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URBAN MOTORCYCLE EXHAUST EMISSIONS IN VIETNAM: STATUS AND TECHNICAL SOLUTIONS

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Summary

Vietnam's major cities experience severe air pollution with Hanoi recording $PM_{2.5}$ concentration of approximately 45 μg/m^3, nearly 9 times higher than the WHO guideline value. This situation is driven by 77 million motorcycles, of which 70% are over 10 years old and 94% lack emission control systems. Motorcycles account for about 76% of urban CO, 68% of HC, and 54% of NO_x. The transition toward electric vehicles faces critical challenges, including 10 - 15 years of infrastructure development versus an 18-month policy deadline, battery production emissions (60 - 100 kg CO_2/kWh), and coal-thermal electricity transferring pollution. This paper analyzes emission control technologies and reveals that electronic fuel injection and E10 achieve only 30 - 40% reductions while increasing NO_x, whereas three-way catalytic converters demonstrate more than 85% reduction across all pollutants at significantly lower cost than immediate electric vehicle conversion. A two-phase framework is proposed: i) immediate retrofitting (2025 - 2028) supported by clean fuel supply and gas power expansion, and ii) a systematic transition (2028 - 2040) enabled by diversified clean energy infrastructure, metro networks, and green hydrogen ecosystem. Throughout both phases, coordination with the petroleum sector is emphasized to ensure energy security during the transformation.

Key words: Catalytic converter, motorcycle emissions, air pollution, Vietnam, emission control technology.

1. Current air pollution status and motorcycle contribution

Vietnam's major cities confront unprecedented air pollution, with $PM_{2.5}$ concentrations persistently reaching hazardous levels. Throughout early December 2025, Hanoi experienced severe episodes with AQI ranging 187 - 275 citywide, corresponding to $PM_{2.5}$ concentrations of 110 - 170 μg/m^3 (22 - 34 × WHO guideline). The 2024 annual average $PM_{2.5}$ concentration reached 45 μg/m^3 (9 × WHO guideline), placing Hanoi among Asia's most polluted capitals [1].

According to World Bank analysis using the GAINS model for Hanoi's PM2.5 emissions in 2015, the transportation sector contributed 15% from vehicle exhaust and 23% from road dust, representing a combined 38% of total air pollution. Other major sources included industrial activities (29%), open burning of rice straw (26%), and residential/commercial combustion (7%) [2].

However, the transportation contribution may have increased substantially since 2015. Vietnam's motorcycle fleet has grown from approximately 44 million units in 2015 to over 77 million by 2024 - a 75% increase. This dramatic expansion in motorcycle ownership, representing one of the world's highest rates at 770 motorcycles per 1,000 people, suggests that transportation's share of air pollution has likely increased beyond the 38% recorded in 2015. Motorcycles are the dominant emission source within the transportation sector. Studies demonstrate that motorcycles are responsible for 60% of transport-related PM2.5 in Ho Chi Minh City and contribute 68 - 70% of PM2.5 emissions from the transportation sector across major Vietnamese cities. The high emissions stem from widespread use of aging gasoline-powered motorcycles with inadequate emission controls and limited public transportation infrastructure [3 - 5].

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Figure 1. *Hanoi air quality spatial distribution in December 2025.*

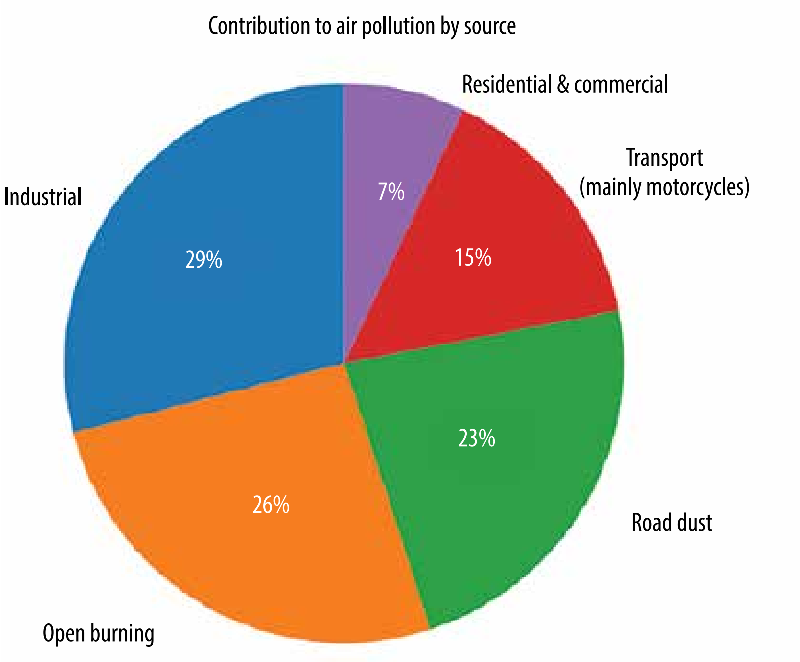

Figure 2. *Illustrative $PM_{2.5}$ source contribution breakdown for Hanoi (conceptual schematic).*

2. Government policies and electric vehicle transition challenges

2.1. Emission standards and geographic restrictions

Vietnam's regulatory response employs dual strategies: emission standards tightening and accelerated electrification. Decision 19/2024/QĐ-TTg mandates Euro 4 compliance (CO ≤ 1.14 g/km, HC ≤ 0.38 g/km, NO_x ≤ 0.07 g/km) for new motorcycles by July 2026 and mopeds by July 2027 [6]. However, these standards apply only to new vehicle sales, creating a regulatory gap with the existing 77 million-unit fleet where 70% exceed 10 years of age.

Implementation employs graduated geographic restrictions. Hanoi's resolution dated November 26, 2025, establishes low-emission zones centered on Ring Road 1, with time-based restrictions taking effect on July 1, 2026, and affecting approximately 450,000 motorcycles. The zone will expand progressively through Ring Roads 2 and 3 by 2028 and 2030, respectively. Ho Chi Minh City pursues a parallel phased implementation targeting the complete prohibition of gasoline motorcycles in downtown by 2032.

2.2. Electric vehicle transition barriers

The electric vehicle transition represents the primary long-term compliance solution but it confronts severe barriers across three dimensions:

Infrastructure: Ho Chi Minh City's 600 charging points serve fewer than 10,000 EVs, requiring expansion to 3,000 stations by December 2028-a 400% increase in 36 months. More critically, Vietnam's 2023 electricity crisis caused USD 1.4 billion in economic losses. Converting millions of motorcycles would demand substantial generating capacity, with coal-thermal sources (47% of electricity) merely transferring emissions from urban to rural areas without net pollution reduction.

Economic: Electric motorcycles are priced at VND 20 - 40 million versus equivalent gasoline models at VND 15 - 25 million, representing a 30 - 60% premium. Battery replacement (VND 8 - 12 million after 5 - 7 years) eliminates operational savings, creating total ownership costs exceeding conventional motorcycles over a typical 10-year lifespan. Current subsidies address only 14% of targeted fleets.

Environmental: Lithium-ion battery production generates significant upstream emissions through energy-intensive mining (lithium, cobalt, nickel) causing water/soil pollution and manufacturing processes, with 60 - 100 kg CO_2 emissions per kWh battery capacity. A typical electric motorcycle battery (1.5 - 2 kWh) embeds 90 - 200 kg CO_2 before first use, requiring 5,000 - 10,000 km operation to offset manufacturing emissions-negating short-term air quality benefits in emission-constrained scenarios. Downstream, batteries require specialized recycling facilities absent at commercial scale in Vietnam. The VinES-Li-Cycle partnership

Figure 3. *Motorcycle scrapyard.*

targets facility commissioning in 2025, which is obviously insufficient for current policy deadlines. With 8- to 10-year battery lifespans, large-scale adoption would generate massive waste streams from 2031 onward, while current facilities landfill 85% of 400,000 tons of annual motorcycle waste without treatment. This lifecycle pollution burden - from mining regions to manufacturing zones to disposal sites - often transfers environmental costs to less developed regions rather than eliminating them [2, 6].

2.3 Public transport infrastructure gaps

Public transportation development in both Hanoi and Ho Chi Minh City remains insufficient to support the immediate motorcycle phase-out. Hanoi operates 2 metro lines (Line 2A since November 2021 and partial Line 3 since August 2024) with plans for 8 lines totaling 318 km under Prime Minister Decision 519/QĐ-TTg. Ho Chi Minh City inaugurated Line 1 (19.7 km) in December 2024, with the city's urban railway master plan targeting approximately 510 km total system length requiring an estimated USD 24 billion investment under Decision 1711/QĐ-TTg dated December 31, 2024. Even with aggressive development timelines, completing these metro networks extends beyond 2027. Existing diesel bus fleets compound the pollution challenge rather than offering solutions. Hanoi's public transport system comprises 2,279 buses, of which 86.8% (over 2,000 vehicles) remain diesel-powered, with only 277 buses (13.6%) using green energy. Ho Chi Minh City operates 2,209 buses with 546 green energy vehicles. Both cities target 100% green energy bus conversion by 2030, but current diesel operations contribute to, rather than mitigate, urban air pollution. Combined metro-bus systems cannot absorb 77 million motorcycles within policy timeframes, creating implementation gaps between emission reduction targets and infrastructure readiness [7, 8].

2.4. Timeline mismatch and international lessons

Chinese cities provide instructive precedent. Over 160 cities implemented motorcycle restrictions by 2009, substantially increasing travel costs for low-income workers and collapsing China's motorcycle market from 26.9 million (2014) to 15.5 million (2018) sales. Shanghai's success required over 20 years of sustained infrastructure investment combined with effective restrictions, rather than rapid policy implementation.

Timeline analysis reveals a fundamental mismatch: systematic EV transition and public transport development require 10 - 15 years, yet policy deadlines allow only 18 months before Euro 4 enforcement. Given that comprehensive metro completion and bus electrification cannot be achieved within this timeline, interim emission control solutions for the existing motorcycle fleet become essential. Bridge solutions must meet four criteria: proven emission reduction achieving Euro 4 compliance (>75% reduction across all pollutants), economic accessibility (VND 2 - 5 million), technical compatibility with an aging fleet regardless of mechanical condition, and social equity protecting livelihoods while advancing environmental objectives [9].

3. Technical solutions for the existing motorcycle fleet

Emission control strategies are divided into primary methods (combustion optimization) and secondary methods (exhaust aftertreatment). Primary methods target pollutant formation at source through improved fuel-air mixing and combustion completeness. Secondary methods chemically convert already-formed pollutants before atmospheric release. While primary methods offer measurable improvements, their reduction magnitudes prove insufficient for Euro 4 compliance, particularly for aging engines where degradation limits optimization potential.

3.1. Primary methods: Combustion efficiency enhancement

Electronic fuel injection (EFI) retrofitting: Replacing carburetors with electronic fuel injection delivers precise fuel metering

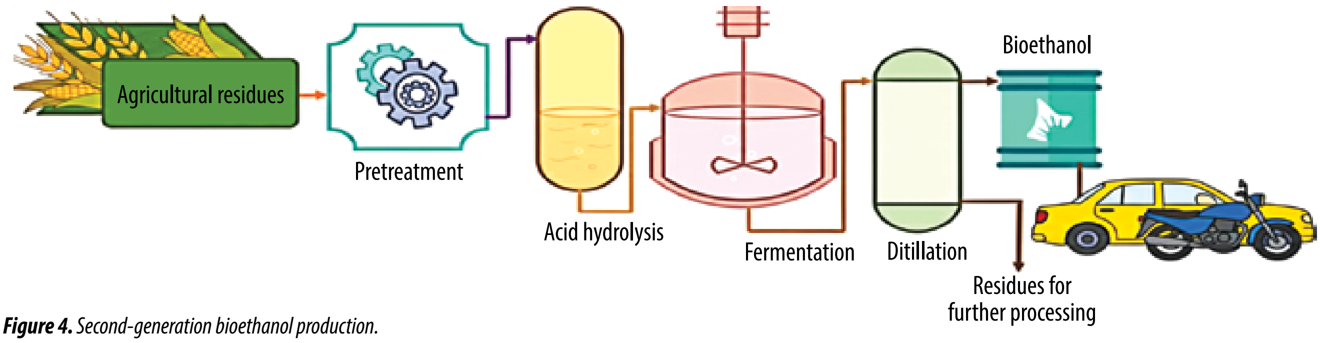

Figure 4. *Second-generation bioethanol production.*

through oxygen sensor feedback. Field studies on 125cc motorcycles documented 82 - 96% CO and 36 - 55% HC reduction but paradoxically doubled NO_x emissions through elevated cylinder temperatures [10]. Retrofit costs of VND 3 - 5 million with 4 - 6 hour installation limit practical applicability to ~40% of Vietnam's fleet, only well-maintained post-2010 motorcycles with adequate electronic infrastructure.

Biofuel (E10) integration: Laboratory studies document 10 - 13% CO and 10 - 15% HC reduction but 40% NOx increase and 51% particle number concentration rise. Vietnam mandates nationwide E10 deployment from June 1, 2026 (Decision 46/2025/QĐ-TTg, Circular 50/2025/TT-BCT), transitioning to E15 by January 2031. However, critical constraints persist that domestic production (450,000 m^3/year from 2 operating plants) meets only 30 - 40% of demand (1.2 - 1.5 million m^3/year), requiring 60% imports. Cassava feedstock causes severe soil erosion (20 - 40 tons/hectare annually) and demands high fertilizer inputs. Second-generation lignocellulosic facilities require USD 100 - 200 million investment per plant with only 2 of 6 planned facilities currently in operation [11, 12].

Fuel additives: Commercial additives claim 5 - 15% emission reductions but independent testing demonstrates minimal benefits. Indonesian studies found bio-additives increased CO_2 emissions (0.28 - 8.01 ppm/ml) versus synthetic additives (0.88 - 13.17 ppm/ml) [13]. Annual costs (VND 1.2 - 3.6 million) approach catalytic converter capital costs without proven emission reductions for aging motorcycles.

Although EFI optimization and E10 fuel adoption can achieve up to 30 - 40% emission reductions, these measures alone do not reliably ensure compliance with applicable motorcycle emission standards (Level 2-3) across the legacy fleet, as emission performance among very old and carbureted motorcycles remains highly variable and difficult to control in the absence of exhaust after-treatment.

3.2. Secondary methods: catalytic converter technology - Application scope and global market

Catalytic emission control technology has evolved into a global industry with two main segments:

Transportation: Market reached USD 169.5 billion (2024) and is forecasted to grow to USD 387.8 billion (2034), corresponding to a CAGR of 8.6%/year. This segment includes three-way catalysts for gasoline engines, diesel oxidation catalysts (DOC) and selective catalytic reduction (SCR) for trucks, ships, and mobile machinery. The Asia-Pacific region accounts for 49.8% of the global market share.

Stationary industrial: Market reached USD 24.5 billion (2024) and is forecasted to attain USD 33.1 billion (2033), corresponding to a CAGR of 3.3%/year. Applications include coal/gas power plants (67.8% market share), refineries (FCC, hydrotreating), cement (kiln DeNOx), steel (blast furnaces), chemicals (VOC treatment), and large marine vessels.

The total global catalytic emission control market exceeded USD 194 billion in 2024, reflecting its essential role in global air pollution control [14, 15].

Operating principles of three-way catalysts

Three-way catalysts (TWC) operate through heterogeneous catalysis on ceramic/metallic substrates (400 - 900 cells/inch^2) coated with Al_2O_3-CeO_2-ZrO_2 washcoat containing nano-sized precious metals (Pt, Pd, Rh). At 350 - 900°C, three simultaneous reactions occur:

Oxidation (Pt, Pd):

$$2CO + O_2 \rightarrow 2CO_2$$

$$C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$$

Reduction (Rh):

$$2NO + 2CO \rightarrow N_2 + 2CO_2$$

$$C_3H_8 + 10NO \rightarrow 5N_2 + 3CO_2 + 4H_2O$$

Figure 5. *Catalytic converter installation and various product configurations.*

Performance: Reduction achieves >95% for CO, >90% for HC, >85% for NOx at λ = 0.97 - 1.03, exceeding Euro 4 requirements. Lifespan exceeds 100,000 km with fuel <10 ppm sulfur [16, 17].

- Research achievements and technology gaps for motorcycles

Developed markets: Euro 4 (2016) and Euro 5 (2021) drove advanced technologies-metallic substrates 600 - 900 cpsi for rapid light-off, Pt:Pd:Rh = 5:5:1 cost optimization, CeO_2-ZrO_2 washcoat thermal stability, close-coupled positioning reducing light-off time to <60 seconds. India (BS-VI 2020) achieved a 70% reduction in particulates, while China (GB14622-2016) applied Pd-Rh systems with HC+NOx ≤0.12 g/km [13, 14]. However, these technologies serve premium new motorcycles (>VND 100 million), while European aftermarket exhaust systems cost VND 15 - 30 million, which is therefore unsuitable for low-cost used motorcycle retrofits.

Vietnamese research: Prof. Le Minh Thang (Hanoi University of Science and Technology) developed MnO_2-Co_3O_4-CeO_2 catalysts on cordierite substrates (Vietnam Patent 20257/2018) without precious metals, achieving > 90% CO/HC at 350 - 400°C with ~50% lower cost, indicating strong potential to reduce import dependence [15]. Challenges: NOx performance has not yet reached the >85% level required for full Euro 4 compliance; long-term testing under tropical conditions (25 - 35°C, 80 - 95% humidity), high-sulfur fuels (50 - 150 ppm vs < 10 ppm in the EU), and aged engines with oil consumption have not been conducted. The technology has not yet been commercialized, and would require about 3 - 5 years and tens of billions of VND investment for market readiness.

Critical gaps: OEMs (Bosch, Denso) serve only new vehicles. European aftermarket products are costly. Asian aftermarket alternatives often exhibit poor quality (Pt/Pd/Rh 30 - 50% below standards, lifespan <30,000 km, and counterfeits widespread). There is a lack of products that are suitable for tropical climates, compatible with aged motorcycles, while affordable for Vietnam's 77 million fleet.

- Feasibility potential for Vietnamese used motorcycles

With Euro 4 standards applying to new motorcycles from July 2026, Vietnam must also address emissions from an existing fleet of approximately 77 million motorcycles, of which around 70% are over 10 years old and 94% lack exhaust after-treatment. While Euro 4 requirements do not apply to legacy vehicles, their age and technical heterogeneity significantly limit the effectiveness of primary emission control measures.

Among the evaluated technologies, exhaust catalytic after-treatment emerges as one of the most feasible short- to medium-term options for emission control in used motorcycles, as it enables the simultaneous reduction of CO, HC, and NO_x while delivering more consistent performance across heterogeneous and aging vehicle conditions. This assessment refers to improving compliance with applicable in-use emission standards and reducing real-world emissions, rather than retrofitting legacy motorcycles to Euro 4 requirements.

Support requirements: (i) the establishment of a clear regulatory framework for vehicle inspection following exhaust system modifications; (ii) the progressive availability of ultra-low sulfur fuels to ensure catalyst durability; (iii) the development of quality standards and certification mechanisms to prevent counterfeit products; and (iv) supportive fiscal policies, such as tax exemptions or reductions for catalyst-related components and materials, to facilitate cost-effective deployment. In parallel, continued research on domestically developed catalyst technologies, including non-precious metal systems, should be encouraged to improve NOx conversion efficiency, validate field performance, and advance commercialization, thereby reducing long-term costs [18].

4. Strategic assessment and implementation pathways

4.1. Short-term strategy (2025 - 2028): Controlling current emissions

Objective: To reduce emissions from 77 million motorcycles by 60 - 70% through a two-tier strategy: mandatory Euro 4 with integrated three-way catalysts for new vehicles from January 2027 (fundamental solution), retrofitting old vehicles with aftermarket catalysts during a 10 - 15 year transition. Three-way catalysts uniquely achieve Euro 4 simultaneously (>95% CO, >90% HC, >85% NOx), superior to EFI and E10.

Three-phase deployment: Ring Road 1 (approximately 600,000 vehicles, 2026 - 2027) → Ring Road 2-3 (~1.5 million vehicles, 2028 - 2029) → nationwide (from 2030 onward), with VND 1 – 2 million subsidies prioritizing low-income households, and a 50% corporate tax reduction for domestic catalyst manufacturers. Mandatory use of clean fuel E10 from June 2026, and gasoline with sulfur content <10 ppm from 2027 to prevent catalyst poisoning. Compulsory SCR systems with DEF for heavy-duty diesel vehicles from January 2027, reducing 80 - 95% NOx. Public transport is electrifying 50% of the bus fleet by 2027, completing Hanoi Metro Line 3, and expanding Ho Chi Minh City Lines 1 - 2.

Petrovietnam's role: Assigns member units with relevant functions to implement the following integrated solutions:

- Producing/distributing E10 and <10 ppm sulfur gasoline through refineries;

- The domestic production of ISO 22241–compliant diesel exhaust fluid (DEF), exemplified by Phu My Xanh, combined with distribution via existing fuel retail networks, provides an enabling foundation for large-scale deployment of SCR systems without relying on imported DEF supplies;

- Developing integrated clean agriculture–biorefinery hubs, leveraging Petrovietnam's existing gas-power-fertilizer infrastructure to convert agricultural residues into high-value products (essential oils, nanosilica, bio-based chemicals, biofuels), while strengthening control over informal open-field burning and reducing $PM_{2.5}$ and NH_3 emissions;

- Replicating Nhon Trach 3&4 model (1,624 MW, >62% efficiency) to O Mon IV and Long Phu 1, expanding capacity to 12,000 - 15,000 MW;

- Converting urban coal plants to gas, retrofitting aging plants with SCR/ESP/FGD reducing 20 - 30% industrial $PM_{2.5}$;

- Collaborating with universities developing non-precious metal catalysts for tropical climate, testing on 10,000+ vehicles, industrializing monazite-based cerium oxide washcoat, reducing costs 50 - 70%;

- Converting 5,000+ stations into catalyst sales/installation points;

- Optimizing refinery operations (BSR 95.6% reliability), environmental investment (for NSRP about USD 300 million), piloting clean hydrogen;

- Establishing centralized recycling treating 200,000 - 500,000 tons/year of plastics, 100,000 tons/year of waste oil.

4.2 Long-term strategy (2028 - 2040): Fundamental system transformation

Replace internal combustion engines achieving an 80 - 90% reduction by 2040. Prerequisites include 10,000 - 20,000 EV charging stations, grid upgrades, tropical-safe batteries, industrial-scale recycling, and cost reduction to 70 - 80% of gasoline vehicles. Hydrogen is designated for heavy-duty applications, while hybrids are for transition. The target is 30 - 50% electric/hydrogen vehicle new sales by 2035 (conservative scenario: 5 - 7 years extension).

Energy foundation: Renewables - solar and offshore wind (160 GW potential, with 6 GW pilot by 2030) targeting 30 - 40% of electricity generation; nuclear - deployment of Gen III/III+ reactors plus thorium reactor research utilizing ~600,000 tons of domestic monazite; and smart grid integration. Metro expansion (318 km in Hanoi, 85 km in Ho Chi Minh City by 2030) targets a 40 - 50% public transport share (realistically 30 - 35%). Green fuel ecosystem is envisaged when renewable electricity is sufficient, including green hydrogen from electrolysis, green ammonia for maritime applications, CO_2 + H_2 pathway to methanol/DME/synthetic diesel, and second-generation biofuels with E15 introduced from January 2031.

Petrovietnam's role: Coordinates member units leading transformation, including: Converting 5,000+ stations into integrated energy hubs (EV charging, H_2/ammonia fueling); Leveraging offshore expertise to provide EPCI/logistics services for offshore wind projects (GWO-certified workforce, major project bidding), partnering for renewable energy exports, integrating offshore wind with at-sea green hydrogen production;

Transitioning refineries toward high-value chemicals (e.g., benzene, paraxylene, polypropylene at Nghi Son), scaling clean hydrogen from pilot projects (2025 - 2030) to commercial deployment (beyond 2030) to serve refineries/fertilizer production/exports; Producing blue hydrogen from gas integrated with CCS, capturing 2 - 5 million tons CO_2/year in depleted fields and combining with EOR; Exporting green ammonia to Japan and Korea; Advancing CO_2 utilization and second-generation biofuels; Participating in the nuclear power program; Research on thorium molten-salt reactor (MSR) and rare-earth refining; Developing lithium/sodium battery; and expanding recycling systems.

Transition logic: Producer → Supporter (clean fuels, domestic catalysts, infrastructure, gas power, refinery greening, recycling, and DEF) → Leader (green energy, high-value chemicals, clean hydrogen, circular economy, and advanced technologies), ensuring national energy security throughout a 15 - 20 year transition.

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