Temasek Defence Systems Institute

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Evaluating Hybrid Propulsion Systems for Naval Vessels

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1. Motivation

- Naval Operations are becoming increasingly complex and energy-intensive.
- Rising fuel costs, emissions regulations, and operational demands drive interest in more efficient naval propulsion.
- Gas turbines provide strong high-speed performance but operate inefficiently at low to moderate speeds, where naval vessels spend most of their operating time.

2. Research Objective

Can a hybrid propulsion system that integrates gas turbines with batteries or fuel cells meet the Navy's performance standards while enhancing fuel efficiency and reducing carbon emissions?

3. Methodology

A physics-informed model was developed for the DDG-51 Arleigh Burke–class destroyer, simulating propulsion power, fuel flow, and endurance.

Steps:

- **Model ship resistance** (Holtrop-Mennen method)
- **Simulate propulsion modes**:
  - Baseline COGAG (gas turbines only)
  - Hybrid (gas turbines + PEM fuel cells + batteries)
- **Operational scenario**: Pearl Harbour to Yokosuka, Jap (3,300 nm) with speed profile ranging 5 – 30 knots.
- **Assess outputs:** endurance, fuel savings, hydrogen storage penalties, and cost.
- **Lifecycle analysis:** 25-year period with inflation-adjusted fuel savings.

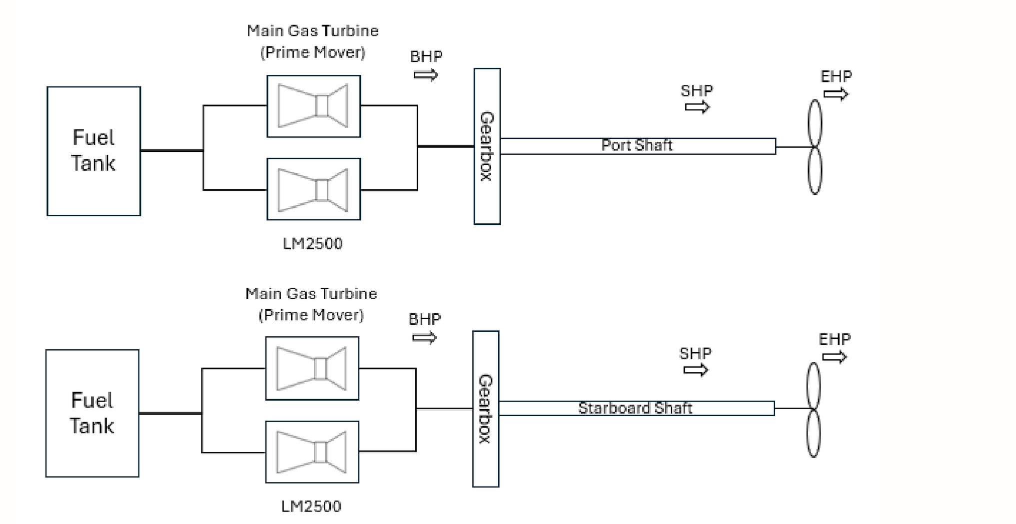


Figure 1. COGAG Propulsion Architecture

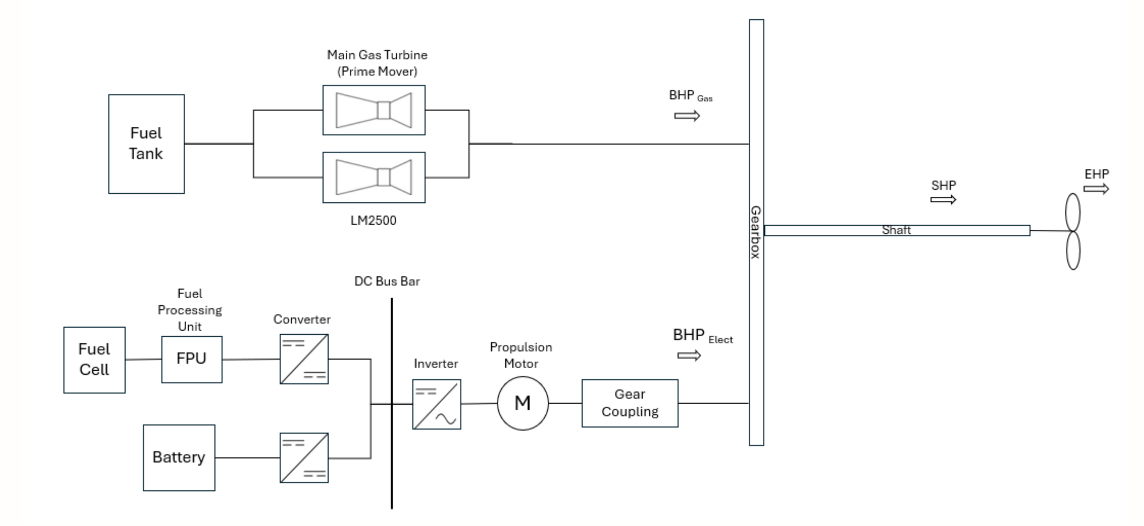


Figure 2. Hybrid Propulsion Architecture

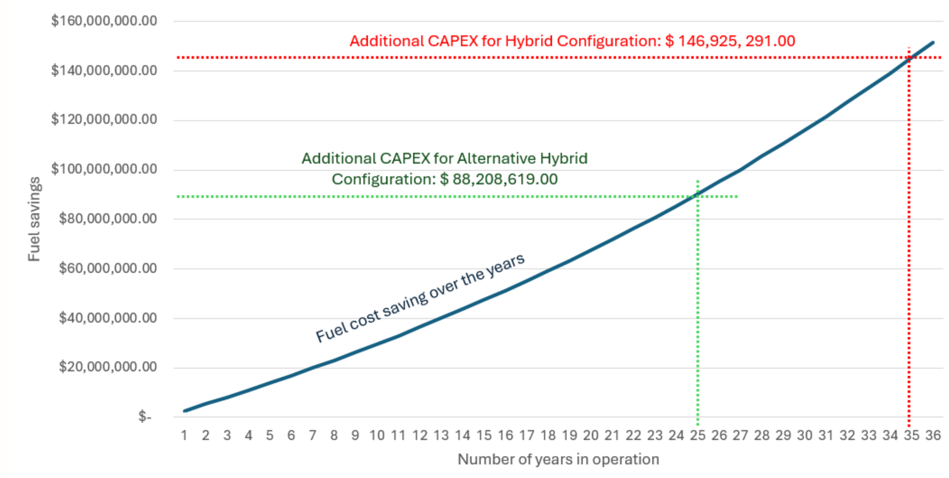
4. Key Results

- **Endurance vs. Speed:** Endurance drops sharply as speed rises due to cubic power low.
- **Mission Scenario**:
  - Baseline COGAG consumed 346,668 gallons of F-76 fuel
  - Hybrid system consumed 194,488 gallons of F-76 fuel + 167,762 kg of hydrogen
  - Fuel saving of 152,180 gallons (approx. 44%)
- **SWaP (Size, Weight and Power):**
  - Hybrid reduces liquid fuel storage by 150,000 gallons.
  - But requires approx. 6,990 m^3 of hydrogen @ 350 bar; 6 times more space than diesel fuel.
  - Added penalties: approx. 37 metric tons weight increase from batteries and fuel cells.

Parameter	13.5 days transit/ 3,300Nm		
	COGAG	Hybrid	Δ (Delta)
Power Output (kW)	344,559	344,559	-
Physical Size (m^3)	199	246	47
Physical Weight (kg)	79,648	116,950	37,302
Fuel Storage (Gal)	450,000	300,000	(150,000)
H2 Storage Volume (m^3)	0	6,990	6,990
Total Storage Volume (m^3)	1,703	8,125	6,422

5. Lifecycle Cost Analysis

- **CAPEX**
  - COGAG baseline: $49.5M
  - Hybrid: $196.4M
- **OPEX Savings**
  - $2.64M annual fuel savings
  - Approx. $90.3M over 25 years with 2.5% fuel inflation
- **ROI:**



6. Discussion & Implications

Hybrid propulsion is most effective at low to medium speeds, where electric drives replace inefficient turbines.

- **Operational Benefits**
  - Extended endurance, fewer refueling stops
  - Lower emissions and acoustic signature
  - More flexible power allocation for combat systems
- **Challenges**
  - Hydrogen storage volume due to low volumetric energy density.
  - Additional weight and complexity from fuel cells and batteries
  - Refueling infrastructure for hydrogen at sea is not yet mature

7. Conclusion

Hybrid propulsion significantly reduces fuel consumption and lifecycle costs under certain conditions.

- **Future Research**
  - Alternative fuel cells to reduce hydrogen dependency
  - Integration of Propulsion Derived Ship Service (PDSS) for shared propulsion/ service load.

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