U.S. Navy Shipboard Fuel Cell Program

U.S. Maritime Administration Workshop on Maritime Energy and Clean Emissions

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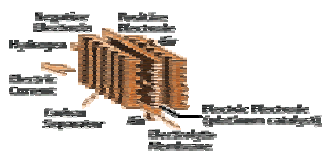
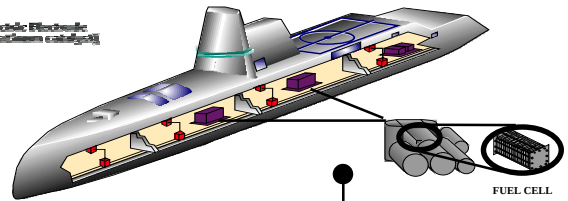
The St. Regis
Washington, DC

Edward House
Naval Sea Systems Command
Philadelphia, PA, USA

Fuel Cell Markets

Fuel cell power system markets could soon exceed $3 billion worldwide*



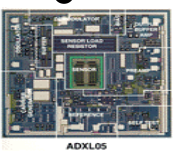


UUV/MCM

10^0 10^1 10^2 10^3 10^4 10^5 10^6 10^7

Power (Watts)

MEMS



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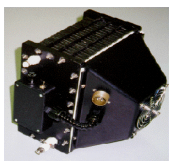


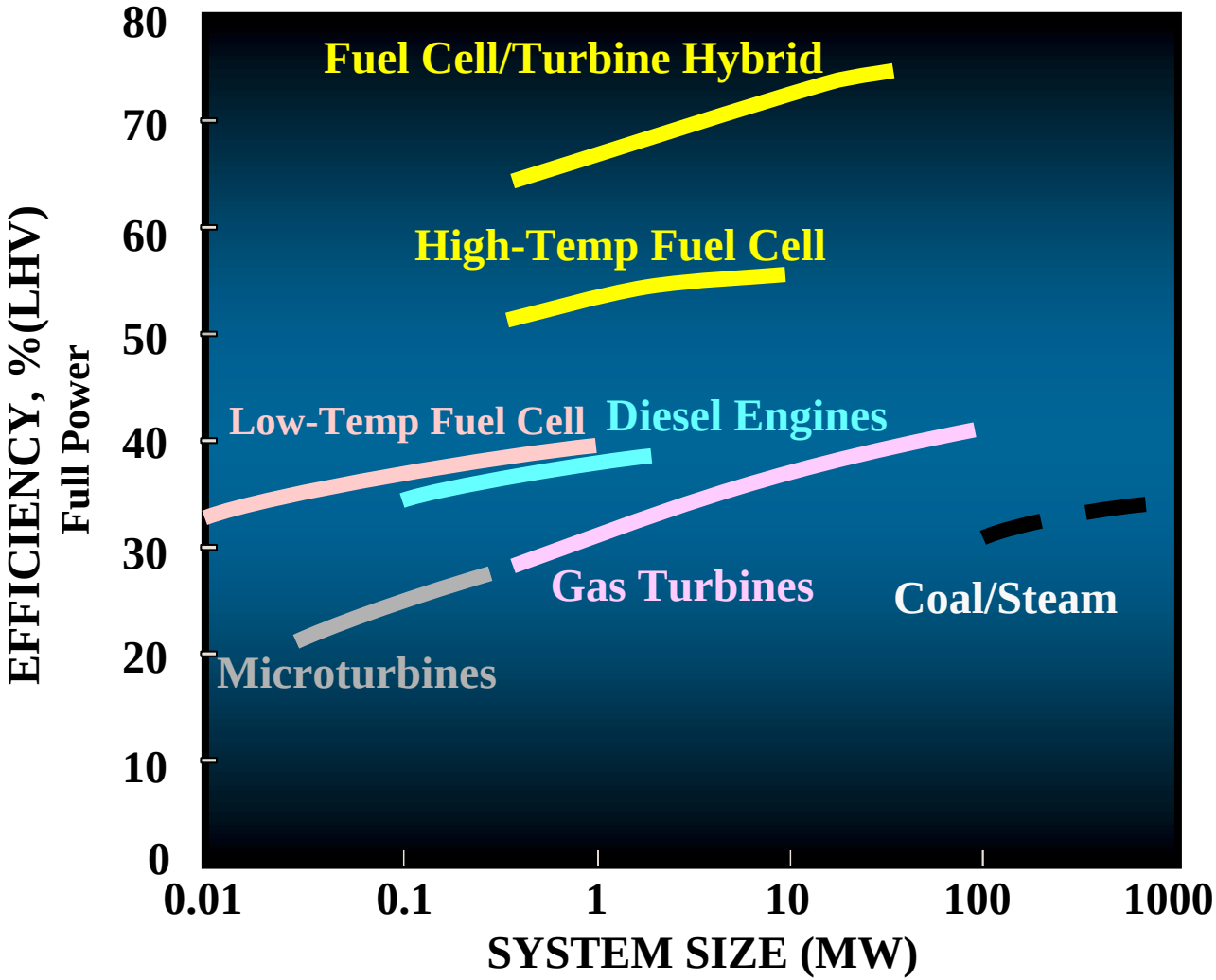
Home Electricity

UAV

Stationary Power

*Arthur D. Little, Inc, Cambridge, MA, reference #44335.

COMPARISON OF EFFICIENCIES FOR ELECTRIC POWER PLANTS



NAVSEA
NAVAL SEA SYSTEMS COMMAND

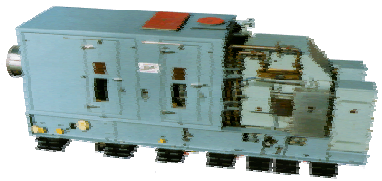
Fuel Cell Types

	Electrolyte	Cell Temp (°F)	Lifetime Projected (Hrs)	Cell Contaminant	Single-Cycle Electrical Efficiency (%)
Proton Exchange Membrane (PEM)	Polymer Membrane (Solid)	180	40,000	S, CO	35-40
Alkaline (AFC)	Potassium Hydroxide (Solid)	200	10,000	CO, CO2	<40
Phosphoric Acid (PA)	Phosphoric Acid (Liquid)	450	40,000	S,CO	35-40
Molten Carbonate (MC)	Potassium Lithium Carbonate (Liquid)	1200	40,000	S	45-55
Solid Oxide (SO) [Tubular, planar, monolithic]	Zirconium Dioxide Ceramic (Solid)	1800	40,000	S	45-60

Annual Fuel Consumption

(3,000 Operating Hours)

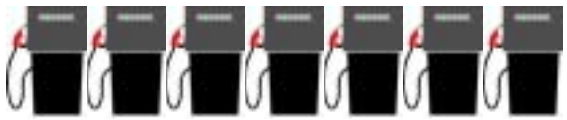
DDG51 Gas Turbine Generator Set



641,465 Gallons

$628,636

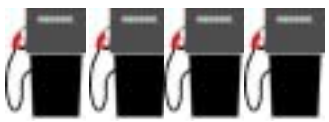
AOE6 Diesel Generator Set



321,703 Gallons

$315,268

Ship Service Fuel Cell



214,315 Gallons

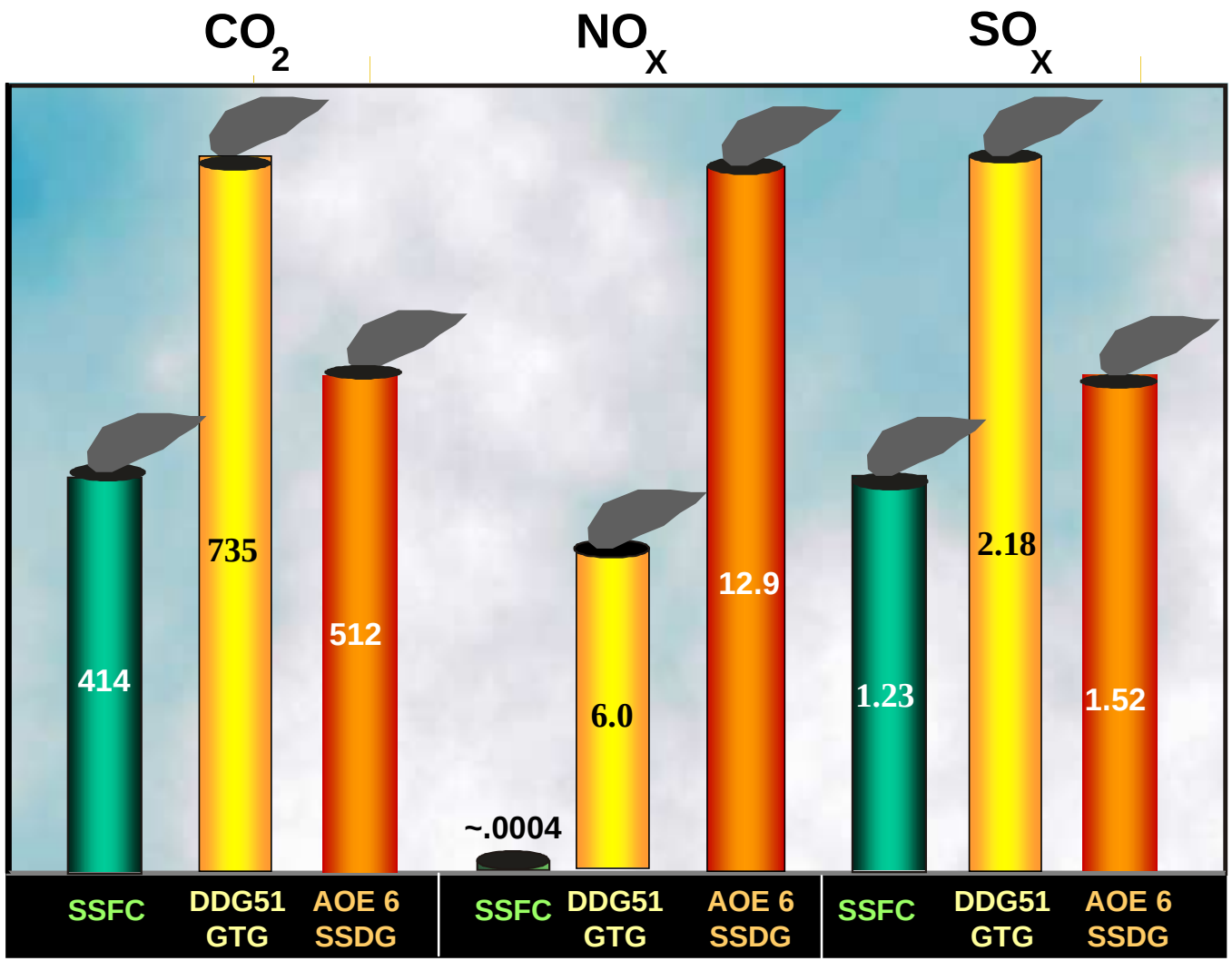
$210,028

 = 50,000 gallons; ($.98/gallon)

Navy Shipboard Fuel Cell Program

EMISSION COMPARISON

(gm/HP Hr @ 100% Power)



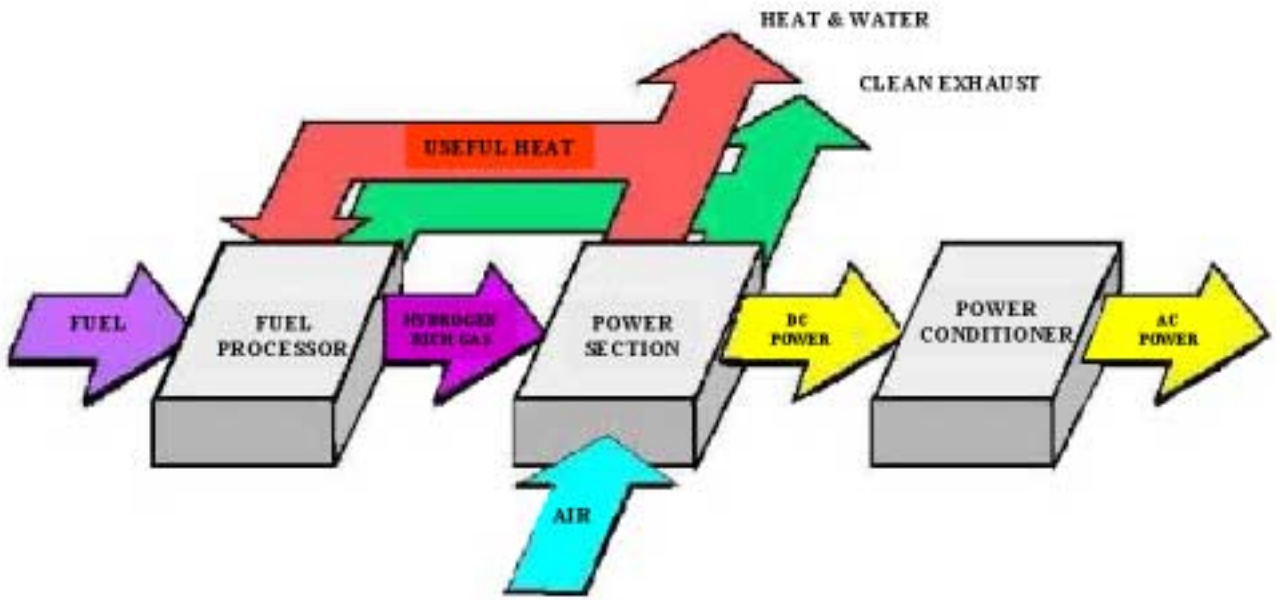
Navy Shipboard Fuel Cell Program

Fuel Cell Design Comparison

Design Issues	Ships	Land Transportation	Utility
Power Density	High	High	Low
Fuel Type	Navy Distillate	Gasoline/H2/ Methanol	Natural Gas/ Coal Derived
Life, MTBO	40,000 Hrs	< 5 Years	40,000 Hrs
Dynamic Response	High	High	Low
Operating Environment	Severe	Moderate	Benign

FUEL CELL POWER PLANT

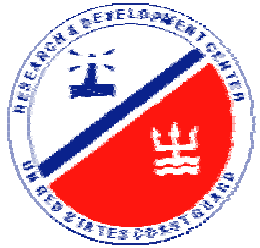
- FUEL CELL POWER PLANT INCLUDES:
  - FUEL PROCESSING
  - FUEL CELL STACK
  - DC-TO-AC POWER CONVERSION



Significant Market Survey Results

- Marine Market Surveys for fuel cell power sources by MTI for PEM systems and FCE for MC systems conclude:
  - Ship Service fuel cell generators for both commercial and military marine markets compete economically with small turbines and marine diesels in terms of life cycle cost.
  - Diesel-fueled fuel cell ship service generator system for commercial marine applications (98% of total market) will be in the 200 kW to 1 Mw range; military applications (2%) in the 500 kW to 2.5 Mw range.
  - Diesel-fueled commercial and military surface ship markets represents a significant potential market; circa 2005.
- Independent USCG marine market survey validates conclusions.
- DOE/Industry also project future higher power, ultra-high efficiency fuel cell power systems adaptable for marine high power propulsion applications

Viable Commercial Marine Market leads to CONTRACTOR COST SHARED Phase II SSFC Demonstration Program



Ship Service Fuel Cell Program

FuelCell Energy

Program Summary

Objective: Develop shipboard fuel cell power systems with acquisition cost, weight, and volume comparable to other market options, for future Navy ships and craft.

State of the Art: Industry is developing fuel cell technology for stationary and non-marine transportation applications operating on non-logistics fuels. Commercial units expected between 2001 and 2005, with stationary systems available before automotive systems. Little effort in diesel reforming.

Approach: Develop fuel cell power systems and components to enable commercial fuel cell equipment to be used in the unique Naval shipboard environment.

Technical Challenges

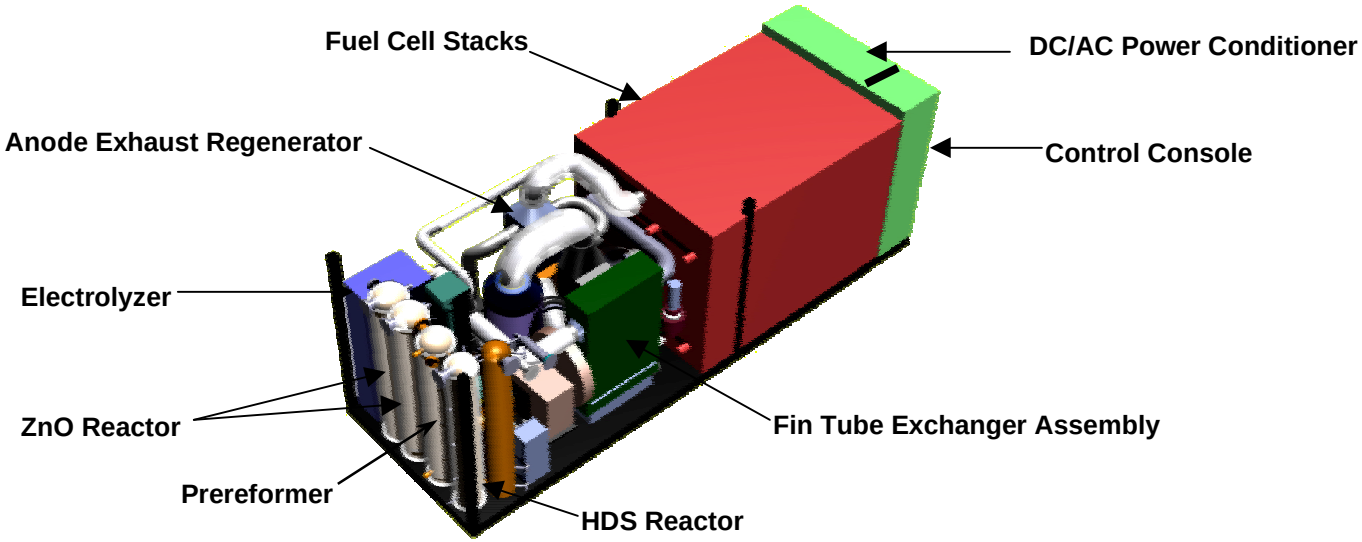
- Fuel Type
  - ✓ Logistic & Alternate Fuel reforming
- Power Density, Cost & System Efficiency
- Reliability and Maintainability
- Duty Cycle/Transient Response
- Marine Environment
  - ✓ Cell Life
  - ✓ Environmental Contaminants
  - ✓ Shock & Vibration
  - ✓ Ship Motions

Goals

	DDG-51 GTG	AOE-6 SSDG	SSFC Goals *2005*	HPFC Goals *2010*
Unit Volume (ft3/kW)	1.1	2.84	2	1.7
Unit Weight (lb/kW)	27.2	36.4	40	30
Fuel Efficiency (at 50% load)	16%	32%	40%	70%
Acquisition Cost ($/kW)	1600	480	1500	1200
Scalable to: (MW)	-	-	3	20

GTG: Gas Turbine Generator
SSDG: Ship Service Diesel Generator
SSFC: Ship Service Fuel Cell Program
HPFC: High Performance Fuel Cell Program

S&T Demonstration / Accomplishment



FuelCell Energy 625kW 450V, 3ϕ , 60 HZ, MC SSFC Power System

PHASE I: Complete FY00

- 2.5 MW SSFC Conceptual Design
- Sub-scale risk reduction demonstrations
  - Cell salt air tolerance
  - NATO F-76 diesel fuel reforming
  - Fuel contaminant removal and cell sensitivity (sulfur)
  - Cell shock and vibration
- Analytical model
- Marine/Navy market surveys

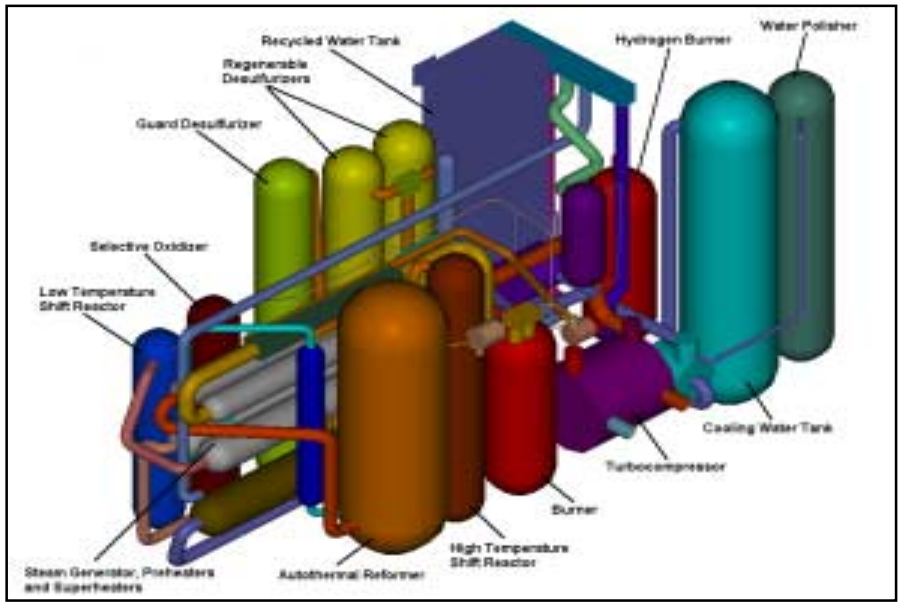
PHASE II:

- 625kW SSFC module detailed design
- 625kW SSFC module fabrication
- Factory testing
- Dynamic simulation model
- IPS program transition planned – ship impact/cost studies underway
- LABEVAL (FY04)

PHASE III:

- At-Sea demonstration (FY05)

S&T Demonstration / Accomplishment



McDermott Technology 500kW SSFC Integrated Fuel Processor (IFP)

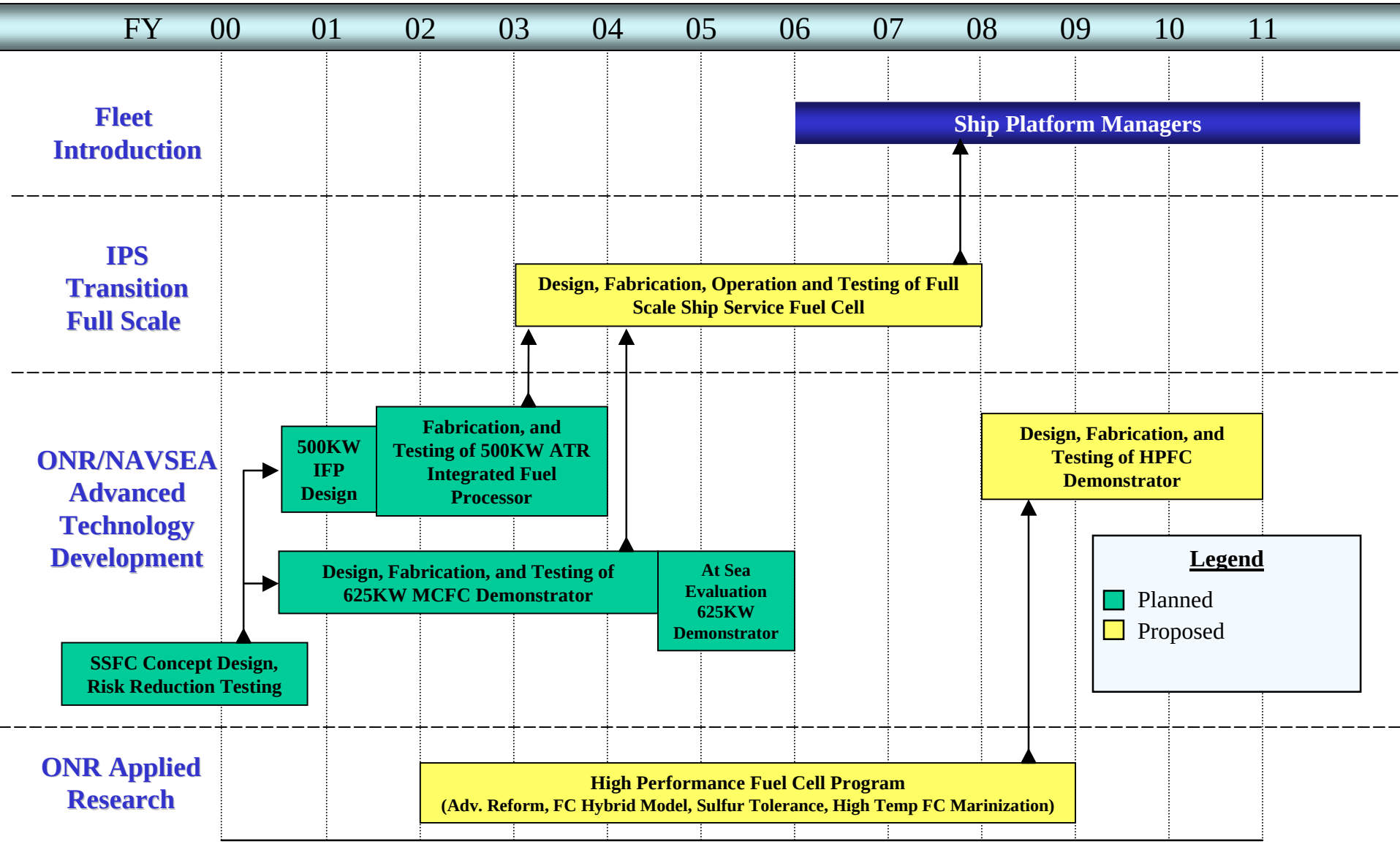
PHASE I: Completed

- 2.5 MW *PEM SSFC* Conceptual Design
- Sub-scale risk reduction demonstrations
  - Cell salt air tolerance
  - NATO F-76 diesel fuel reforming
  - Fuel contaminant removal and cell sensitivity (sulfur, CO, ammonia, amines)
  - Cell shock and vibration
- Analytical performance model
- Marine/Navy market surveys

PHASE II:

- 500kW IFP preliminary design
- 500kW IFP detailed design
- 500kW IFP fabrication
- 500kW IFP factory testing
- Dynamic simulation model

Program Timeline/Transition



Naval Fuel Cell Development Center

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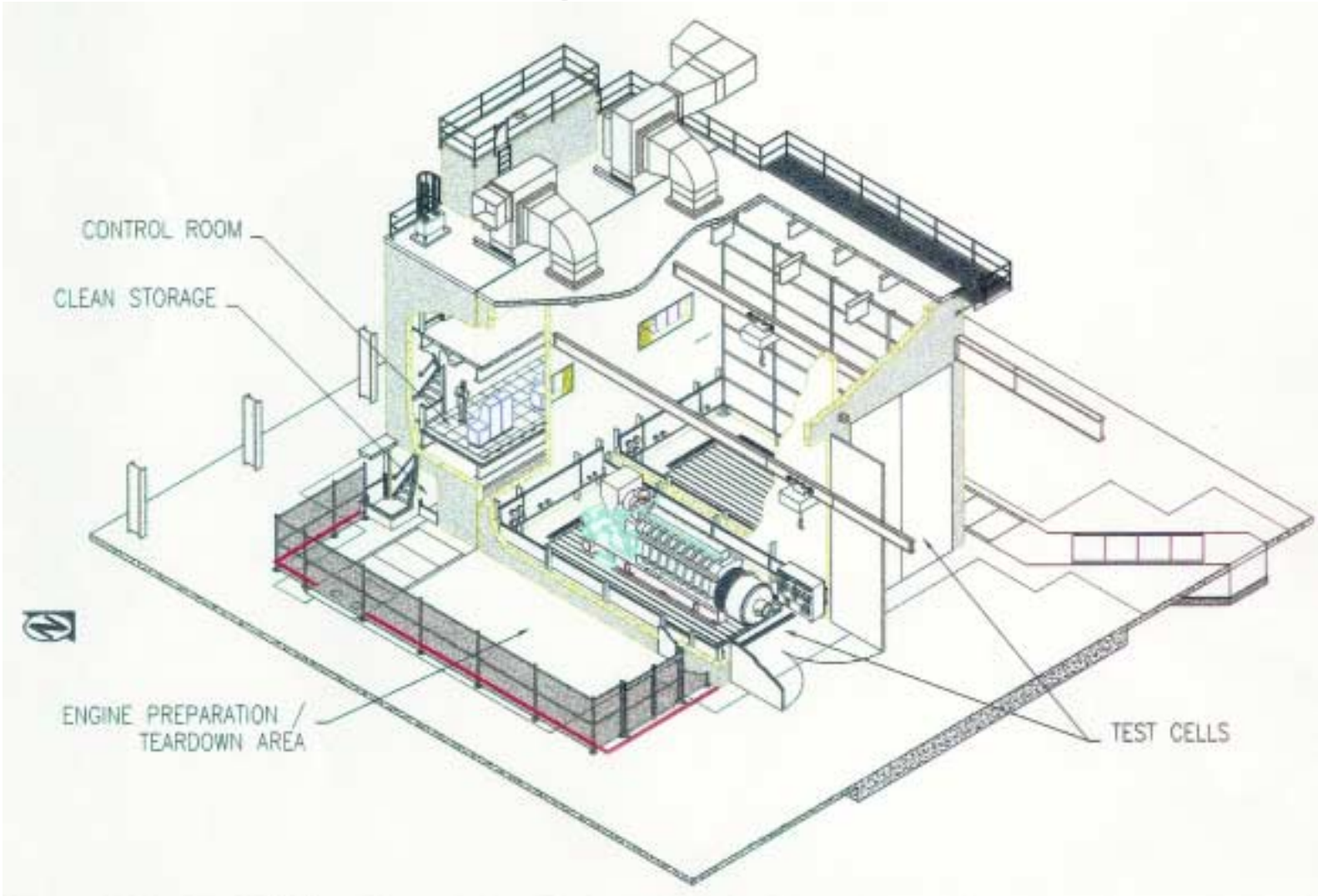
Diesel Engine Test Facility



Milcon P-104 Test Cell
Hybrid Gas Turbine / Fuel Cell Test Site

GT MILCON P-104

PROJECT SUMMARY

- SCOPE: - construct a complete facility for testing propulsion and auxiliary gas turbines in the 30,000 HP range & fuel cells both alone and in hybrid cycle tests
- COST: $10.6M
- FOOTPRINT: 8200 FT^2
- LOCATION: Building 633
- Design: FY01
- Construction: FY02

Transition Benefits

Affordability

- Ship Service Fuel Savings of ~30% (>$1M / yr / Navy Ship)
- Workload savings due to Unattended Operation and Reduced PMS

Performance

- Fuel Cells inherently Meet Future Air Emission Limits (96% Reduction in NOx, CO and HC)
- Enables reduction of Radar Cross Section and Infrared Signature

Ship Design Flexibility

- Modular Approach Applicable to all Ship Power Requirements
- Applicable to Multiple Platforms
- Facilitates All-Electric Ship with Integrated Power System and Zonal Electrical Distribution System
- Reduces Intake and Exhaust Ducting Volume by 60%
- Permits use of alternate non-petroleum fuels

Original Signatories MOU Approval 2 February 1998

RADM John T. Tozzi
Assistant Commandant for Systems

RADM G. Gaffney, II
Chief of Naval Research

RADM M.T. Coyle
Deputy Commander for Engineering

MISSION STATEMENT:

- **Foster the use of Fuel Cells for ship applications utilizing diesel fuels to fulfill national transportation needs.**
- **Transfer the technology to the public.**
- **Actively involve industry in the development efforts.**
- **Reduce duplicative efforts - coordinate/cooperative on marine fuel cell requirements.**
- **Demonstrate the effectiveness of focused interagency partnership.**

Diana H. Josephson
Deputy Undersecretary for Oceans Management & Atmosphere

John E. Graykowskir
Maritime Administration

R.S. Begura
Director, Office of Fossil Energy

Fenton Carey
Associate Administration for Research, Technology & Analysis