UUV Power System Overview

2005 UUV Power System Workshop

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Objective:

- Examine Feasibility of Existing Power/Energy Systems to Meet UUV Requirements
- Describe Desirable System Features

Conclusions:

- Current obvious energy sources don't satisfy DARPA UUV objectives.
- New Storage/Conversion systems and concepts are needed.

Outline:

- Mission Definition and System Requirements
- Options Considered
- Performance Comparisons

UUV Missions

The 2000 Navy **UUV Master Plan** identified four Signature Capabilities for UUV's:

- Maritime Reconnaissance
- Undersea Search & Survey
- Communications/Navigation Aids
- Submarine Track & Trail

http://www.chinfo.navy.mil/navpalib/technology/uuvmp.pdf

Mission Parameters and Derivation of Specific Volume

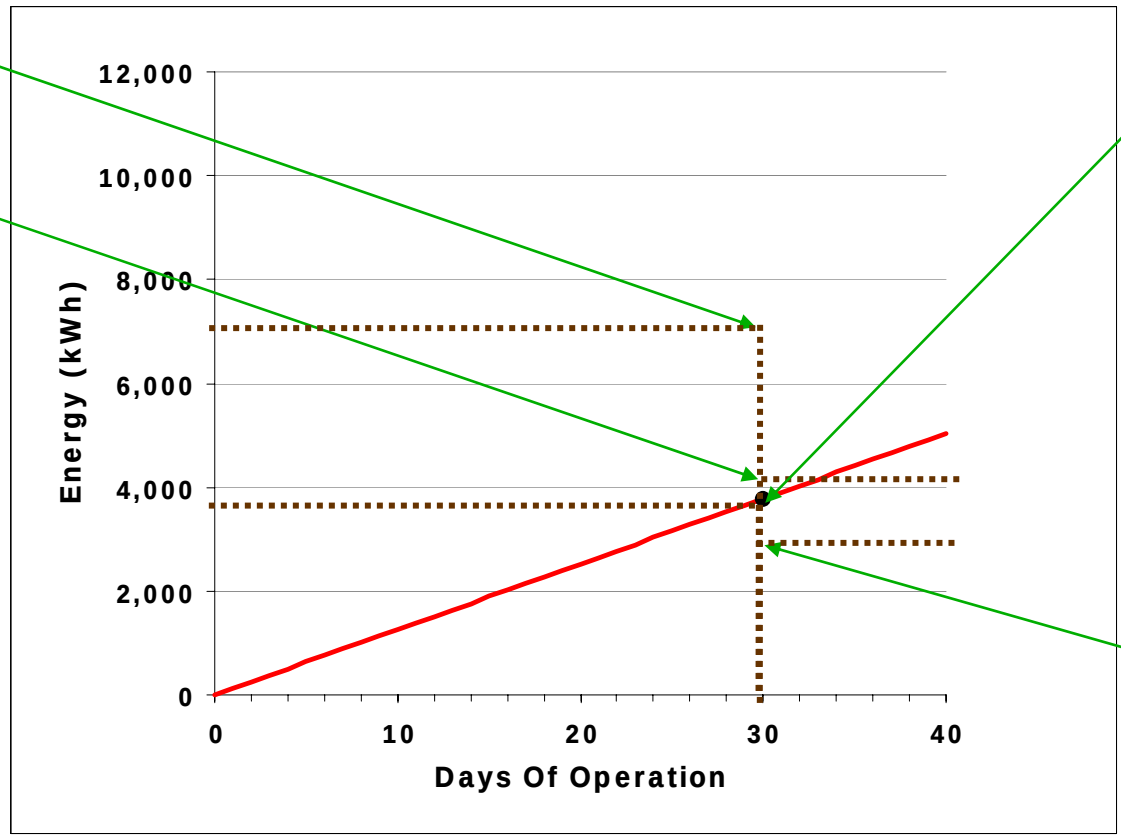
Assumptions:

- Average/Cruise Power: 5 - 10 kW
- Peak/Sprint Power: 30 - 40 kW
- Time in Sprint: ~1%
- Hull Outer Diameter: 60" (1.52m)
- Hull Length Available: 2 – 3 m
- Volume Available: 3,500 – 5,000 liters

Case 2:
10 kW Cruise
40 kW Peak
30-day mission
requires ~7.5MWh

Case 2:

requires ~1500Wh/L



Case 1:
5 kW Cruise
30 kW Peak
30-day mission
requires ~3.8MWh

Case 1:

requires ~1000Wh/L

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Desirable System Features

- Safety- Requirement
- Air Independent
- Reliable
- Rapid Start-Up
- Neutrally Buoyant System
- Low/No Observables (noise, discharges)
- Easy/Rapid Refueling
- No Hull Penetrations

Desirable System Features, cont.

- Logistic Fuels (vs. Designer Fuels)
- Cost Effective
- Dormancy/Long Hold-Time
- Long Shelf Life
- Scaleable to wide range of sizes/powers
- Wide set of operating environmental conditions

How Do Batteries Compare?

Battery Type	Specific Energy	Energy Density	Specific Gravity	Neutrally Buoyant Energy Density
	Wh/kg	Wh/L	g/cc	Wh/L
Ag/Zn Rechargable	110	115	1.0	110
Li Polymer Secondary	107	197	1.8	107
Rechargeable Li Ion	124	151	1.2	124
Primary LiSOCl2	305	325-408	1.1-1.3	~307

Current Batteries achieve <30% of Goal Energy Density.

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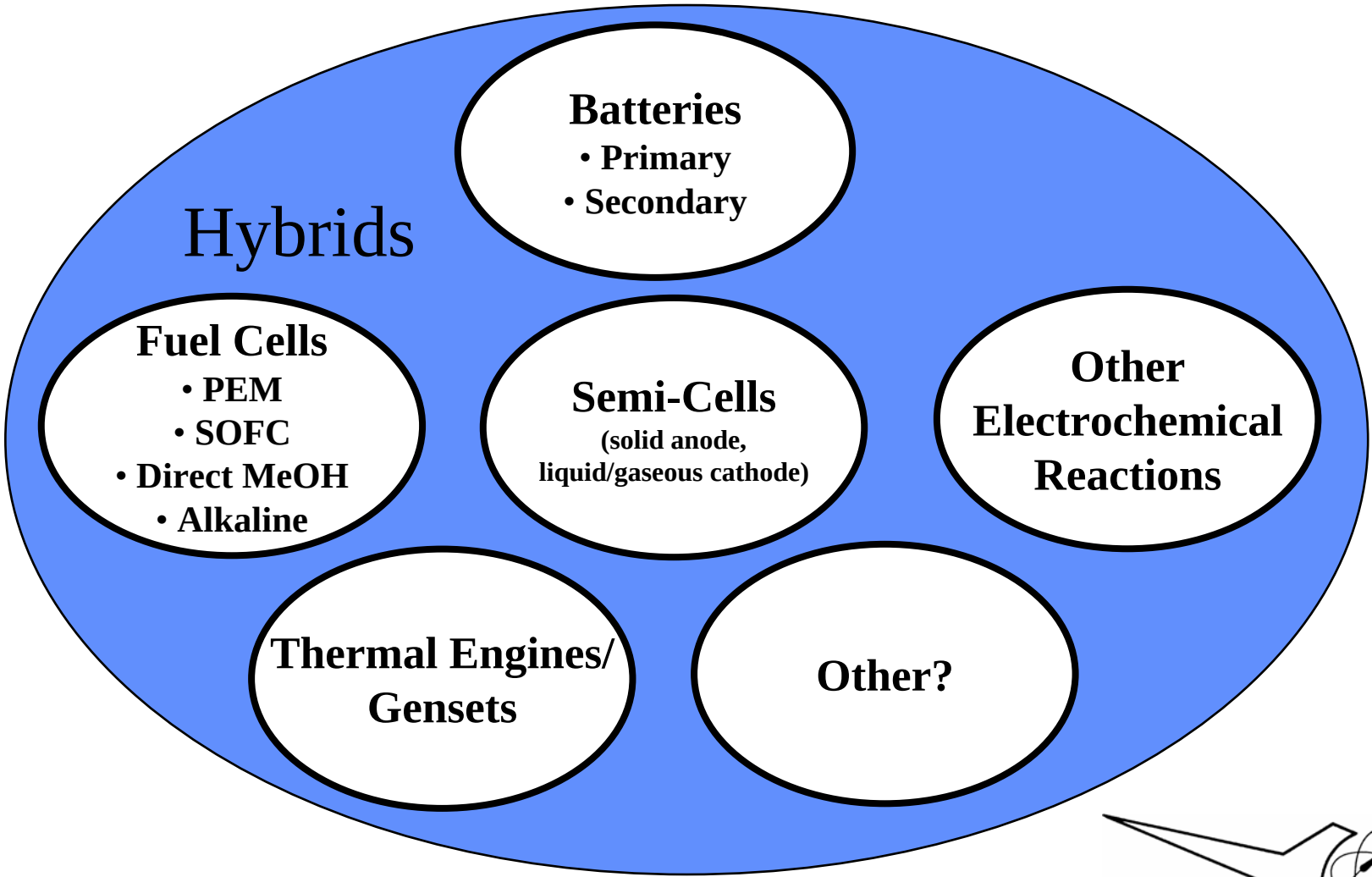
Converter Technologies

Converter efficiency is vital since reactant mass & vol >> converter mass & vol.



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Candidate Fuels

- Pure Hydrogen
  - Gaseous H_2, 5kpsi and 10+kpsi
  - Liquid H_2 (1 Atm, 20 K)
  - Supercritical
- Reversible Hydrides
- Chemical Hydrides
  - Dry Hydrides
  - Slurry/Dissolved Hydrides
- Reformed Hydrocarbons
  - Methanol
  - JP8/Kerosene
  - Butane/Propane
- Thermal Decomposition Fuels

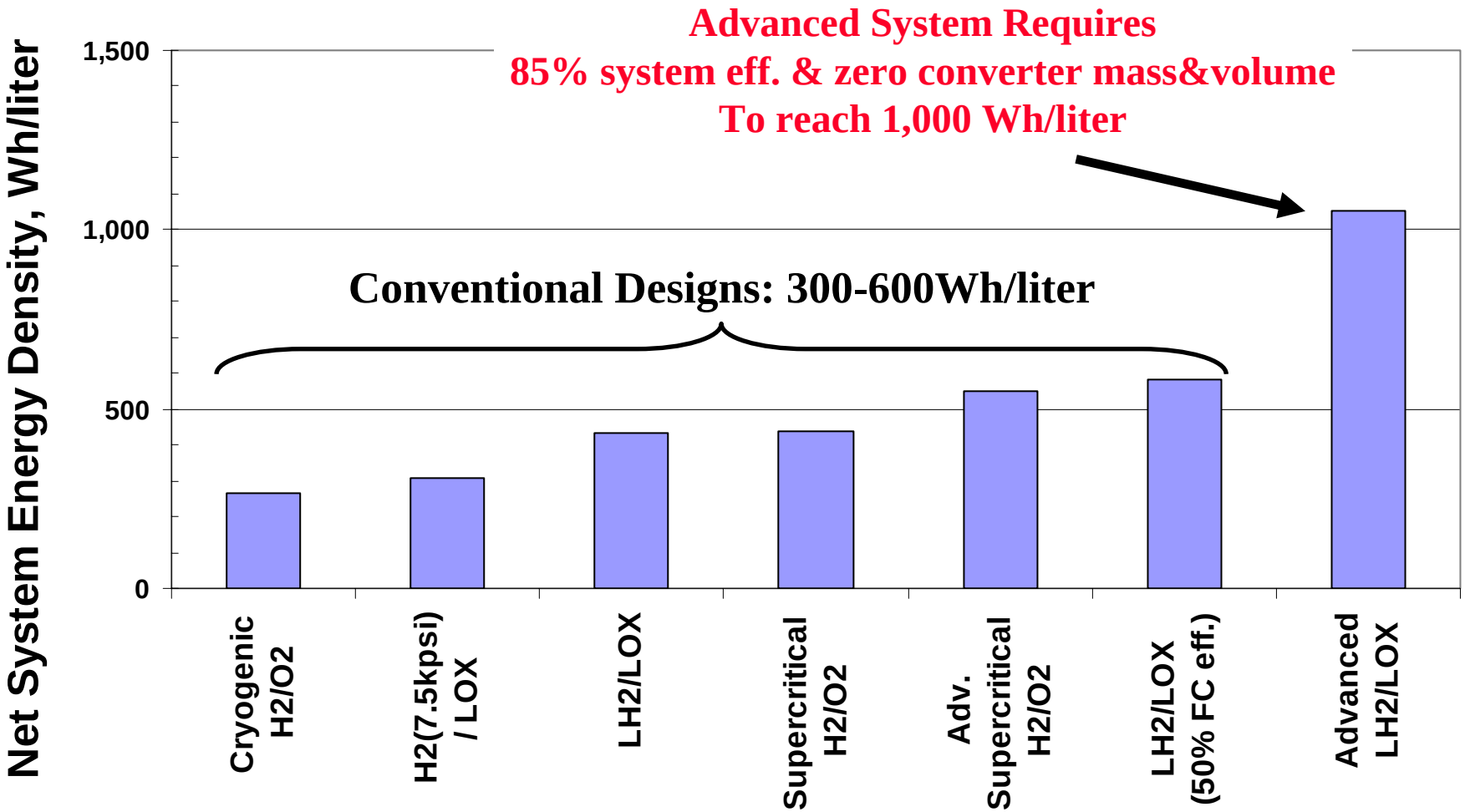
Oxygen Supply Options

Oxidant Type	Effective Oxygen Density (kg O_2/m^3 of system)	(g of O_2 / cc of system)	System Density (kg/m^3)	(g/cc)
Gaseous O_2 (300K) @ 5 kpsi	355	0.36	539	0.54
Gaseous O_2 (300K) @ 10 kpsi	497	0.50	803	0.80
66% H_2O_2	320	0.32	1,153	1.15
Sodium SuperOxide (NaO_2)	368	0.37	961	0.96
90% H_2O_2	497	0.50	1,297	1.30
Chlorate Candles	657	0.66	2,002	2.00
LOX in 10 kpsi Vessel	945	0.95	1,330	1.33
Nitrogen Tetroxide (N_2O_4)	977	0.98	1,586	1.59
LOX (1%/day Boiloff)	1,057	1.06	1,073	1.07
Liquid Ozone	1,490	1.49	1,506	1.51

System Configurations

- Multiple fuel/oxidant systems considered
- Each is ~5,000 liters total volume
- All neutrally buoyant
- Not rigorous designs but approximate

Fuel Cell: Pure H_2



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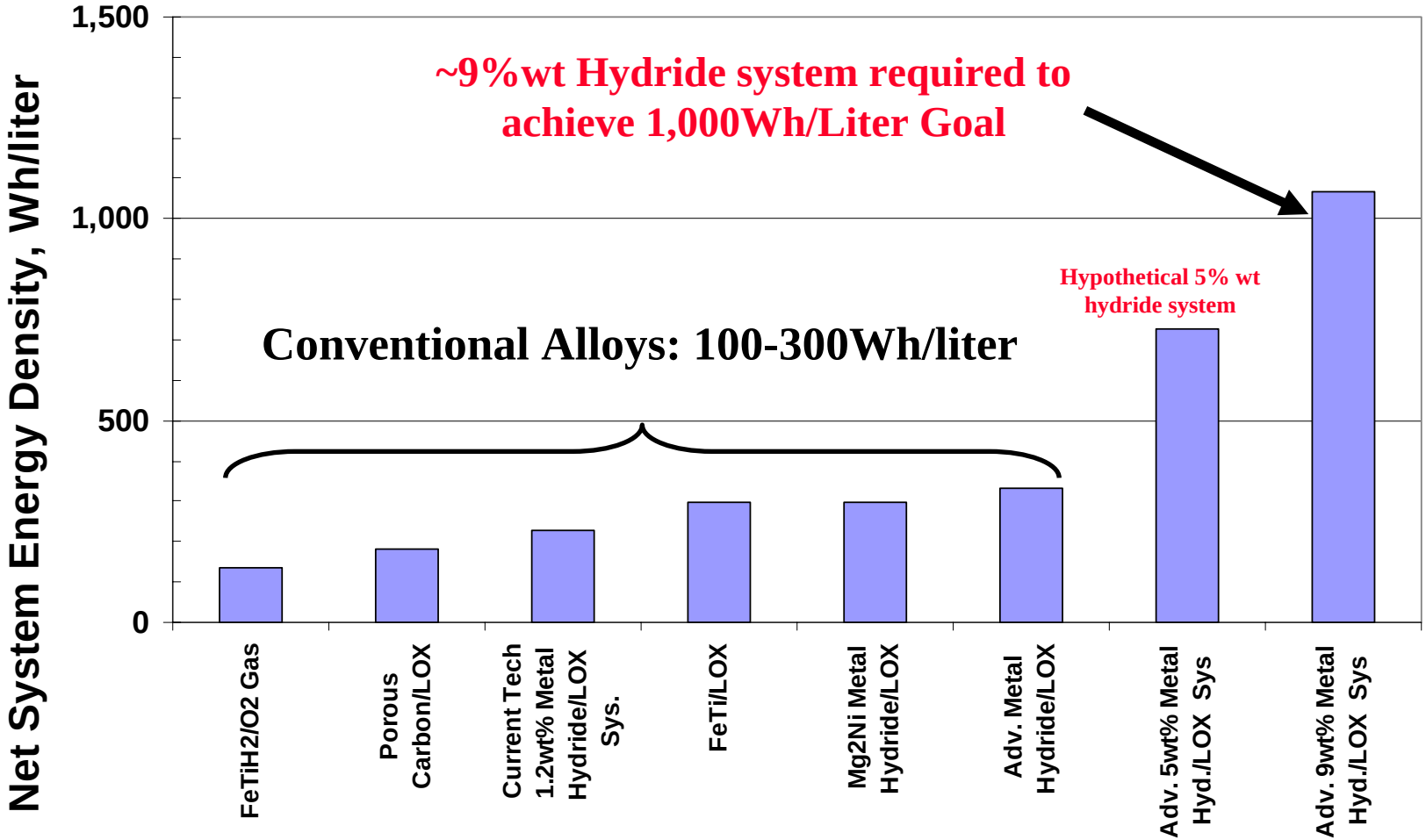
Fuel Cell: Metal Hydrides



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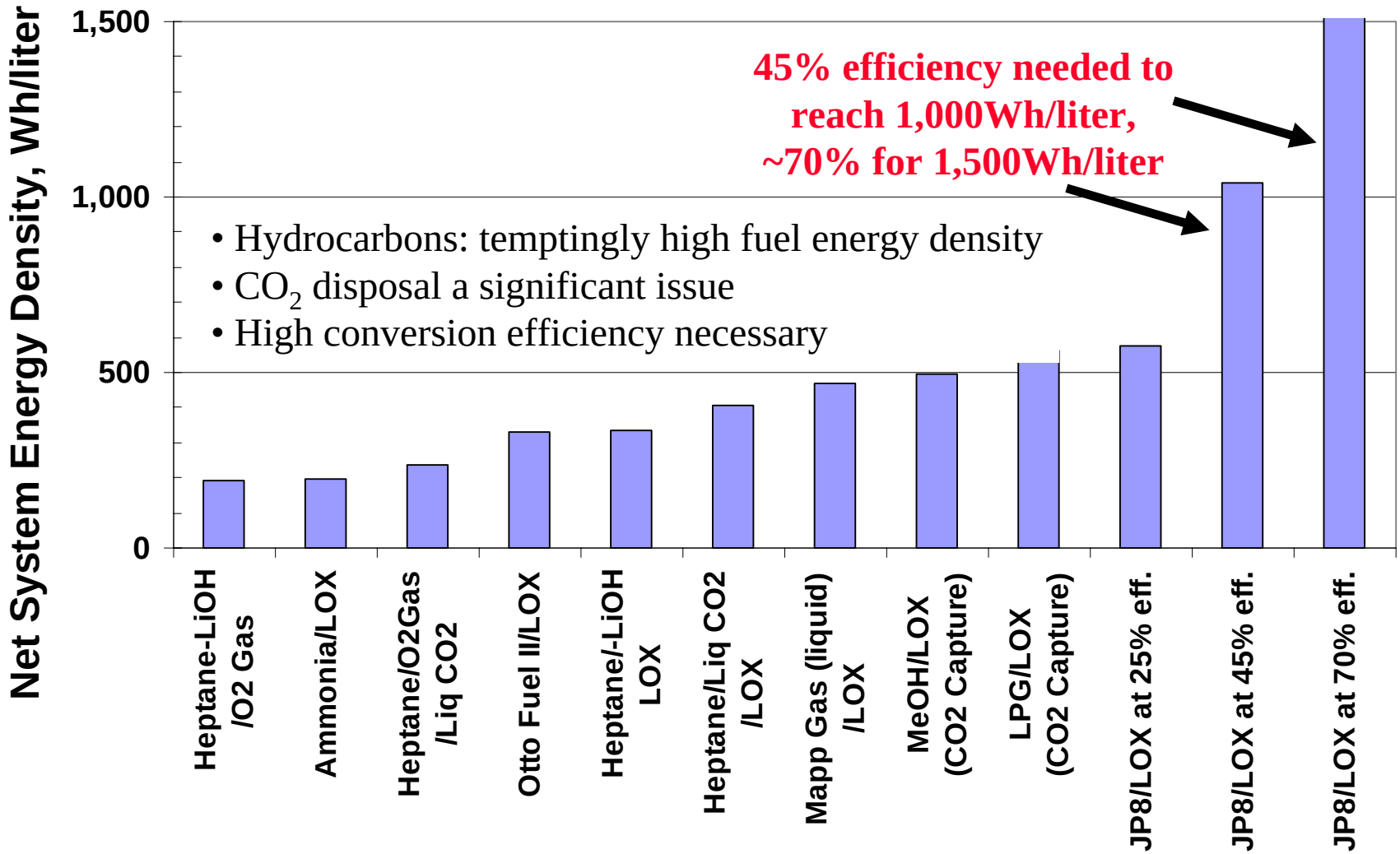
Fuel Cell: Hydrocarbons



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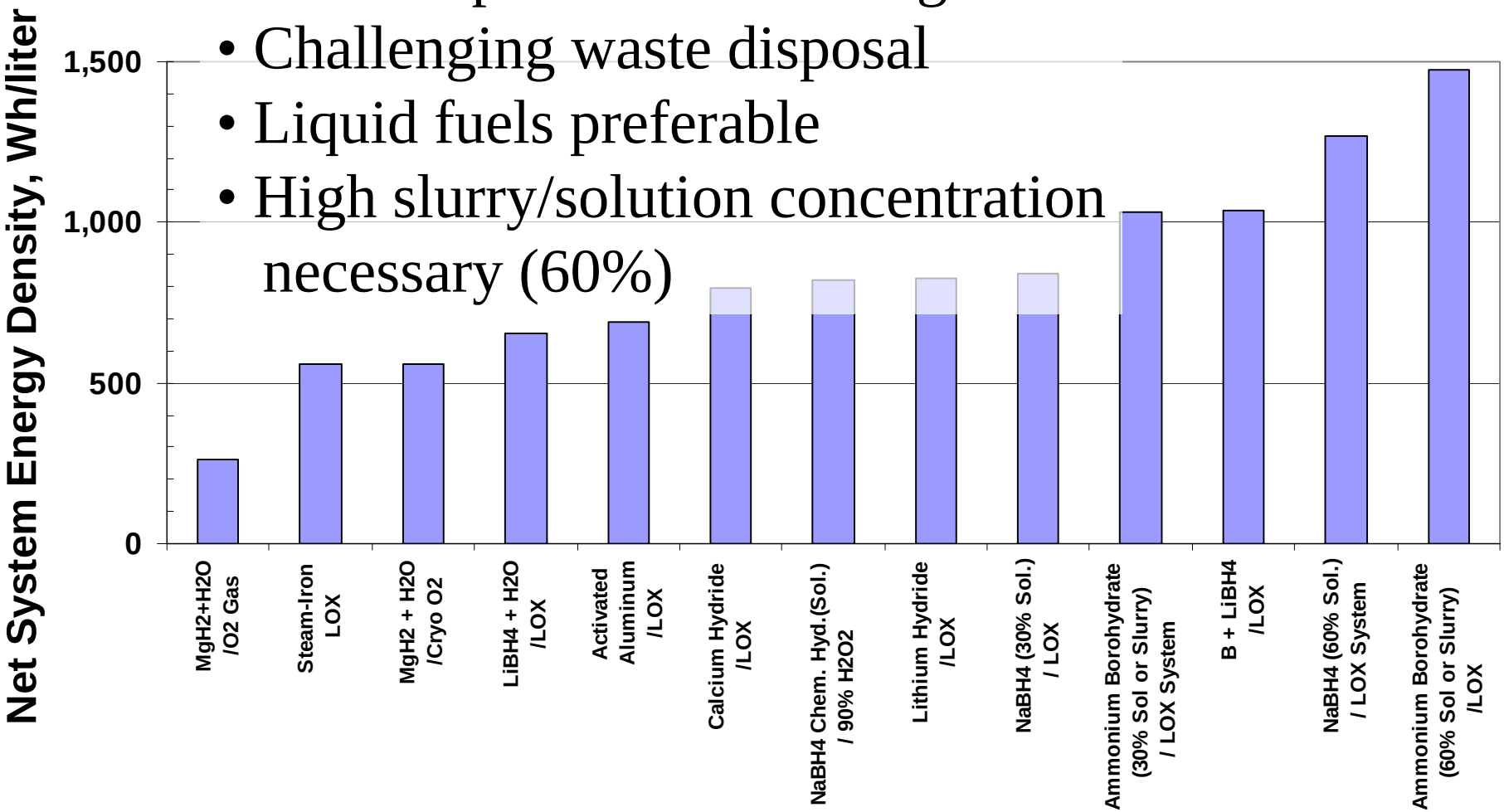
Fuel Cell: Chemical Hydrides

- Many hydride options
- Definite potential to make goals
- Challenging waste disposal
- Liquid fuels preferable
- High slurry/solution concentration necessary (60%)



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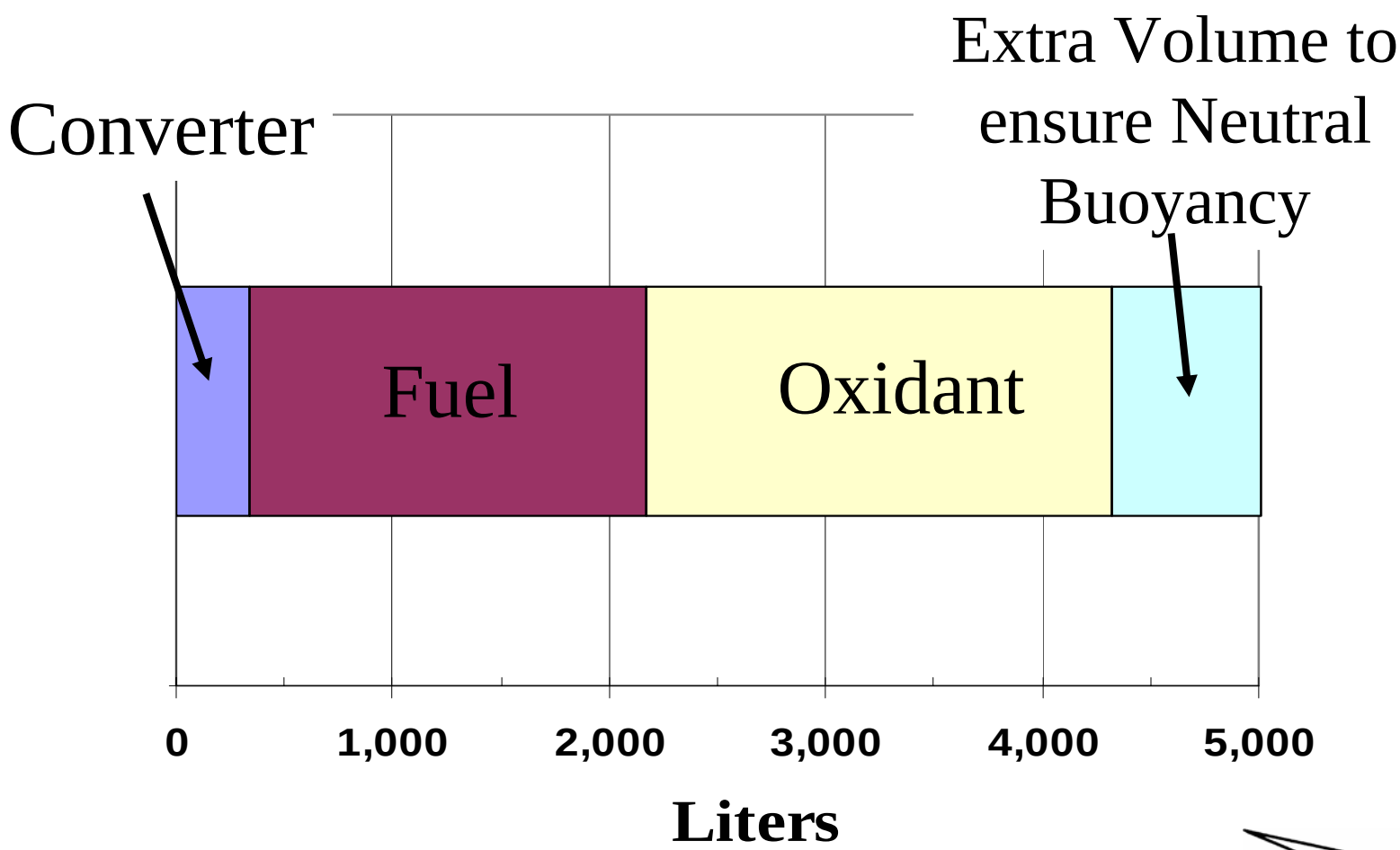
Typical Volume Distribution within Power/Energy Hull Section



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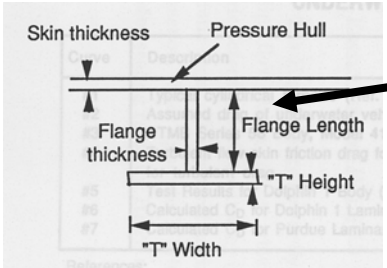
Design Elements to Consider

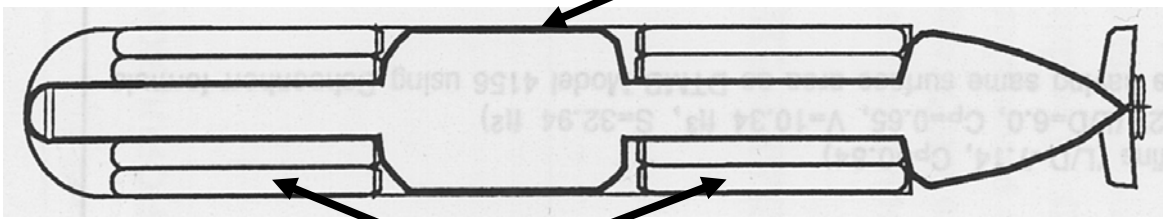
Use of Inner Rib Volume



Volume between pressure vessels ribs can be used for storage

Hull Fairing for Storage of Liquid Reactants

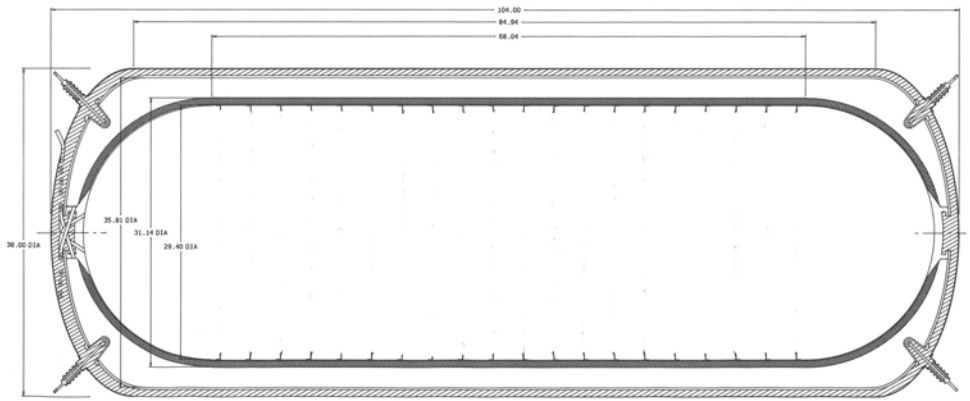
Darker Line Denotes Hull



Wetted Fuel/Oxidant Volume External to Hull

Tank-in-a-Tank

- **Better volumetric storage**
- **Reduces wall thickness for highly pressurized systems**
- **Reduces insulation/boil-off for cryogenic systems**



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Closing Thoughts

- Standard configuration & fuels won't make the goals.
- Purpose is not to dictate system solutions but to highlight issues. Also alerts you to how systems may be judged.
- Conversion efficiency important: reactants dwarf converter mass/vol.
- Exploit asymmetries in subsystem densities to improve overall performance.
- Be innovative.
- "Think Outside the Box, but Inside the Hull".

Questions?

References Consulted

1. "Fuel Cells in Underwater Vehicles: Requirements, Restrictions, Research", Maria G. Medeiros, Naval Undersea Warfare Center, presented at the NHA Annual Hydrogen Conference, March 29- April 1, 2005.
2. "The Navy Unmanned Undersea Vehicle (UUV) Master Plan", 9 November 2004, available at http://www.chinfo.navy.mil/navpalib/technology/uuvmp.pdf
3. "Submarine Auxiliary Fuel Cell Power System Study", Alfred Myers Program Manager, Final Technical Progress Report, Part 1, prepared for NASA Lewis Research Center by International Fuel Cell Corporation, 15 May 1990.
4. "Power Sources for Unmanned Underwater Vehicles", A. Lee, B.D. James, I. F. Kuhn Jr., G. N. Baum, Directed Technologies Inc., Sea Technology, October 1989, pages 25-32.
5. "Closed Cycle Submersible Power Systems, Phase 1", prepared for US Navy Naval Sea Systems Command, by Hydrogen Consultants Inc., Frank Lynch Principle Investigator, October 1989.

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