Distributed
ENERGY SYSTEMS

Extending today's resources...
creating tomorrow's choices

"Electrolytic Hydrogen Production for Military and Aerospace Applications"

THE NATIONAL HYDROGEN ASSOCIATION

Presented to the NHA Fall 2007 Topical Forum

Columbia, SC

October 3, 2007

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Presentation Outline

- Introduction to DES
- Introduction to PEM electrolysis
- Overview of military applications
- Status of current development activity
- Look ahead to future application development

DES Corporate Structure

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Distributed Energy Systems Corporate Brand

Power Generation Business Unit

- DG Projects
- Wind Power
- CHP Systems
- Oil and Gas Power
- Remote Power
- Power Electronics

Hydrogen Generation Business Unit

- Industrial Electrolyzers
- Hydrogen Optimization

Technology Generation Business Unit

- Backup power
- Hydrogen fueling
- Renewable hydrogen
- Closed loop RFC’s

DES Operations and Facilities

Connecticut: Formerly Proton Energy Systems

Vermont: Formerly
Northern Power Systems

Combined Company:
- > 200 employees
- ISO 9000:2000 registered
- Proton Energy Systems founded 1996
- Northern Power Systems founded in mid-1970's

Electrolysis of Water, circa 1800

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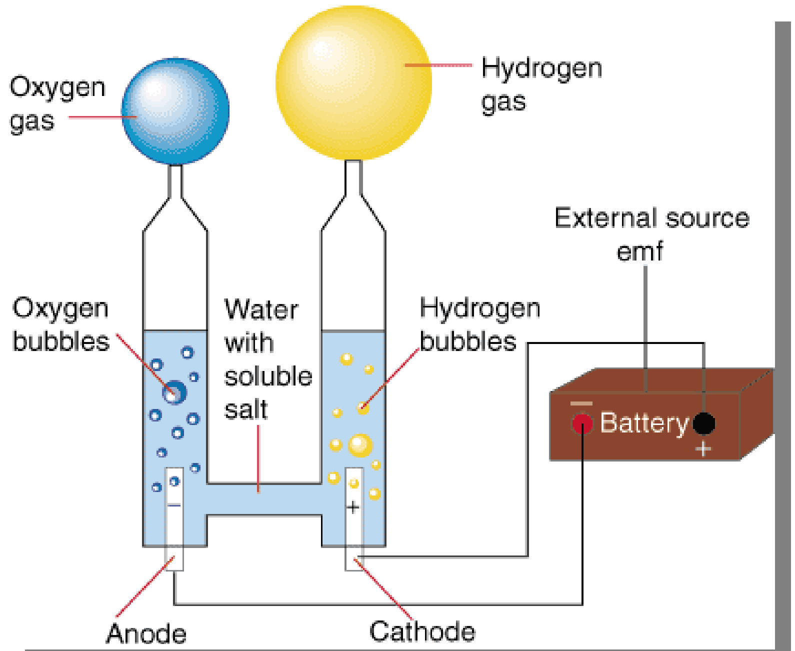
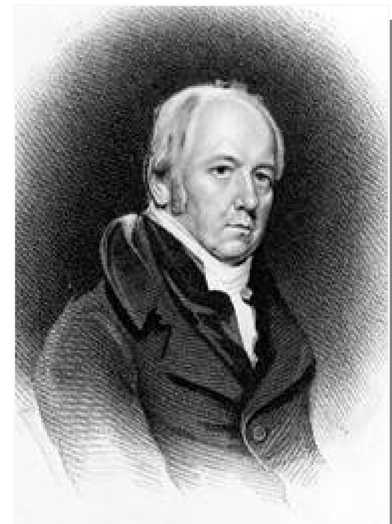
Effect first discovered by William Nicholson, English chemist

$$2H_2O_{(l)} \rightarrow 2H_{2(g)} + O_{2(g)}$$





William Nicholson, ca. 1812
Engraving by T. Blood after a portrait painted by Samuel Drummond (1765-1844)

Oxygen gas (O_2) forms at anode

Hydrogen gas (H_2) forms at cathode

Development of PEM Electrolysis

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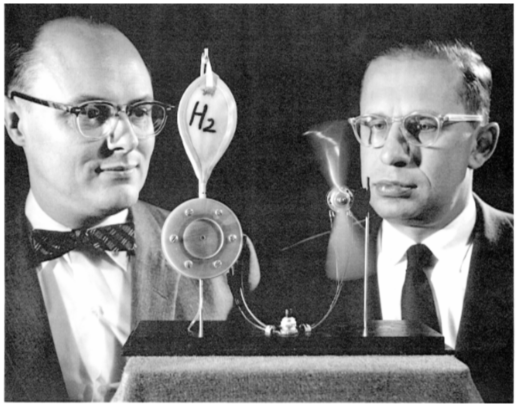
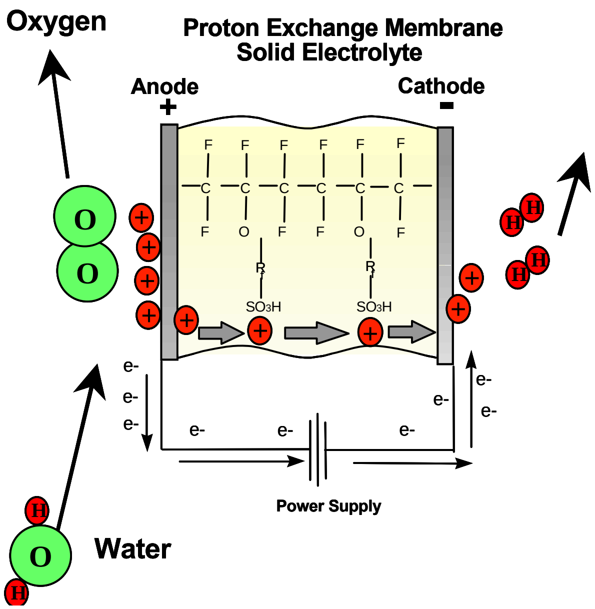
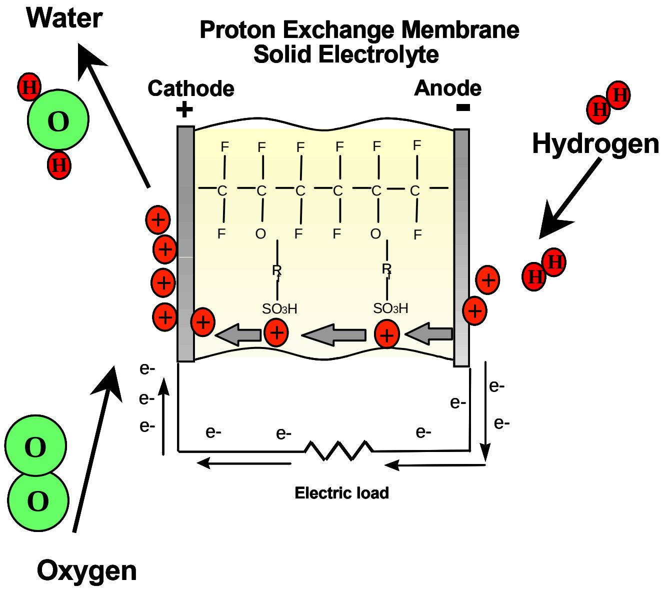


Initial PEM innovators
Grubb & Neidrach,
GE Research, 1955

PEM Electrolysis



PEM Fuel Cell



DES PEM Electrolysis Capabilities

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Systems Manufacturing

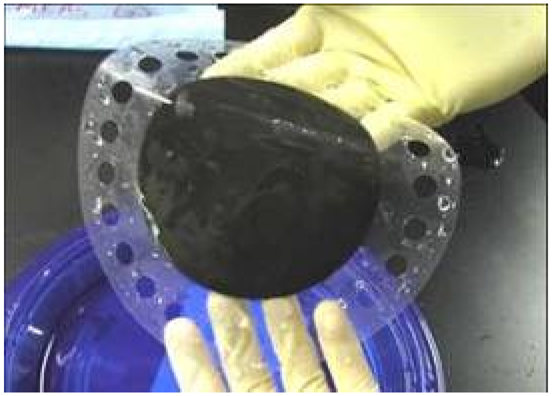
Cell Stack Manufacturing

ISO 9001

Registered Facility

TUV Rheinland of North America, Inc.

Product Testing



Cell Stack R&D

DES Commercial Hydrogen Products

HOGEN S-Series
- 20-40 SCFH H_2
- H_2 Pressure: 200 psig

HOGEN GC
- 300 or 600 cc/min
- H_2 Pressure: 200 psig

HOGEN H-Series
- 76-228 SCFH H_2
- H_2 Pressure: 200 psig

World-wide Commercial Experience

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Over 700 HOGEN® electrolyzers in 50+ countries

Military Electrolyzer Applications

Application Area	Electrolyzer Requirements
Hydrogen Fueling • **Clandestine combat vehicles** • **Electric utility vehicles** • **Fuel canisters for portable**	• **High output (>100 kg/day?)** • **High pressure desirable** • **Renewable interface option**
Backup Power / RE Storage • **Tent City microgrid** • **Remote sensors** • **Critical backup**	• **High pressure** • **High conversion efficiency** • **High reliability** • **Low maintenance**
Air Independent Energy Storage • **Space and high altitude** • **Underwater systems**	• **Lightweight and/or low volume** • **May need very high pressure** • **Very high reliability**
Life Support (O2 generation) • **SSN submarines** • **Manned space platforms**	• **Very tight leakage allowances** • **Highest reliability**

Earliest Military Application: 1959
PEM Electrolyzer for Submarine Life Support

Integrated Low Pressure Electrolyzer for Virginia Class Submarines
Photo courtesy of Hamilton Sundstrand

USS Virginia

DES High Pressure Stacks

High pressure electrolysis is the enabling capability for efficient and compact hydrogen energy storage.

Advanced HP Stack, 1100 psi

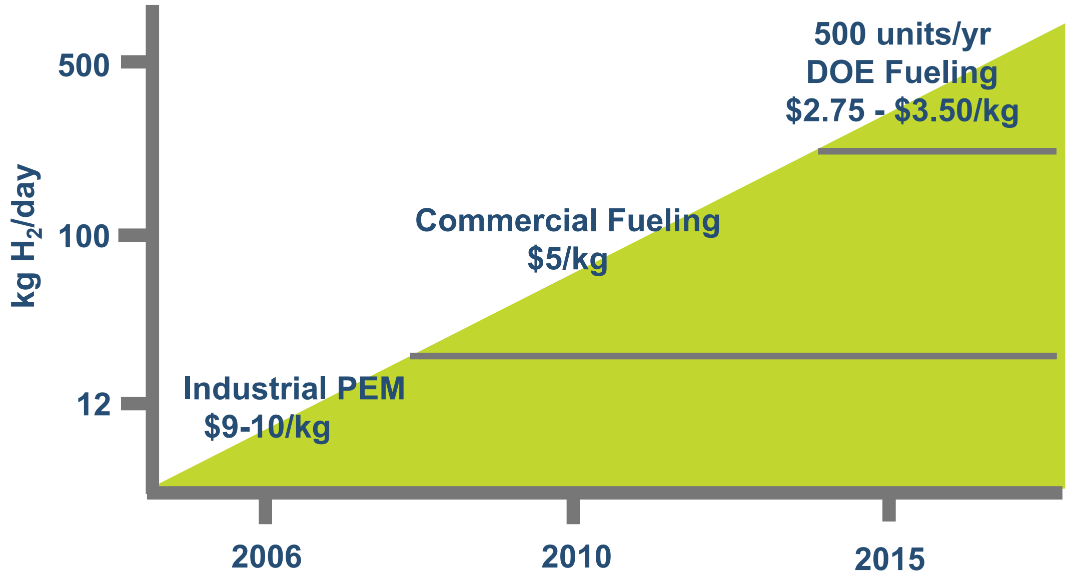
2000 psi, up to 40 scf/hr

IR&D 2400 psi H_2 stack

Stirling replenisher, 2400 psi

DARPA 3,000 psi H_2/O_2 stack

Pathway to Commercial Fueling



$/kg H_2 Fuel Cost is Derived from H2A Model

- **Industrial PEM => Commercial Fueling => DOE Fueling: 50 kW => 300 kW => 1 MW**
- **Fueling Metric is $/kg H2 ; 1 kg H2 roughly equals a gallon of gasoline on an energy basis**
- **$/kg H2 Fuel Cost is Derived from Capital Cost, Electricity Cost, and Maintenance Cost**

Assumes 20 year life, $.04/kwh power, 90% capacity factor

Fuel Conversion Efficiency

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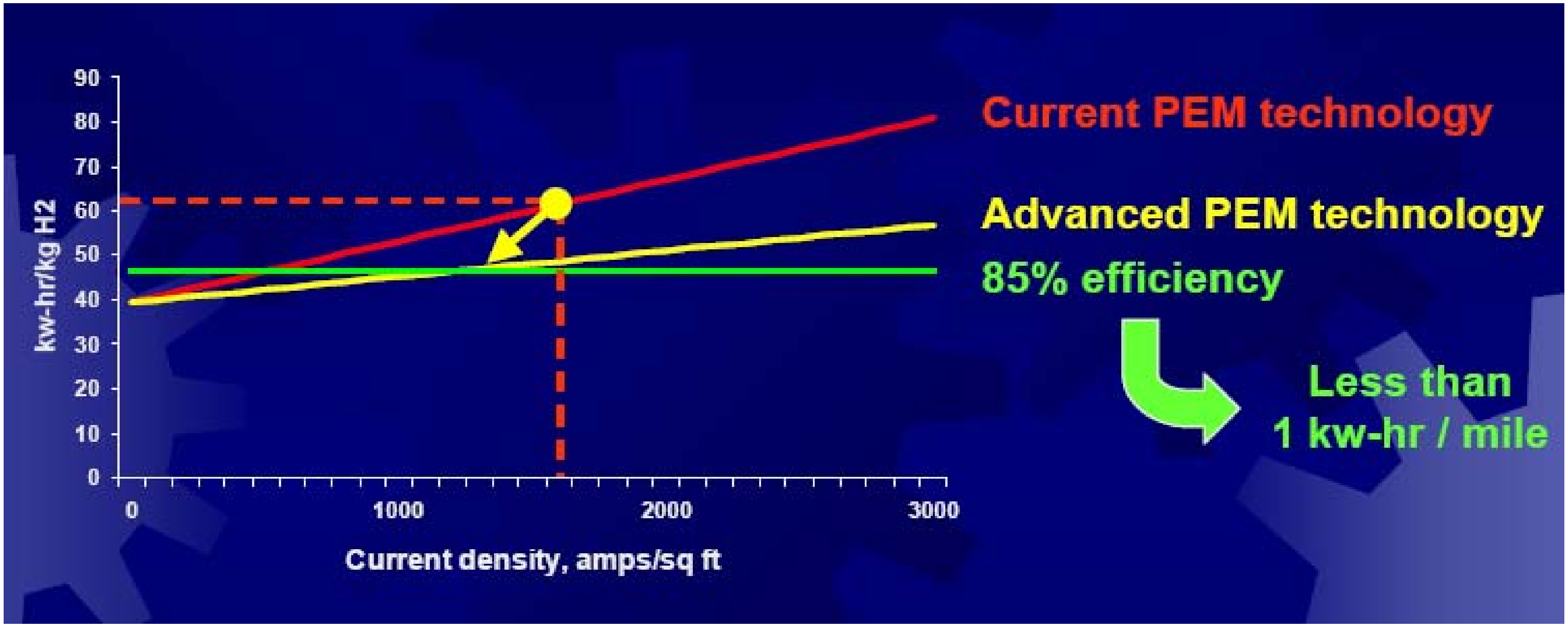

At 85% efficiency, the hydrogen cost per mile is the same as driving a gasoline fueled car that gets 75 mpg.

Assumes $0.04/kWhr power and $3.00 per gallon gas price. Does not include cost of compression.

UNLV Hydrogen Fueling Station
Las Vegas, NV

Distributed Generation of Hydrogen via Wind

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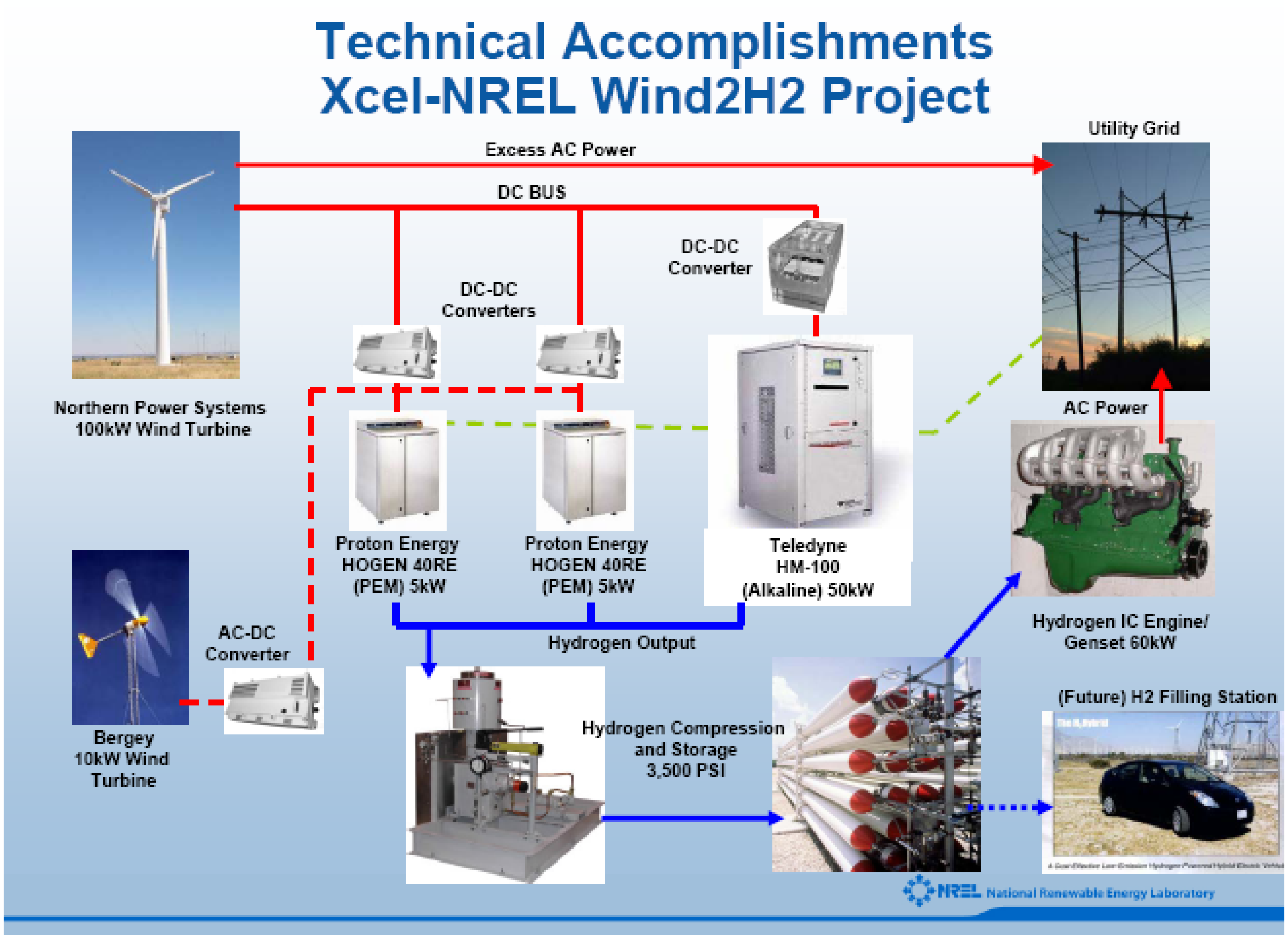


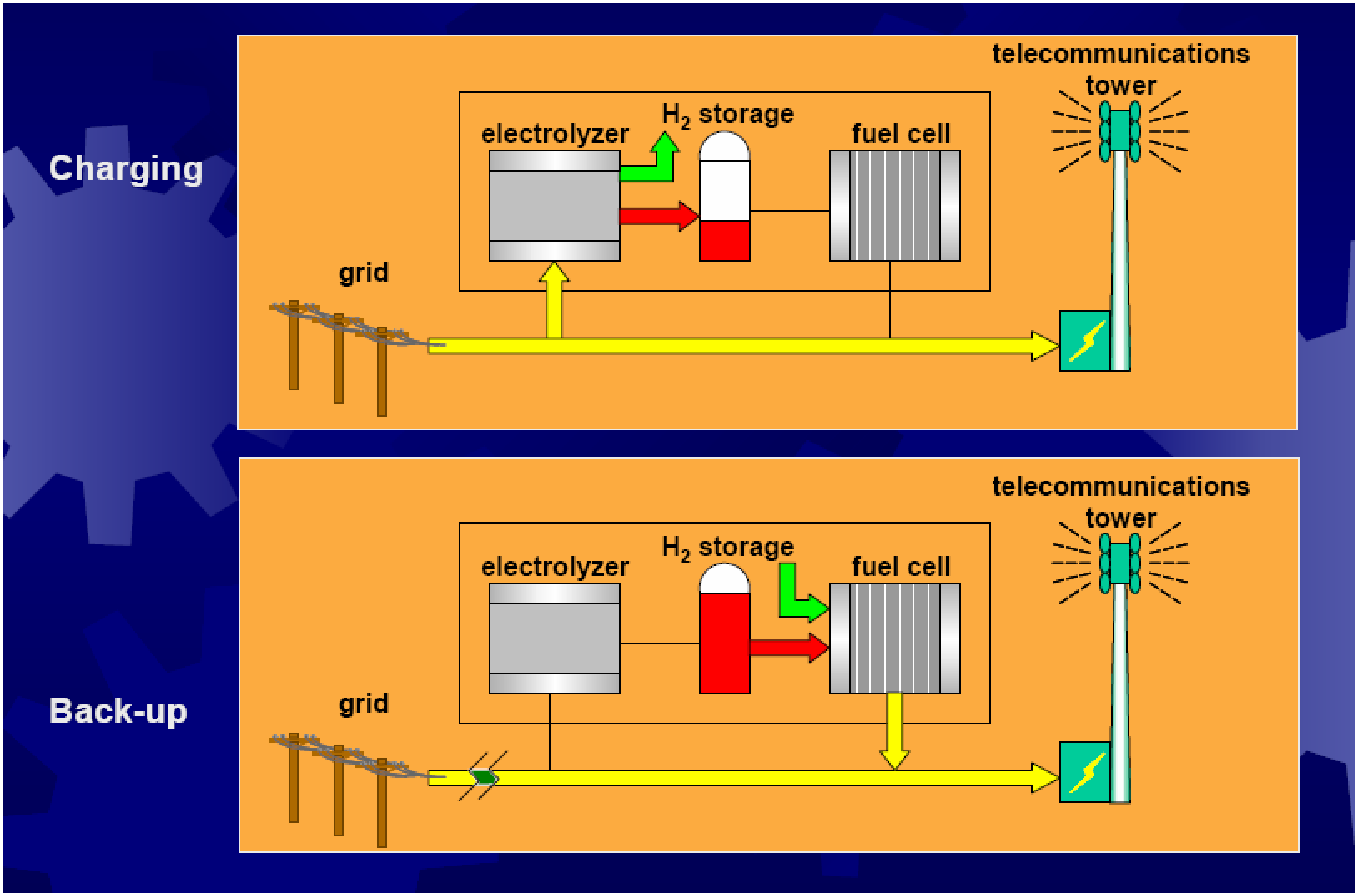
Wind to Hydrogen for Transport

Entegrity Wind Turbines

H6M Electrolyzers at Synthetic Energy

Synthetic Energy, Idaho
Wind to Industrial Hydrogen:
>130000 SCF every two weeks
to NORCO via tank trailer

Regenerative Fuel Cells: Stationary Backup Power



Regenerative Fuel Cells: comparison of specific energy to batteries

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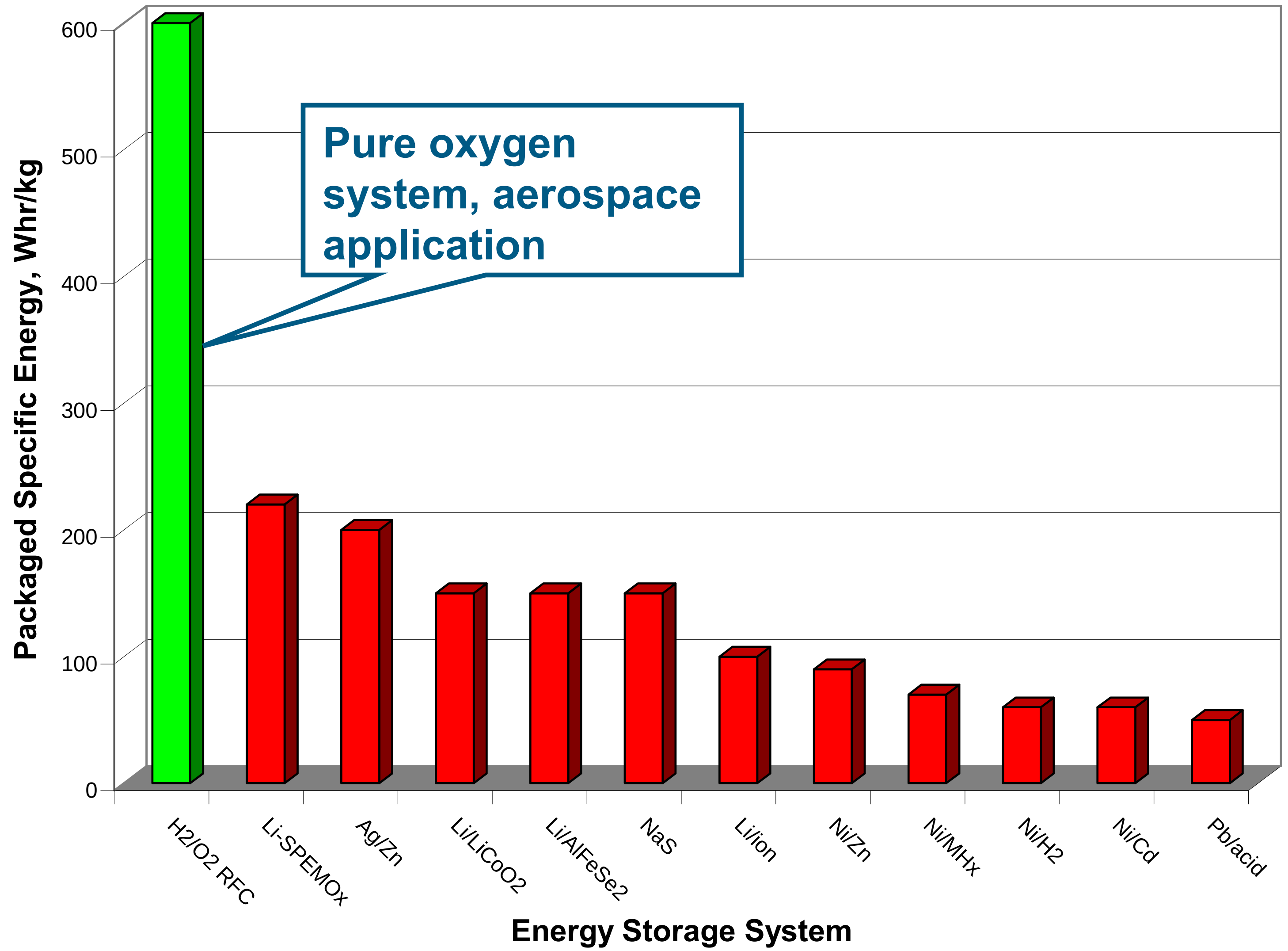

Source: Mitlitsky, et al, "Regenerative Fuel Cells", Energy and Fuels, 1998.

RFC Backup Power Economics

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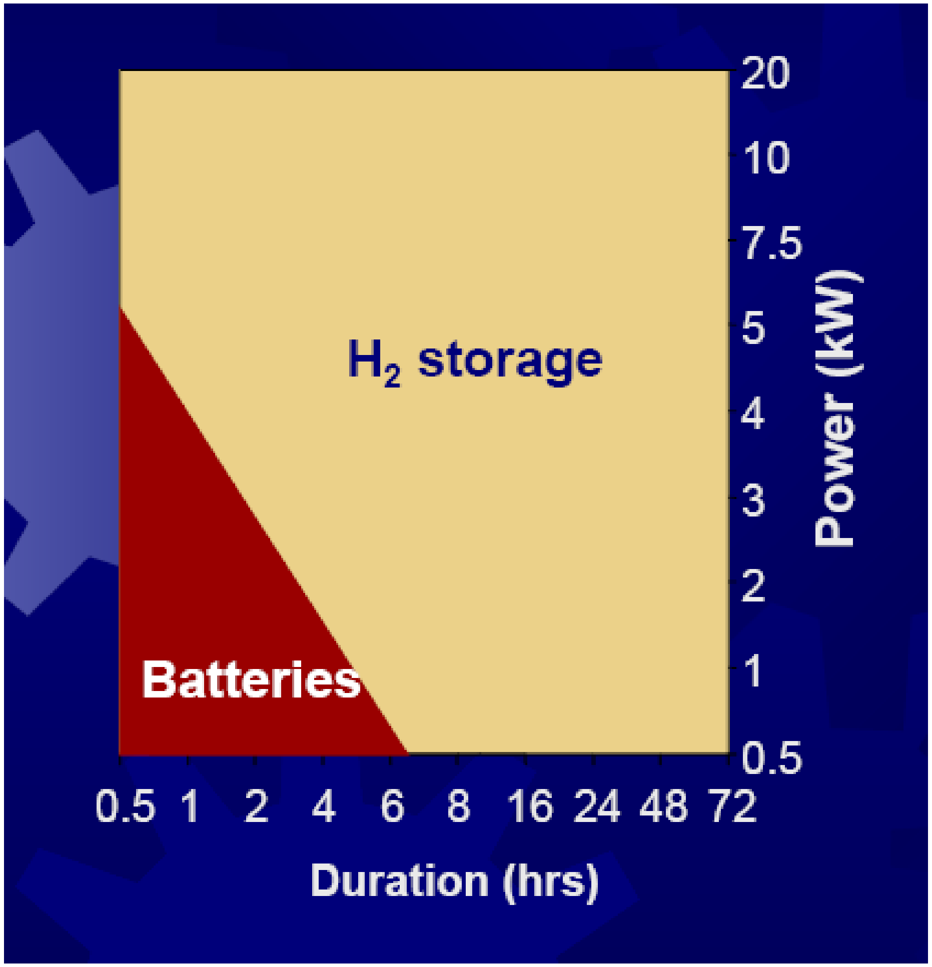

In general, the RFC solution is favored over VRLA batteries for longer backup times and higher power levels.

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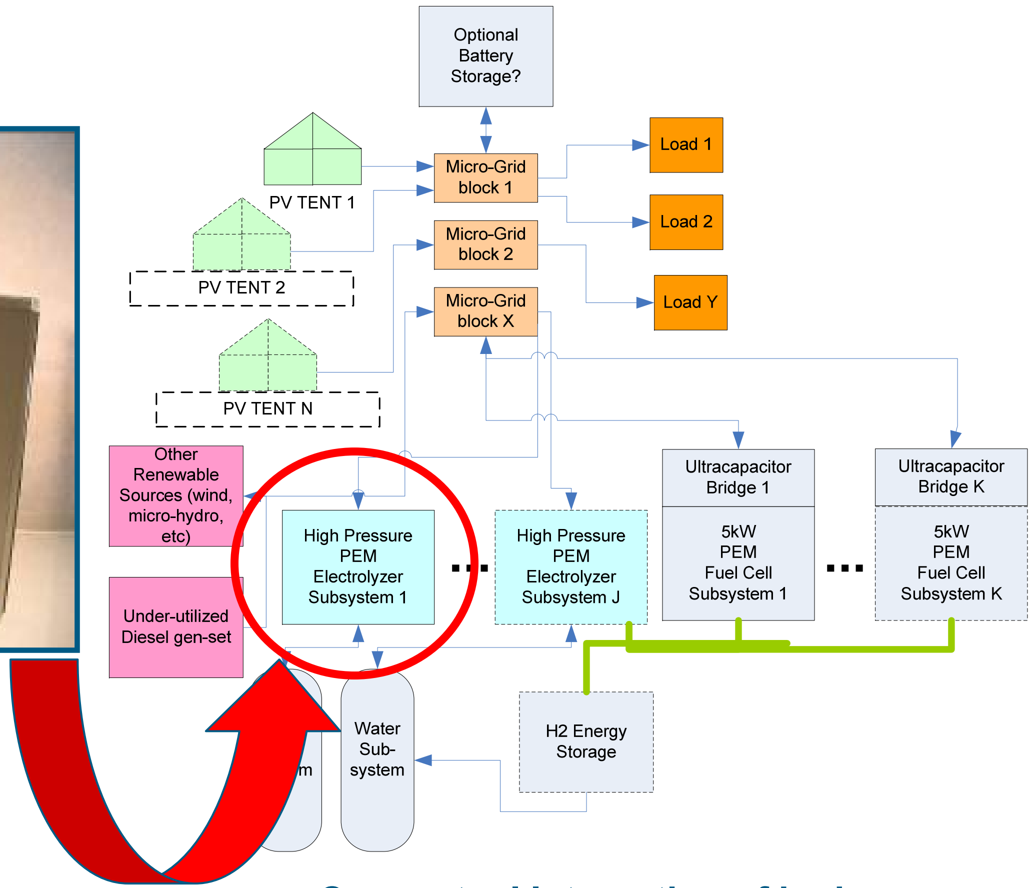
High Pressure Electrolyzer Module (HPEM) for Energy Storage Demonstration at CERL

10 scf/hour hydrogen production at 2400 psig



Conceptual Integration of hydrogen energy storage into camp microgrid

Backup Power Demonstration, SRNL and Center for Hydrogen Research

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HOGEN® RE, renewable ready electrolyzer

1 kg capacity metal hydride storage bundle for compact, low pressure storage

15 kW RFC backup power system, Wallingford, CT

SRNL We Put Science To Work™

CHR CENTER for HYDROGEN RESEARCH

Residential Integration of PV-Hydrogen

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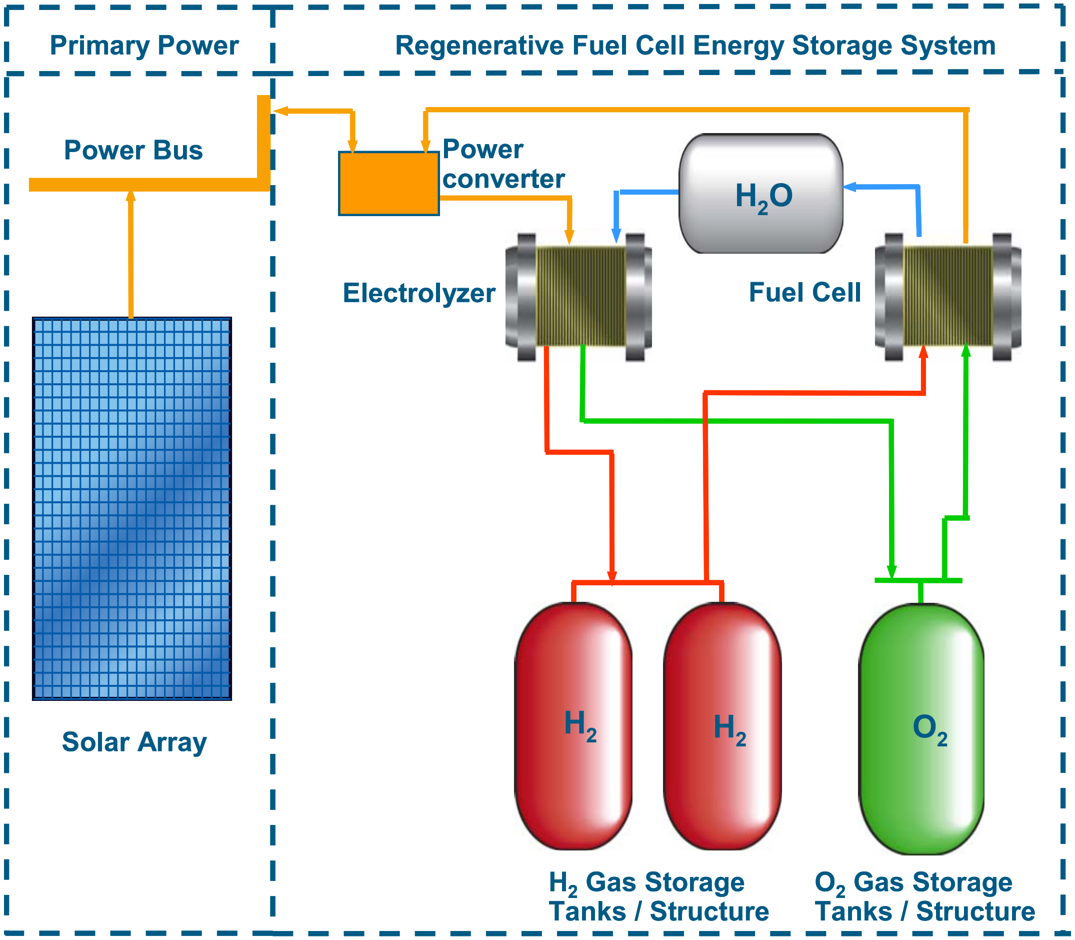
United States Merchant Marine Academy

"America's First Solar Hydrogen Home"

Energy Secretary Bodman views the hydrogen energy storage system

DRFC for MDA High Altitude Airship



1 kW closed loop DRFC demonstrator ready for test

URFC Energy Storage for HALE Vehicle

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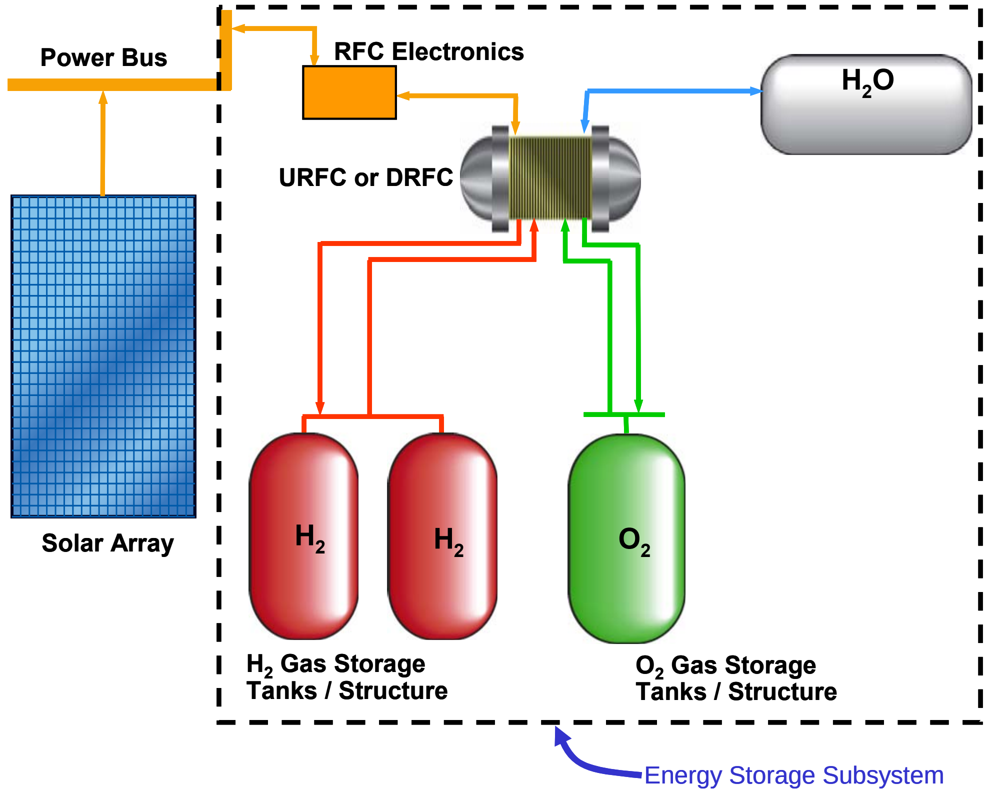
1kW capable URFC
test system delivered to NASA



Air Independent Energy Storage Plus On-Board Fuel Production

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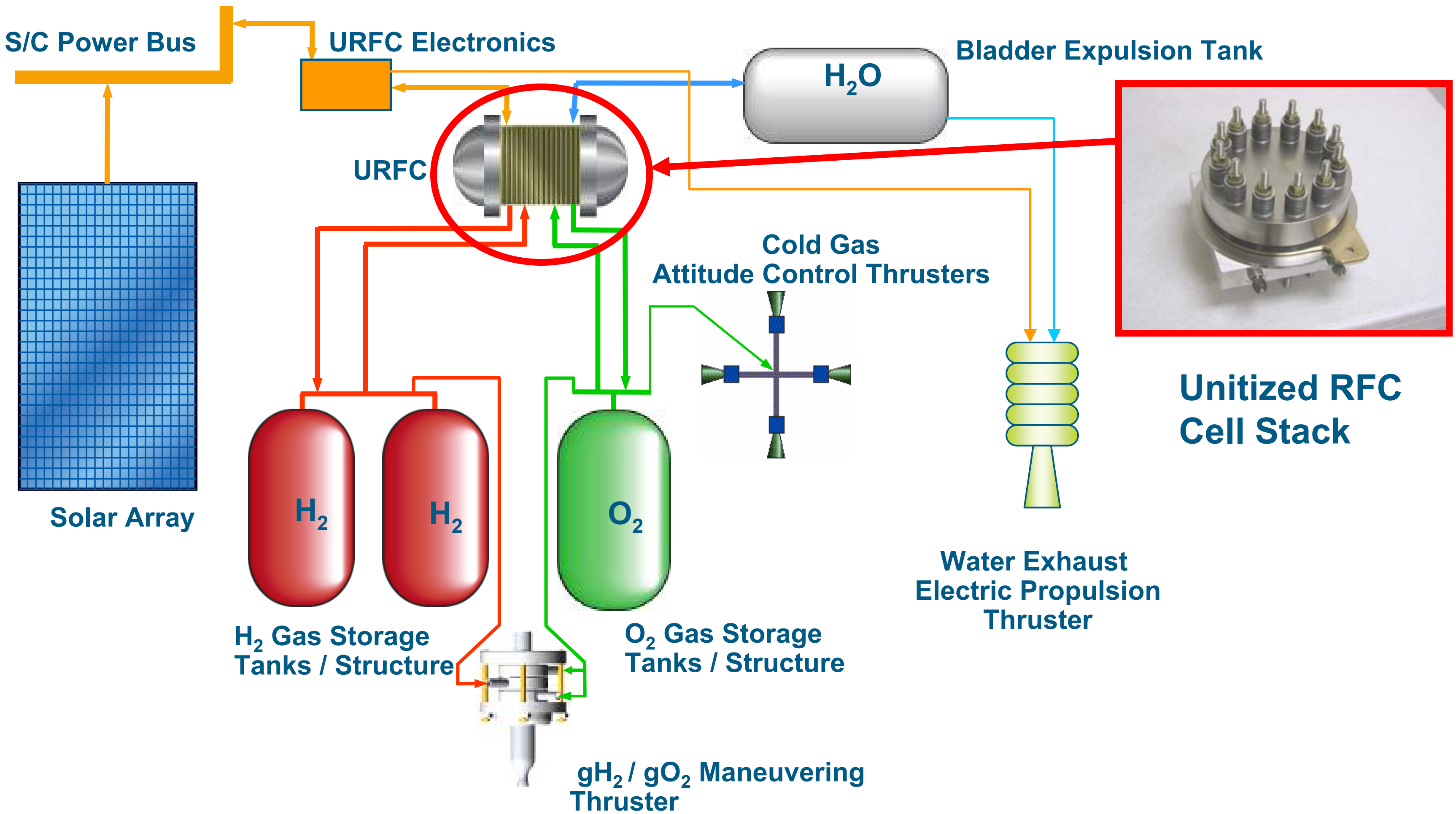
DARPA Water Rocket: Unitized, Zero-G RFC

Contact number: N00173-01-D-2006



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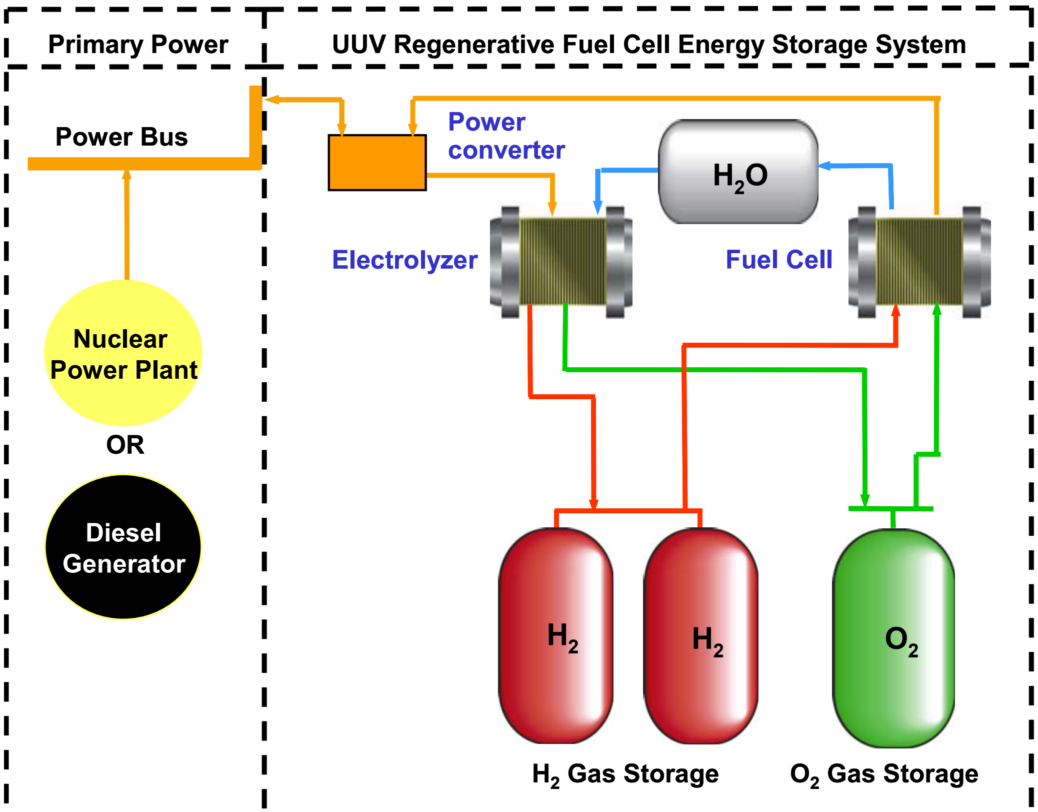
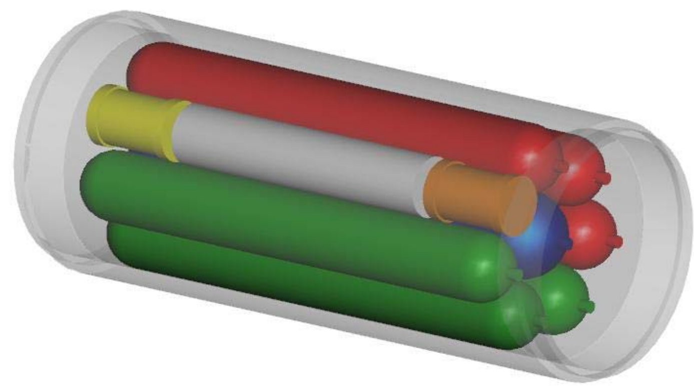
UUV Power System Concept with On-Board Recharge: eliminates high pressure gas transfer during recharge





UUV Energy Storage Section

Energy Storage Estimates for 21” MRUUV

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NAVSEA NEWPORT Undersea Warfare Center Division

21” MRUUV
Alternative Propulsion Systems

Chemistry	Energy (kw-hr)	Cycles
Lead Acid	5.6	>300
Silver Zinc (Ag Zn)	22.0	15-20
Lithium Thionyl Chloride (LiSOCl2)	96.5	1
Li Ion Polymer (Predicted)	25.0	>300
Fuel Cell ???	?	?
PEM H2-O2 RFC	**70-90**	**>300**

Alternate UPS Concept for Navy Shipboard Application

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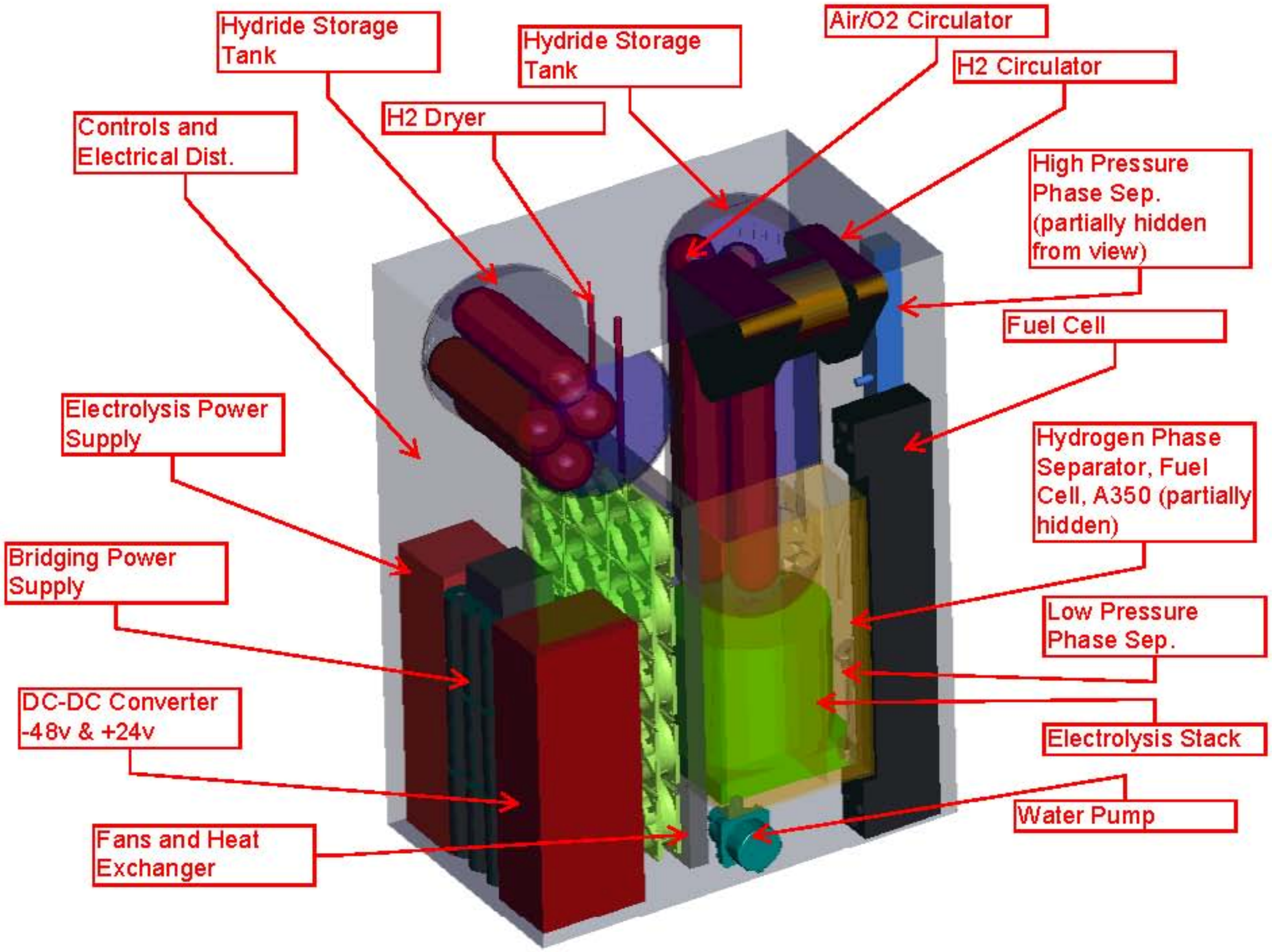
RFC Packaging Concept to Replace MIL-P-24765 UPS: > 3X improvement in backup time over incumbent



“Electrolysis is the enabling technology for air independent energy storage, renewable fuel production, and off-grid backup power systems.”