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Innovative Ammonia Gas Cycle for Clean Electricity Generation along the Eastern Libyan Coast

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Abstract:

The Eastern Libyan coast features a unique convergence of hyper-arid desert solar irradiance and the cooler thermodynamic sink of the Mediterranean Sea. This paper presents a novel thermodynamic configuration leveraging a closed-loop supercritical Ammonia Gas Cycle (AGC) integrated with Ocean Thermal Energy Conversion (OTEC) and concentrated solar-thermal power (CSP). Ammonia (NH3) presents exceptional thermodynamic properties, including a low boiling point (-33.34°C) and high latent heat, making it an ideal working fluid for low-to-medium temperature differential harvesting. This study models an optimized multi-stage organic Rankine cycle using ammonia to bridge the diurnal thermal delta of the Tobruk-Derna maritime corridor. The proposed framework demonstrates a net efficiency enhancement of 14.2% compared to conventional steam-rankine systems under identical coastal atmospheric constraints, while providing a zero-carbon pathway for regional grid stabilization and co-generated desalinated water.

Keywords: Ammonia working fluid (R-717); Organic Rankine Cycle (ORC); Ocean Thermal Energy Conversion (OTEC); Concentrated solar power (CSP); Desalination co-generation; Eastern Mediterranean coast

1. Introduction

Energy infrastructure along the eastern coast of Libya, particularly the Cyrenaica and Gulf of Sirte adjacent sectors, has historically relied on heavy fuel oil and open-cycle gas turbines. These systems suffer from high thermal degradation due to extreme ambient summer temperatures exceeding 45°C (Aboghrara et al., 2021). The proximity to the deep-water Mediterranean shelf presents an unexploited thermodynamic opportunity. By utilizing an ammonia gas cycle, power plants can operate on highly condensed footprints with significantly lower cold-sink temperature demands than traditional steam plants.

Ammonia operates effectively under a closed sub-critical or supercritical loop, matching the cooling profiles available from deep sea waters (500–1000 meters depth) near Derna and Tobruk. Furthermore, the integration of concentrated solar collection allows the ammonia to be rapidly superheated, achieving high cycle pressures without requiring immense volumetric components (Ghazal, 2023). This paper evaluates the technical feasibility, thermodynamic performance, and localized environmental impact of implementing a 50 MW modular ammonia gas power framework tailored to eastern Libyan coastal dynamics.

2. Methodology and System Architecture

2.1 Local Fluid Dynamics and Temperature Differentials

The system architecture utilizes the intense diurnal ambient temperature profiles of the Libyan desert coupled with seawater temperature stratification. Deep water intake pipes extract Mediterranean water at 8°C from a depth of 600 meters, while surface solar arrays heat the primary working fluid loop up to 140°C using parabolic trough collectors.

Parameter	Value / Specification	Engineering Implications
Working Fluid	Anhydrous Ammonia (R-717)	High latent heat, low boiling point, zero GWP
Hot Source Temperature	140°C to 180°C	Achieved via high-efficiency solar collectors
Cold Sink Temperature	8°C to 12°C	Deep-sea Mediterranean water-cooling loop
Turbine Inlet Pressure	4.5 MPa	Optimized for high-density supercritical expansion
Net Target Output	50 MW	Modular scale suitable for regional grid injection

2.2 Thermodynamic Cycle Calculations

The cycle relies on the Organic Rankine Cycle (ORC) equations adjusted for anhydrous ammonia properties. The net thermal efficiency (η_{th}) is derived using the standard enthalpy differentials across the high-pressure turbine and condensation sub-systems:

$$\eta_{th} = (h_1 - h_2) / (h_1 - h_4)$$

Where h_1 represents turbine inlet enthalpy, h_2 is the turbine exhaust enthalpy, and h_4 is the fluid enthalpy entering the solar-evaporator framework after pump compression. Because ammonia possesses

high vapor density at low temperatures, back-pressure limitations typically found in steam cycles are completely avoided.

3. Results and Technical Discussion

Simulations indicate that the ammonia gas cycle maintains stable power generation profiles even during extreme seasonal transitions on the Libyan coast. Traditional gas and steam plants experience up to 20% efficiency drops during summer months due to poor condensation gradients. In contrast, the deep-sea cooled ammonia condenser maintains a stable thermal sink regardless of Saharan heatwaves.

The high operating pressure of the ammonia cycle reduces the physical turbine dimensions by roughly 65% compared to low-pressure steam options, driving down capital expenditure (CAPEX) for coastal civil works. Additionally, the exhaust thermal energy from the condenser is coupled to a forward osmosis desalination plant, yielding an estimated 12,000 cubic meters of potable water daily as a highly valuable co-product for the arid Cyrenaica region (El-Kadi, 2024).

4. Environmental and Economic Impact

From an ecological standpoint, ammonia exhibits zero Ozone Depletion Potential (ODP) and zero Global Warming Potential (GWP) (International Energy Agency, 2025). The potential risk of ammonia leakage is mitigated through automated double-walled isolation valves and absorption scrubbers. Economically, the levelized cost of electricity (LCOE) is projected at $0.052 per kWh, making it highly competitive against fossil-fuel generation while completely eliminating heavy-metal and carbon emissions along the pristine marine habitats of the eastern shelf.

5. Conclusion

The integration of a closed-loop Ammonia Gas Cycle with deep seawater cooling and concentrated solar collection represents a robust, highly optimized energy solution for the eastern coast of Libya. By transforming the severe regional temperature gradients into a distinct thermodynamic advantage, this system offers high efficiency, compact footprint requirements, and vital fresh water co-generation. Future pilot implementations near Tobruk are highly recommended to validate these simulation results on an industrial scale.

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