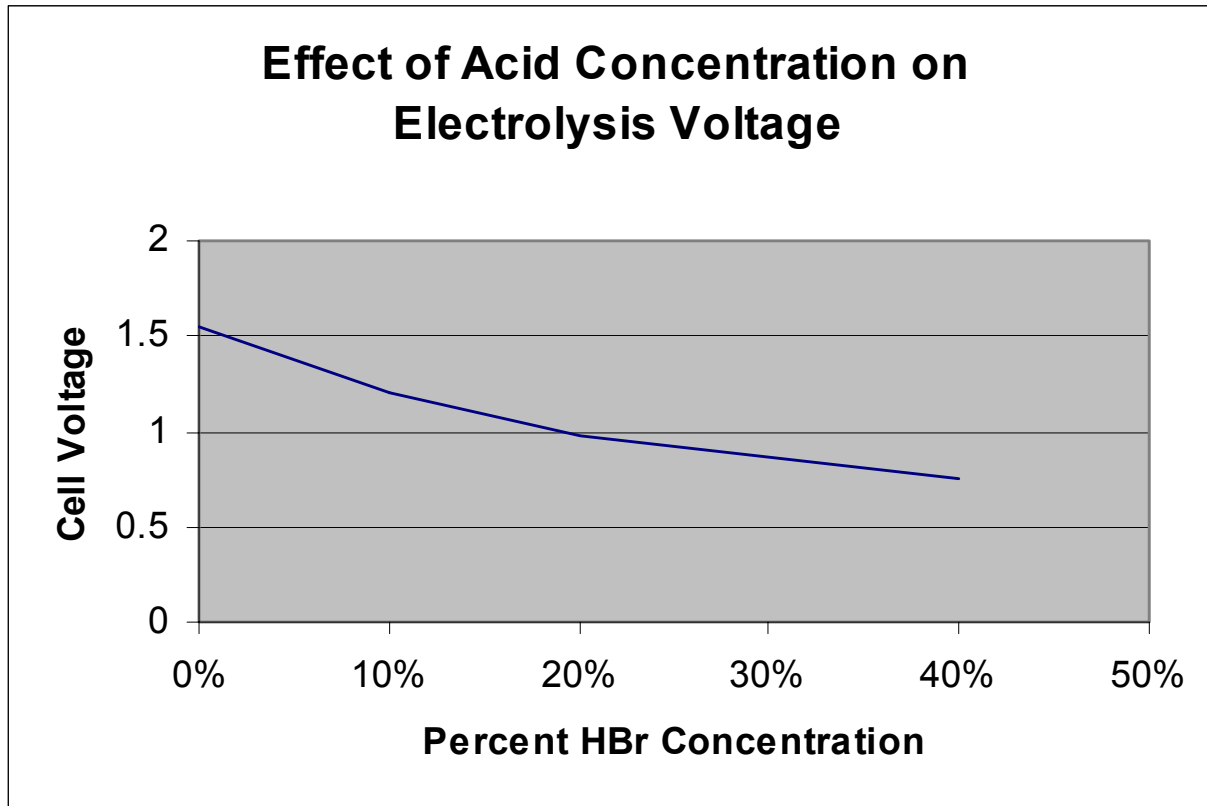
Hydrogen Bromine Regenerative Fuel Cell Block Diagram



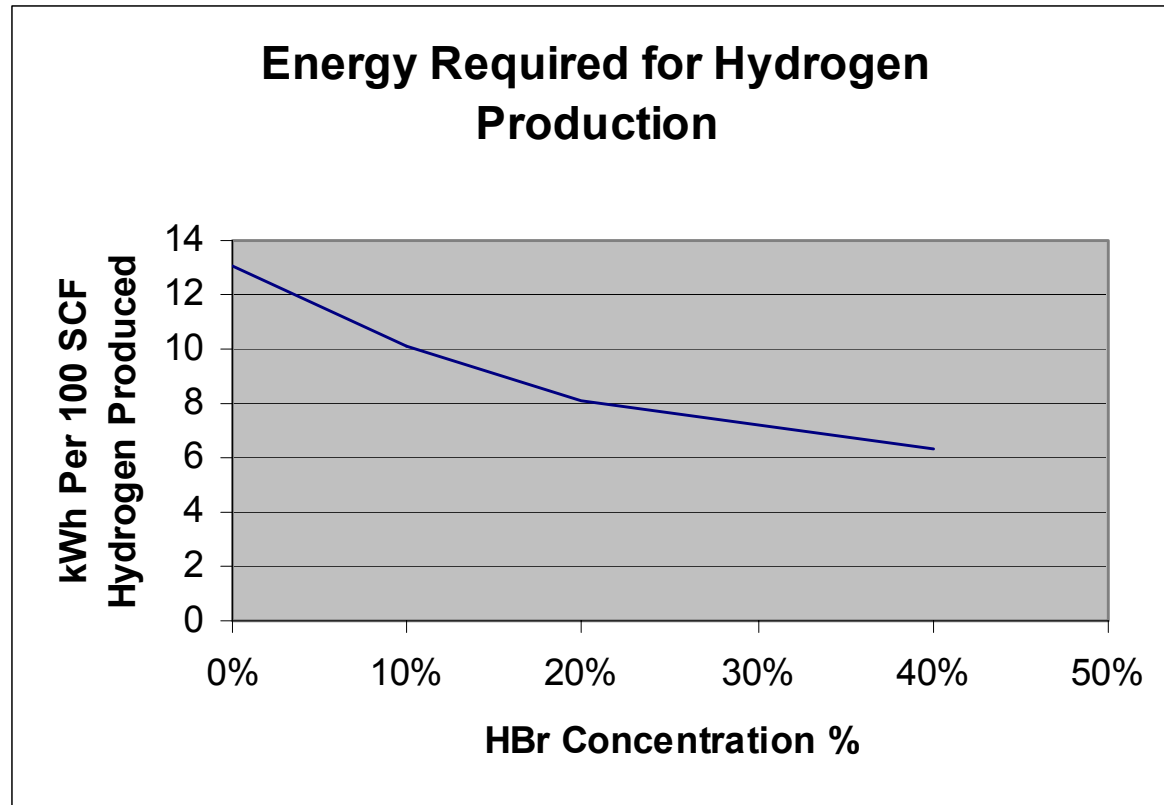
Hydrogen Bromine Regenerative Fuel Cell Polarization



Acid Concentration Has a Significant Effect on Cell Performance

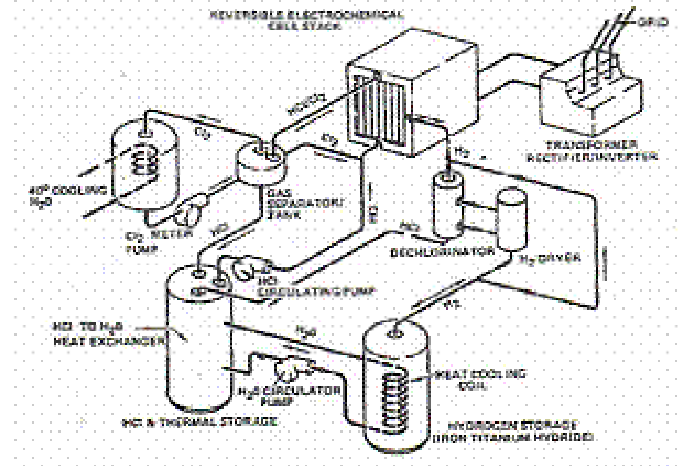


Higher Acid Concentrations Yield a Lower Energy Requirement for Hydrogen Production



System Design

- Regenerative Fuel Cell Stack
- Fluids Management System
- Hydrogen and Halogen Storage
- Thermal Management
- Power Conditioning
- Controls



Example Hydrogen/Chlorine Regenerative Fuel Cell



Development Issues

- Robust Materials
- Mass Transport at the Electrodes
- Shunt Currents in Larger Stacks
- Scale-Up to Practical Systems
- Halogen and Halogen-Acid Handling



Summary

- Recent Advances May Make Hydrogen/Halogen RFC Viable
 - Materials
 - Modeling
- Hydrogen/Halogen RFC Offers Potential Advantages Over Other Technologies
- Successful Development Can Have National Importance
- Significant Challenges Ahead