Navy Shipboard Fuel Cell Program

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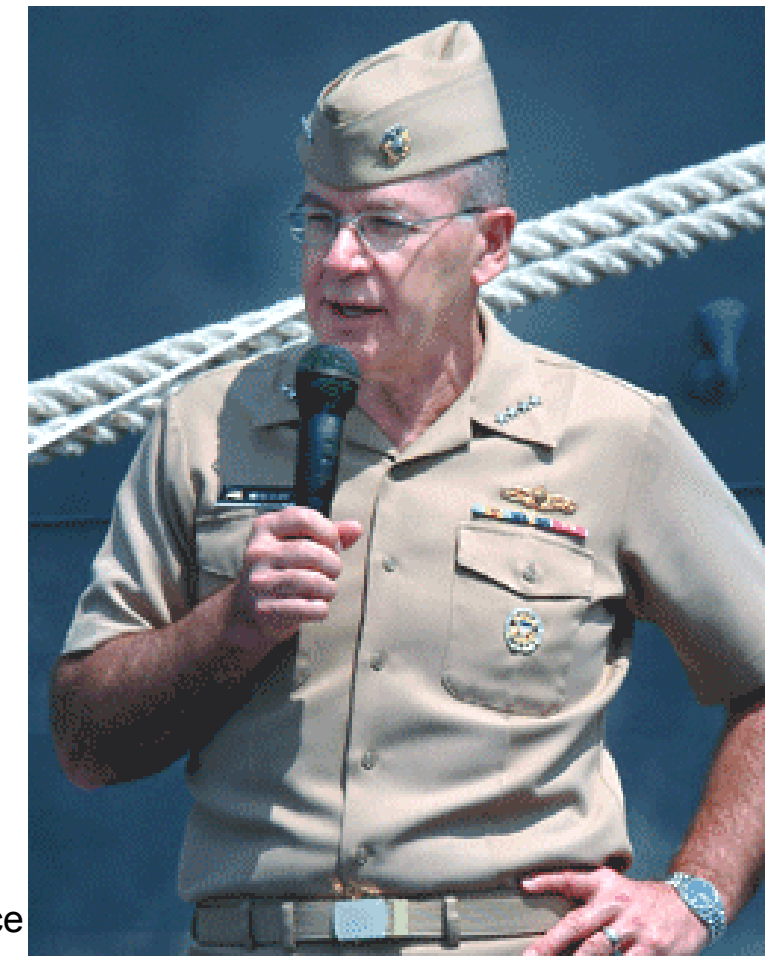
CNO Guidance for 2004

- "*Incorporate **fuel efficiency** into acquisition and modernization plans*"

- "*Develop and experiment with **alternative propulsion** and **power generation** systems for all naval applications*"



Commercial

Automotive

Heavy Vehicle

Marine

Industrial

Electronics

Residential

Locomotive

10^1 10^2 10^3 10^4 10^5 10^6 10^7 10^8

POWER (WATTS)

Soldier Power

Sensors, Unmanned Vehicles

Portable Power

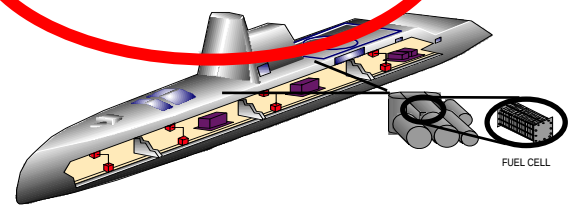
USV/UUV/ Submersible

Vehicles, Generators

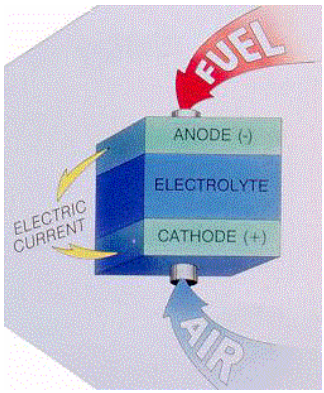
MEFFV

Ship Service

Ship Propulsion



Military

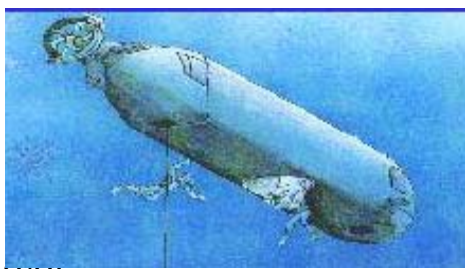


Reduced Acquisition & Life Cycle Costs

- Greater System Efficiencies
- Reduced Maintenance Costs
- Enables Spiral Development

Enhanced Survivability

- Reduced IR Signature
- Reduced Acoustic Signature
- Distributed Power Generation



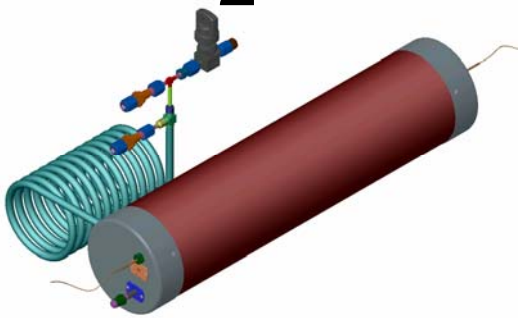
Design Flexibility

- Modular Approach to Ship Power
- Multi Platform Applicable

Power+Energy, Inc.
Leader in H2 separation systems

- Founded in 1993, based near Philadelphia, PA.
- Leading global supplier of Pd alloy hydrogen purifier systems
- Broad ranging capability from bench-top to high volume bulk hydrogen purifiers.
- Multiple customers use P+E membranes for Methanol reformer applications

P+E's H_2 Purifier Product Line



Hydrogen Purifier Cells

Fully Automated H_2 Purifiers

High Capacity 1300 slpm
Modular H_2 Purifier System

P&E Will Present

- Measured performance data for a novel membrane H_2 separator/purifier being manufactured for the Department of Defense
  - Efficiency,
  - power density [W/l]
  - Purity, Δ pressure
  - operating temperature
  - transient time
  - durability
- Comparison of membrane to DOE targets
- Engineering path to higher performance

Engineering for Hydrogen Separation from Reformate

- Substantial differentiation vs. H2 purifiers
- Design compensates for low H2 concentrations
- Reduced susceptibility to process upsets
- Rugged design for real world conditions
- Durability to withstand thousands of operating cycles

PEM Fuel Cells Need Pure H2

- Availability of cost effective, high purity H2 is a barrier to the widespread use of fuel cells
- Pd alloy membranes can simplify H2 sourcing from a wide range of fuels
  - Avoids infrastructure investments for H2 distribution and high pressure storage
- Advances in Pd membrane design greatly increase durability, efficiency & reduce cost

DOD Is Providing Global Leadership by Actively Seeking H2 Solutions

- Hydrogen for mobile applications requires that it be generated on demand at the point of use.
- DOD is targeting the use of existing logistical fuels to generate H2 as it is needed.
- Minimizes logistical challenges and avoids hydrogen storage and distribution barriers.
- Equally valuable to consumers & industry.

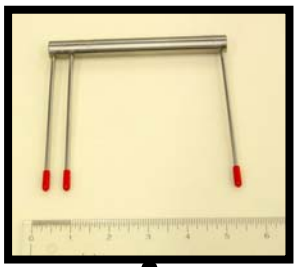
Power+Energy's Next-Generation Pd Alloys Membranes for NAVSEA

- Phase II SBIR Contract Deliverable:
  - Compact, rugged 50 kW (H2) hydrogen separator
  - Sulfur tolerant (up to 20 ppm)
- Long term Goal:
  - Compact, rugged 500KW (elect) hydrogen separator
  - Sulfur compatible (100-1000 ppm)
  - Minimal maintenance, simple servicing
- Phase II SBIR (DARPA / ARO)
  - Compact, rugged 100 watt separator for methanol

Compact Hydrogen Separators

100 Watt

5” x 0.5”

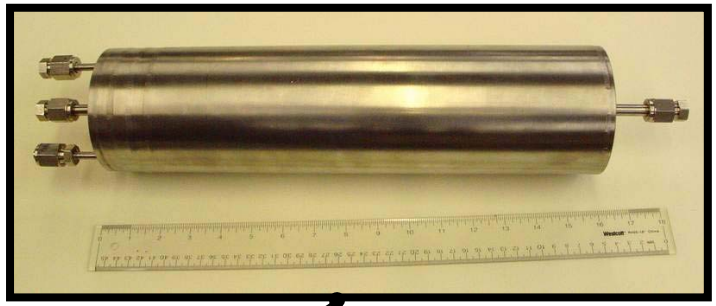


500 Watt

6” x 0.75”

50 kWatt

16”x 4”



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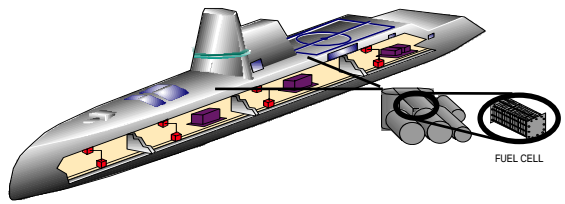
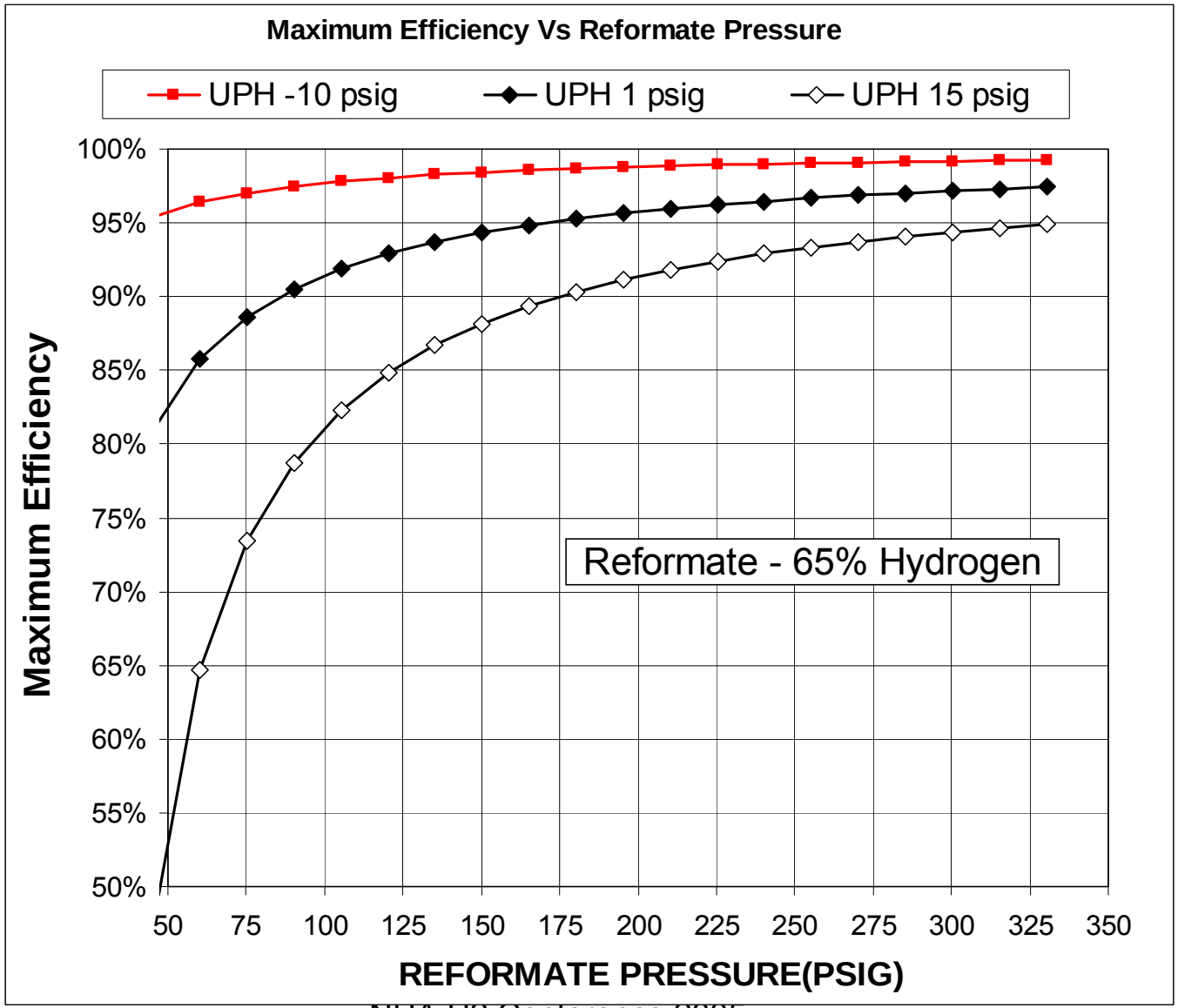


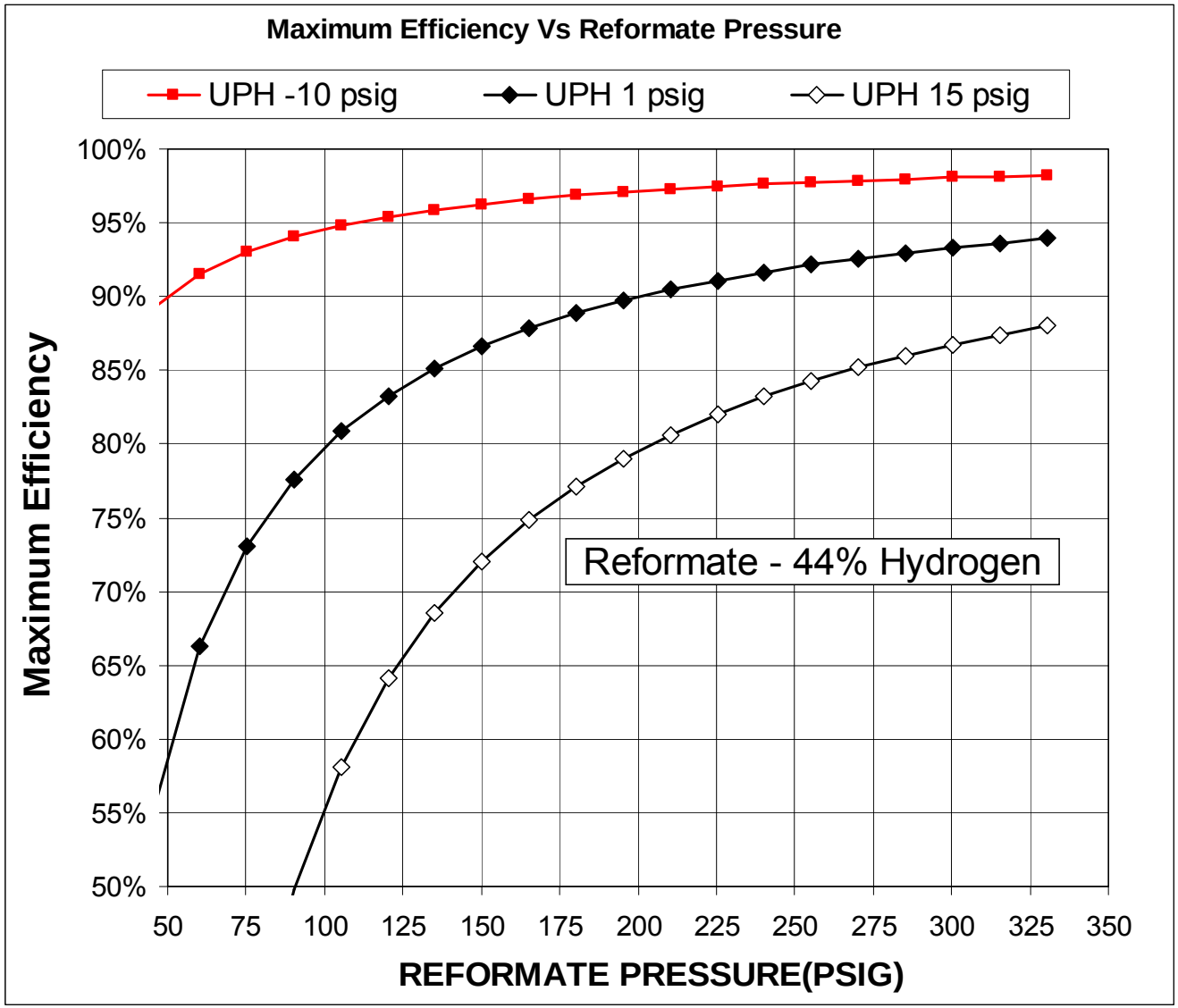
Department of Energy Targets*

Measured performance of new P+E separator/purifiers meets or exceeds 2005 DOE targets for Hydrogen Separation Membranes

DOE Performance Criteria	Units	Year		Year	Year
		2005 Target	P&E	2010 Target	2015 Target
Cost per SCFH per Yr	$/scfh	$15.00	<< $15.00	$1.67	< $0.33
Durability	hours	8,760	>17,520	26,280	> 43,800
ΔP Operating Capability	psi	200	250	400	400 - 1000
Hydrogen Recovery	% of total gas	>70	90%+	>80	>90
Hydrogen Purity	% of total gas	> 99.9	>99.99999	> 99.95	>99.99

*H2 Membrane Performance Targets from September 2004 DOE Workshop


Maximum Efficiency Vs Reformate Pressure
UPH -10 psig
UPH 1 psig
UPH 15 psig
Maximum Efficiency
100%
95%
90%
85%
80%
75%
70%
65%
60%
55%
50%
Reformate - 65% Hydrogen
50
75
100
125
150
175
200
225
250
275
300
325
350
REFORMATE PRESSURE(PSIG)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UPH 15 psig
100%
95%
90%
85%
80%
75%
70%
65%
60%
55%
50%
Maximum Efficiency
Reformate - 44% Hydrogen
50
75
100
125
150
175
200
225
250
275
300
325
350
REFORMATE PRESSURE(PSIG)

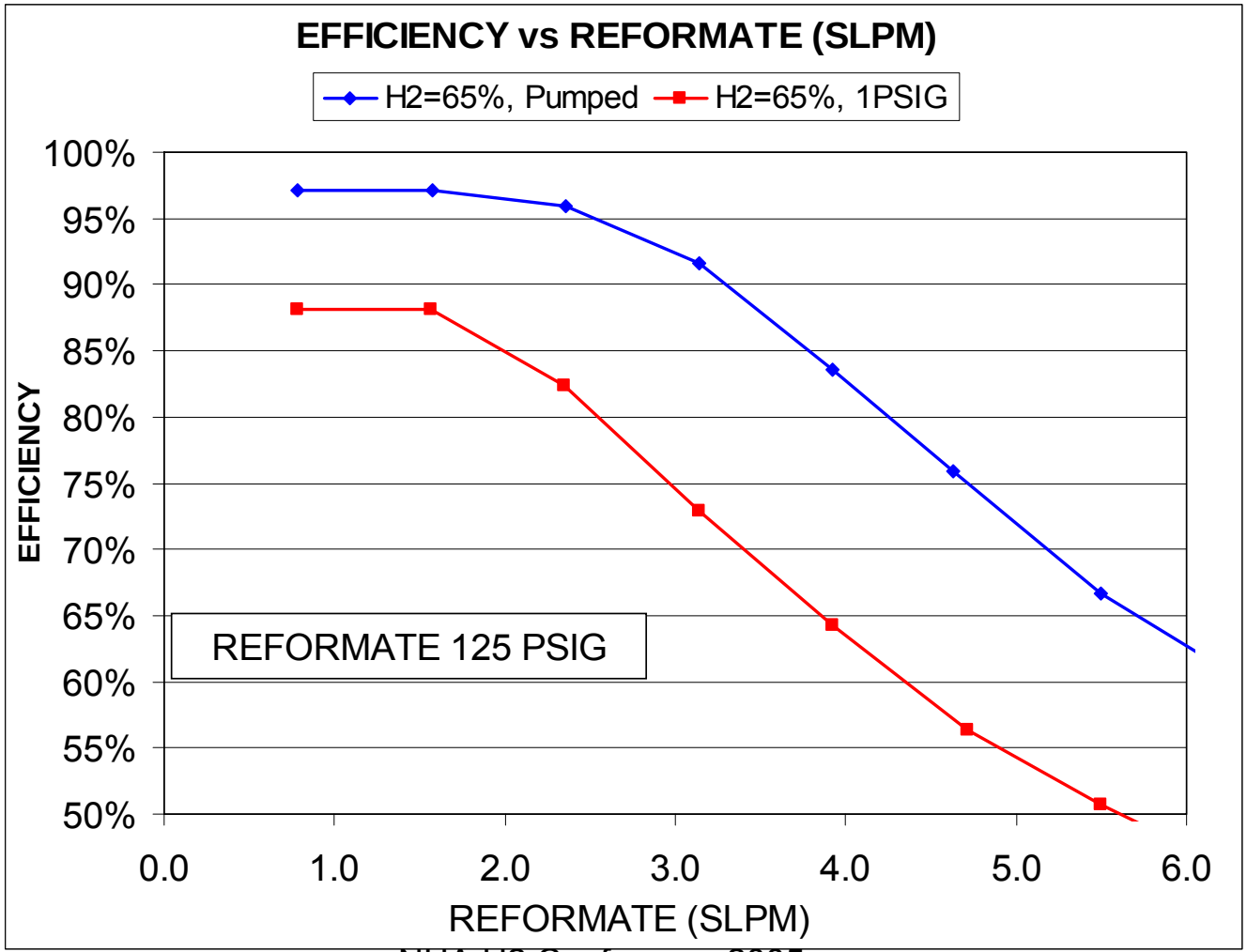
P+E Compact H2 Separator Design

- Current P+E Reformate Separator 4,700 We/liter
- NAVSEA 50KW Prototype[1] 6,500 We/liter
  (16” x 4” diameter)
- DOE criteria, 2004 System: 700 We/liter
- DOE criteria, target System: 2,000 We/liter

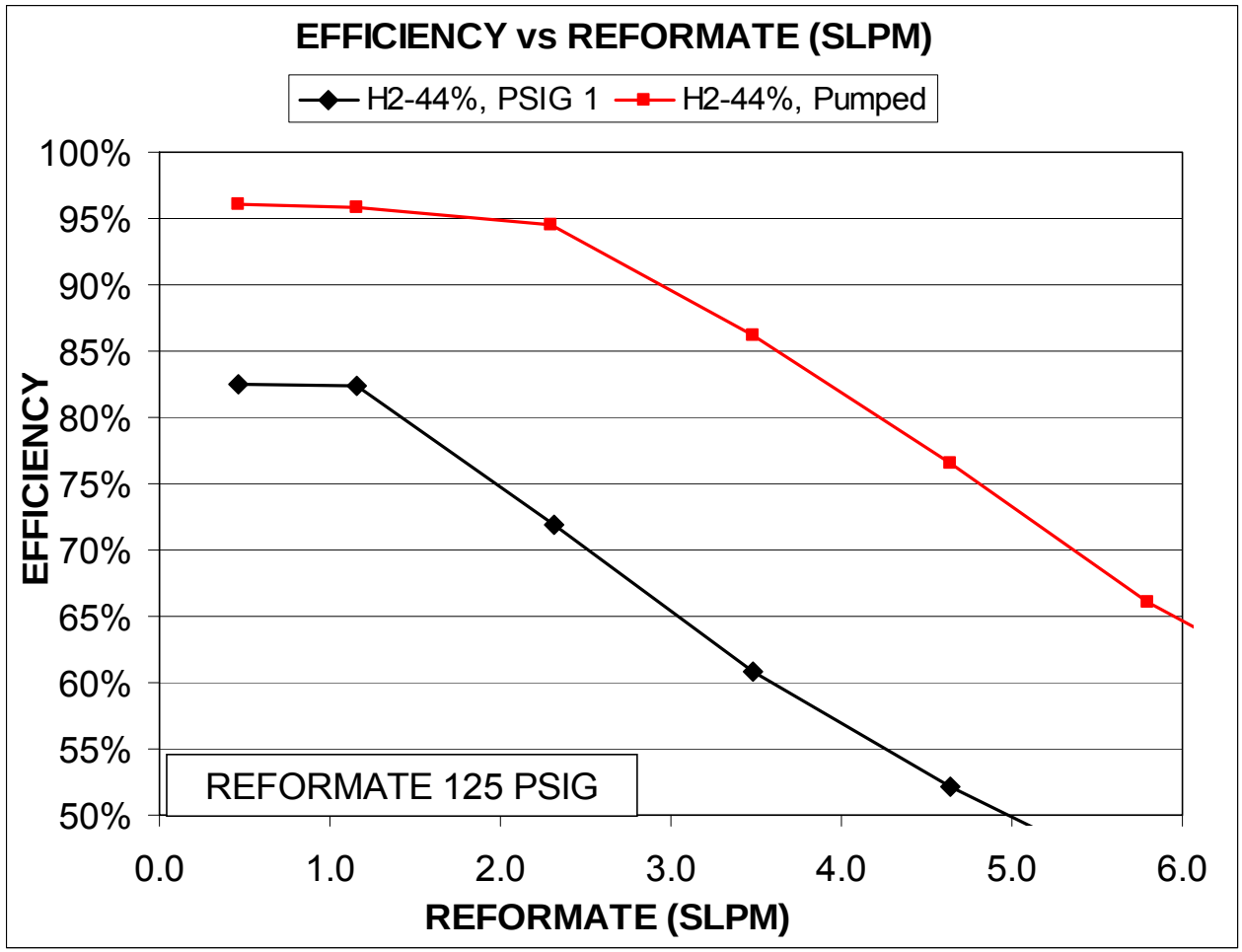
[1] Sulfur resistant, deliverable in Q4 2005

* 1 We (Watt Electrical) = 2 Watts Hydrogen

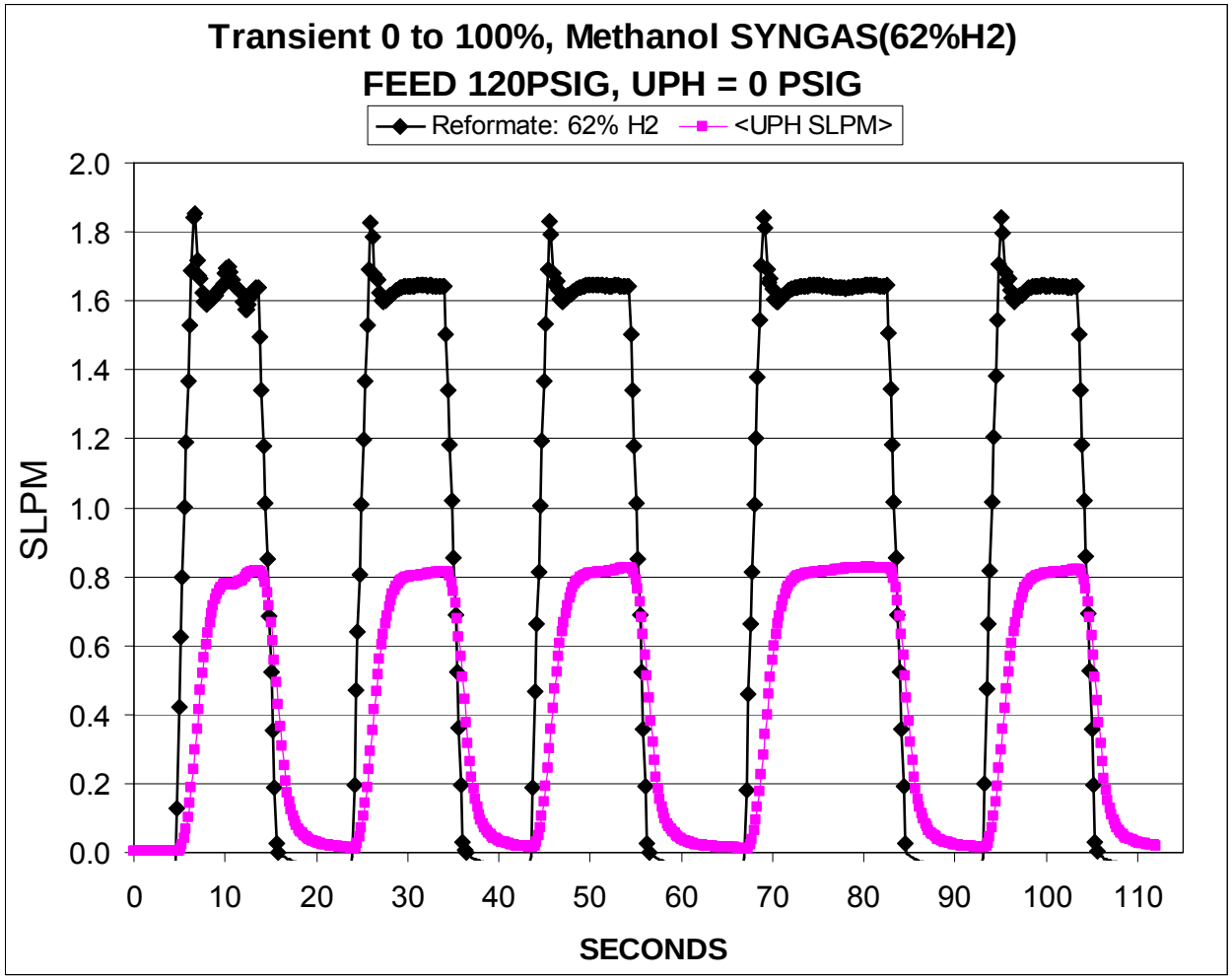
High Hydrogen Recovery Efficiency



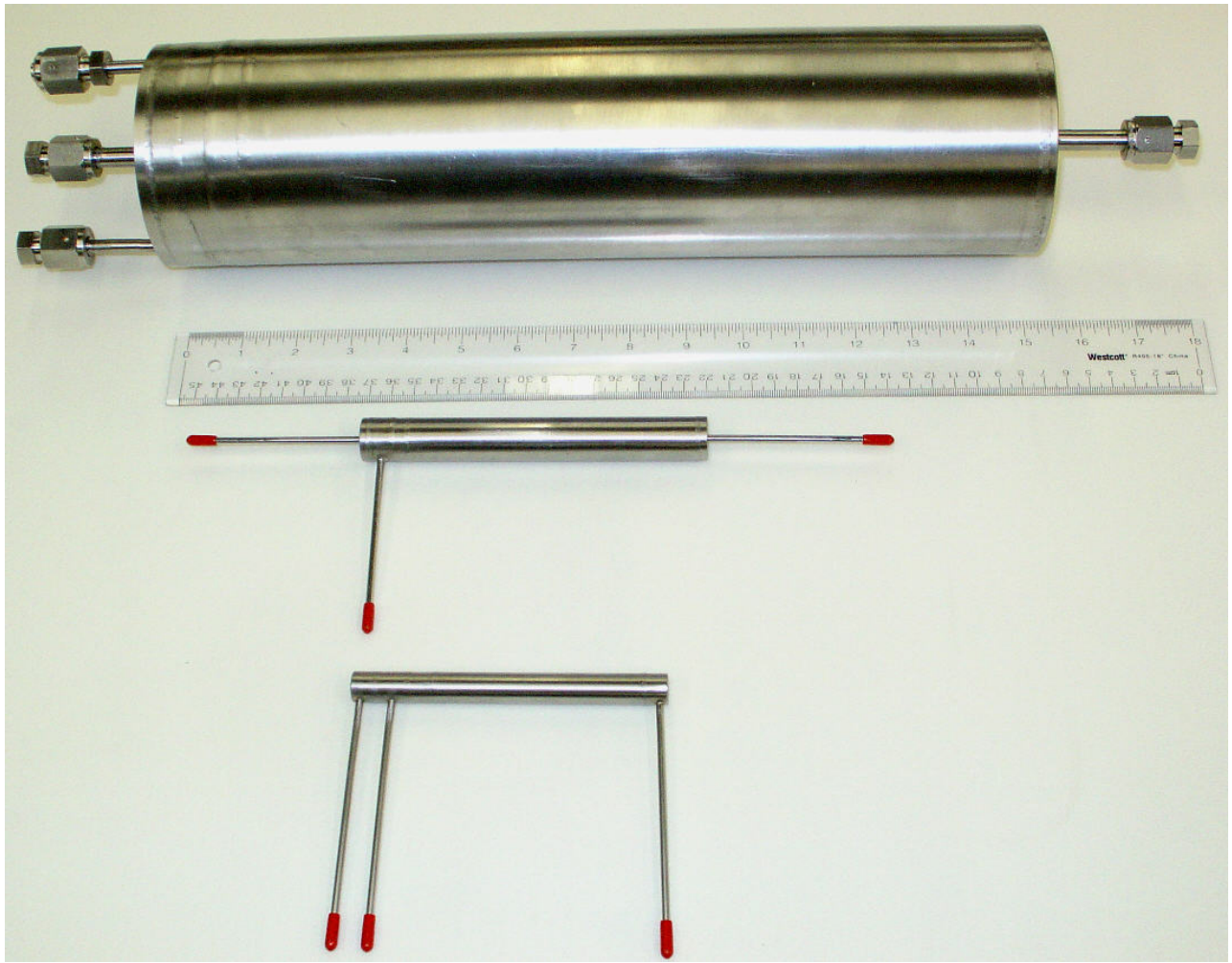
High Hydrogen Recovery Efficiency



Rapid Response to transient demands



Sample of H2 Separation Modules



Engineering Path for Improved Membrane Efficiency & Economics

- P+E has previously reported* on the development of a novel nano-structure composite membrane.
- 2-10 micron thick membrane will greatly increase flux rates, membrane cost (scf/h)
- Recent separator developments are fully compatible w/ nano composite membrane

* “A novel low-cost heated Pd membrane separator for hydrogen recovery from reformates.”

P. Bossard, J. Mettes, presented at American Chemical Society Meeting, Philadelphia 8/25/04

Summary

- Next-generation Pd alloy membranes are now available for reformate H2 separation
- Novel membrane configuration reduces membrane area and volume
- Demonstrated H2 recovery efficiencies are significantly greater than previous reports
- Novel configuration results in a durable, compact package ready for real world use

Conclusions

- DOD Leadership has supported the development of rugged, efficient membranes
- High Efficiency, durable Pd membranes are now commercially available
- Membranes will enable the use of a wide range of existing fuels as a source for H2
- Existing infrastructure for fuels can support distributed, mobile and remote power generation
- Membranes will simplify the utilization of alternative fuels as a source of hydrogen.

Navy Shipboard Fuel Cell Program

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