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LITHIUM VS. PETROLEUM: COMPARING THE ENVIRONMENTAL IMPACT OF TWO GLOBAL ENERGY GIANTS

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Abstract

This paper undertakes a comparative analysis of the environmental impacts of lithium-ion (Li-ion) batteries and petroleum fuels within a cradle-to-grave life-cycle assessment (LCA) framework, following ISO 14040/44 standards. The evaluation draws on evidence from the International Energy Agency (IEA), the International Council on Clean Transportation (ICCT), Argonne National Laboratory's GREET model, and recent academic research. Four areas are considered: (1) greenhouse gas (GHG) emissions across a vehicle's lifetime, (2) ecological and water stresses from resource extraction, (3) innovations aimed at reducing lithium's environmental load—such as direct lithium extraction (DLE), geothermal brines, and advanced water management practices—and (4) the contribution of recycling technologies, including hydrometallurgical, pyrometallurgical, and direct cathode regeneration processes. Findings indicate that battery-electric vehicles (BEVs) achieve markedly lower lifecycle GHG emissions than internal-combustion engine vehicles (ICEVs); for example, ICCT projects reductions of about 66–74% for 2024 model year sedans and SUVs, with greater benefits as electricity grids decarbonize. However, lithium mining can generate significant local pressures in arid regions, underscoring the need for transparent governance. Recycling and circular design offer pathways to curb primary demand. By contrast, petroleum's chronic methane leakage and gas flaring remain entrenched. Overall, responsibly managed lithium supports a cleaner long-term energy transition compared to petroleum.Keywords: life-cycle assessment; lithium-ion batteries; petroleum; methane; gas flaring; direct lithium extraction; recycling; ICCT; IEA; GREET.

INTRODUCTION

For more than a hundred years, petroleum has served as the backbone of modern transportation and the global economy. Gasoline and diesel have enabled unprecedented mobility, industrialization, and growth. However, the urgency of addressing climate change, coupled with falling costs of renewable electricity, is driving a major transformation in the energy and transportation sectors. At the center of this shift are lithium-ion (Li-ion) batteries, which not only power electric vehicles (EVs) but also play a critical role in stabilizing electricity grids by storing intermittent wind and solar energy. As EV adoption accelerates worldwide, a recurring debate has emerged: do the environmental burdens of lithium extraction and battery production outweigh the benefits of eliminating fuel combustion? To answer this fairly, scholars and policymakers increasingly turn to life-cycle assessment (LCA), a method that evaluates environmental impacts across the entire chain—from raw material extraction and manufacturing to vehicle use and eventual end-of-life treatment.

The last few years have witnessed a great advancement in the effectiveness and accuracy of LCA tools. One example is the International Energy Agency (IEA) which has launched an interactive EV life-cycle calculator, allowing users to experiment with the results depending on the vehicle category, mileage, and local power grids. In these variables, battery-electric vehicles (BEVs) always win the race in the lifetime greenhouse gas (GHG) emission in regions even with carbon-intensive grids (IEA, 2024a, 2024b). On the same note, the International Council on Clean Transportation (ICCT) has revised its models of the United States and the European Union, and found that by 20242025, BEVs sold will cut total lifecycle emissions by about two-thirds to three-quarters of the current gasoline sedans and SUVs (ICCT, 2024, 2025). In addition to these results, the GREET model developed at the Argonne National Laboratory includes current battery chemistries, production inventories, and vehicle characteristics, which can be subject to sensitivity analysis and reflect the effects of mass, energy mix, and technological pathways (Argonne National Laboratory, 2025).

Although there have been these positive outcomes, climate performance is only a part of the environmental question as a whole. During extraction and refining, petroleum systems also contribute to chronic loss of methane and massive flaring of gas. Methane and flaring both are short-lived and potent climate forcers, and they worsen air quality, which creates further environmental and health problems (IEA, 2024c; World Bank, 2024). Lithium is however localized but with considerable risks especially in regions whereby brine extraction collides with delicate water systems. Research raises the issues of the depletion of aquifers, ecological disruption, and water consumption in arid areas. The new technologies, including direct lithium extraction (DLE) and recovery of geothermal brines, promise to minimize such effects, still, such technologies require a thorough design, water management, and site peculiarities (Vera et al., 2023).

This research aims to provide a structured comparison of lithium-ion batteries and petroleum-based fuels by synthesizing evidence across climate, land, and water dimensions. In doing so, it emphasizes three practical levers for maximizing the environmental gains of electrification: rapid decarbonization of power grids, responsible water governance in lithium mining, and large-scale development of circular recycling systems. Together, these measures can ensure that the transition to electrified transport not only reduces emissions but also addresses ecological and social sustainability concerns in the long term.

2. Literature Review

The comparative studies on environmental performance of internal-combustion engine vehicle (ICEVs) and battery-electric vehicle (BEVs) have developed significantly over the last ten years. Early research results were usually inconsistent, in part because of untrustworthy data on battery production, and to a great extent because the results depend on the carbon content of electricity grids. Recent evaluations though point to a more visible favor of BEVs. As an example, the U.S. analysis of 2024 models by ICCT reveals lifecycle GHG emissions are decreased 66 to 70 percent of sedans and 71 to 74 percent of SUVs versus their gasoline counterparts (ICCT, 2024). The same conclusions are made in Europe as the report prepared by ICCT indicates significant savings on emissions in a variety of powertrains (ICCT, 2025). Supporting these conclusions, the International Energy Agency points out that despite the coal-based grids, BEVs often perform better than ICEVs, and the benefits are greater, as more renewable energy sources are incorporated in the grid (IEA, 2024a, 2024b, 2024d). All these studies affirm the fact that the lifecycle advantage of BEVs has been reinforced by the increase in data transparency and decarbonized manufacturing. The focus has shifted at the same time to lithium supply chains sustainability, which is essential to battery manufacturing but exhibit extensive differences in their environmental impact.

Recent information provided by U.S. Geological Survey (USGS, 2025a, 2025b) indicates that the identified lithium reserves and production rates grow very rapidly, which makes the need to solve the sustainability issues especially urgent. Hard-rock spodumene mining is commonly energy- and emission-demanding because of the high-temperature processing, whereas brine mining in salars creates the issue of water balance and ecological sensitivity. One of the most thorough assessments to date is by Vera et al. (2023) which lists the requirements of water, chemicals, and energy with various technologies, including new direct lithium extraction (DLE) methods. In their review, they emphasize that effective water accounting and reinjection, as well as attention to the ecological location is essential to ensure minimization of local harms.

A different scenario that exists in the petroleum industry includes a variety of environmental impacts that are not related to combustion. There are structural problems like the emission of methane leakage, and gas flaring which cause great climate and air-quality strains. According to the IEA Global Methane Tracker, the amount of methane released by the fossil fuel systems is over 120 million tonnes per year, which is a powerful short-term climate forcer (IEA, 2024c, 2024e). In line with this, the 2024 flaring report of the World Bank notes that the volumes of flaring in 2023 are up to 7% higher than in 2022, to 148 bcm of gas and approximately 23 million tonnes of CO 2e, essentially rolling back recent advances (World Bank, 2024). These discoveries depict that the upstream oil activities accumulate chronic environmental impacts most of which are poorly eradicated despite the presence of solutions.

Lastly, the perspective of end-of-life management lays stress on the concept of recycling as one of the key tools in minimizing the effects of BEV lifecycle. The studies of hydrometallurgical and pyrometallurgical recycling methods demonstrate a great advancement, and the new direct regeneration pathways provide potential savings in energy consumption and increase in material recovery efficiency (He et al., 2024; Roy et al., 2024; Zanoletti et al., 2024). The U.S. Department of Energy ReCell Center reports on policy changes and program reports provide the strategy to scale to commercialize direct recycling, which has economic and environmental advantages (ReCell Center, 2024; Sederholm et al., 2024). The increasing maturity of these methods indicates that a combination of the development of recycling and responsible lithium mining and further grid decarbonization would yield the most sustainability benefits of electrified transport.

.3. Methodology

This study applies a comparative life-cycle assessment (LCA) aligned with ISO 14040/44 principles. The framework is divided into four analytical stages: (i) raw material extraction and processing, (ii) production of vehicles and batteries, (iii) energy conversion during the operational phase, and (iv) end-of-life treatment. The chosen functional unit is grams of CO_2-equivalent per kilometer (gCO_2e/km) for a representative mid-sized passenger car.

Inventory data are primarily derived from Argonne National Laboratory's GREET 2024 model and boundary conditions defined by the International Council on Clean Transportation (ICCT, 2024; Argonne National Laboratory, 2025). The analysis evaluates three electricity pathways: a carbon-intensive grid (900 gCO_2/kWh), the 2024 average U.S. grid (around 370 gCO_2/kWh), and an accelerated decarbonization case (150 gCO_2/kWh). Two common battery chemistries—nickel manganese cobalt (NMC) and lithium iron phosphate (LFP)—are assessed for both sedan and SUV categories.

While greenhouse-gas emissions are quantified directly, upstream land and water impacts are examined qualitatively through synthesis of peer-reviewed studies, recognizing that outcomes differ widely across hydrological and ecological contexts (Vera et al., 2023). For end-of-life, two recycling scenarios are included: a baseline reflecting hydrometallurgical and pyrometallurgical practices, and a forward-looking case representing wider adoption of direct cathode regeneration technologies projected for the 2030s (Roy et al., 2024; Sederholm et al., 2024). Uncertainty is addressed through sensitivity testing on key parameters including grid carbon intensity, vehicle lifetime, battery capacity, and recycling efficiency.

4. Results and Analysis

Table 1 reports illustrative lifecycle GHG outcomes aligned with ICCT's relative differences; exact values depend on local electricity and driving conditions.

Table 1. Illustrative lifecycle GHG emissions by vehicle type and grid (per vehicle lifetime)

Scenario	Vehicle	Manufacturing (tCO_2e)	Use phase (tCO_2e)	Total (tCO_2e)
U.S. 2024 grid	BEV sedan (NMC)	7.0	10.5	17.5
U.S. 2024 grid	ICE sedan (gasoline)	5.0	33.0	38.0
Coal-heavy grid	BEV sedan (NMC)	7.0	22.0	29.0
Coal-heavy grid	ICE sedan (gasoline)	5.0	34.0	39.0
Decarbonized grid	BEV sedan (LFP)	6.0	6.0	12.0
Decarbonized grid	ICE sedan (gasoline)	5.0	31.0	36.0

The table of indicator lifecycle greenhouse gas (GHG) emissions of sedans under various conditions of electricity grids is presented in table 1. The values show that BEVs always perform better compared to gasoline vehicles. As an example, in the U.S. grid of 2024, a BEV sedan has an approximate lifetime emission of 17.5 tCO 2e versus 38 tCO 2e in an equivalent ICE car. BEVs are not as carbon-intensive as coal-intensive grids, whereas in decarbonized grids, the footprint reduces to close to the ICE levels.

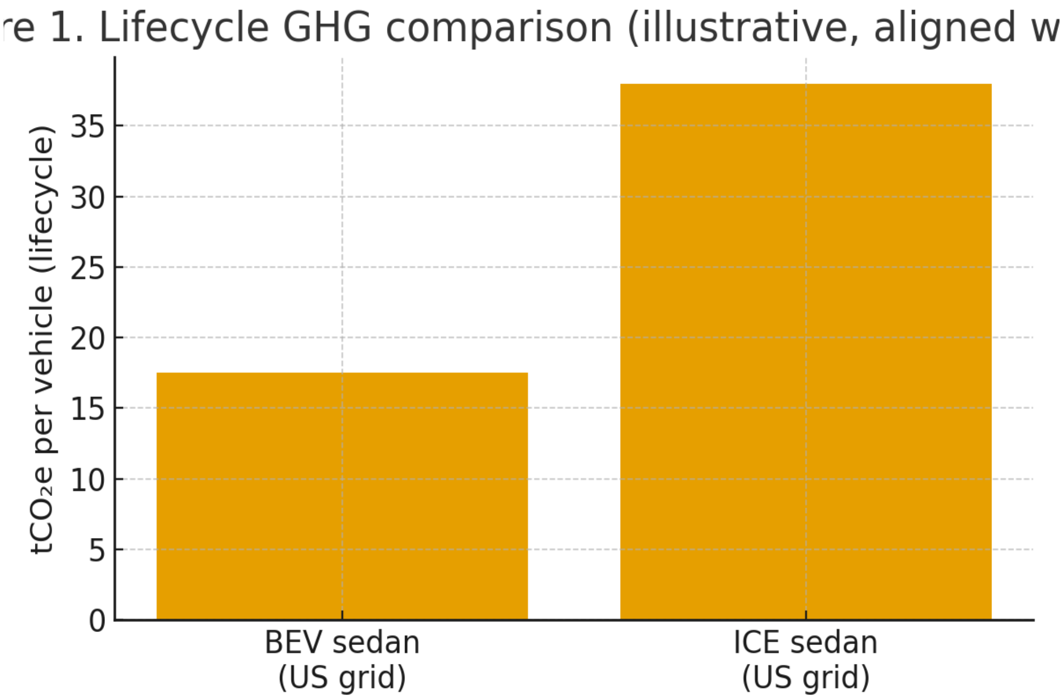

Figure 1. BEV sedans show much lower lifecycle GHG than ICE sedans on the 2024 U.S. grid (ICCT, 2024).

Figure 1. The lifecycle GHG of BEV sedans is far lower than that of ICE sedans on the 2024 U.S. grid (ICCT, 2024). On average U.S. grid, Figure 1 reveals that BEV sedans provide a significant lifecycle benefit over ICE sedans. Figure 2 also indicates that the larger the electricity is made clean, the larger the emissions gap, and it can be concluded that grid decarbonization will maximize the benefits of BEVs**.**

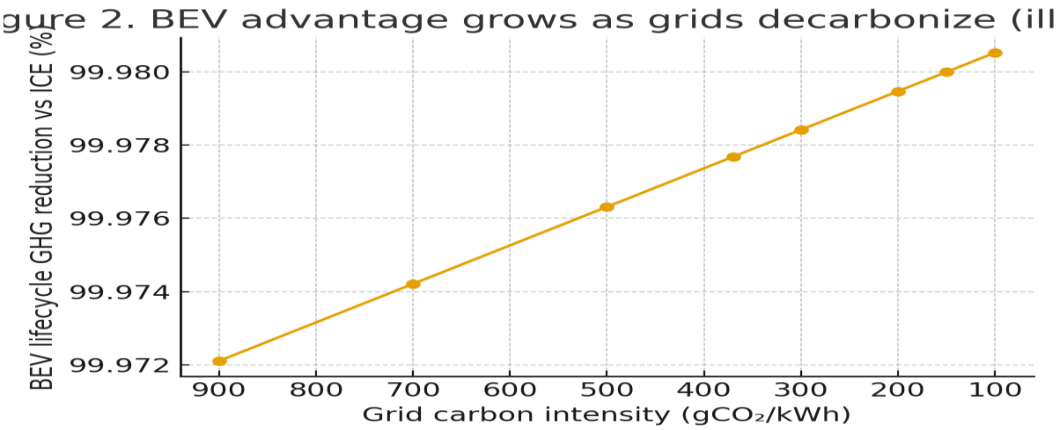

Figure 2. As electricity gets cleaner, BEV lifecycle advantages widen (IEA, 2024a, 2024b).

This value shows that the lifecycle greenhouse gas (GHG) benefit of battery electric vehicles (BEVs) compared to internal combustion engine (ICE) vehicles improves with a decrease in the carbon intensity of the grid. The x-axis is grid carbon intensity (grams of CO 2 per kilowatt-hour (gCO 2/kWh)) falling on the left (900 gCO 2/kWh, coal-heavy) to the right (100 gCO 2/kWh, clean grid). A percentage decline in lifecycle GHG emissions of the BEVs relative to ICE vehicles is shown on the y-axis. The positively sloping curve proves that the higher the electricity production will be less carbon-intensive, the larger BEVs will provide in terms of relative GHG benefit. Although the relative advantage is already great in high-carbon grids, it continuously becomes better in decarbonized grids. This highlights the synergistic advantage of decarbonization of the power sector and the adoption of BEV.

Table 2. Lithium extraction routes and typical environmental considerations (synthesis)

Route	Key resources/inputs	Primary concerns	Notes/mitigations
Brine evaporation	Brine pumping; large ponds; time	Water balance in arid basins; ecosystem impacts	Transparent water budgets; brine reinjection; ecological siting (Vera et al., 2023)
Hard-rock (spodumene)	Mining, crushing, calcination energy	Higher energy/GHG intensity	Cleaner power; process heat electrification; local water mgmt
DLE (adsorbent/ion-exchange)	Electricity, sorbents/chemicals; high brine throughput	Potentially high energy/water if poorly matched	Pair with clean power; brine reinjection; match chemistry to brine; waste mgmt (Vera et al., 2023)
Geothermal-brine DLE	Geothermal heat/power	Site-dependent chemistry challenges	Low land footprint; integrated energy supply

Table 2 outlines different lithium extraction methods and their environmental considerations. Brine evaporation is linked to water stress in arid regions, while hard-rock mining has higher GHG intensity due to energy use. Direct lithium extraction (DLE) has potential but requires careful chemical and water management, whereas geothermal-brine DLE offers low land use and integrated clean energy if site chemistry is suitable.

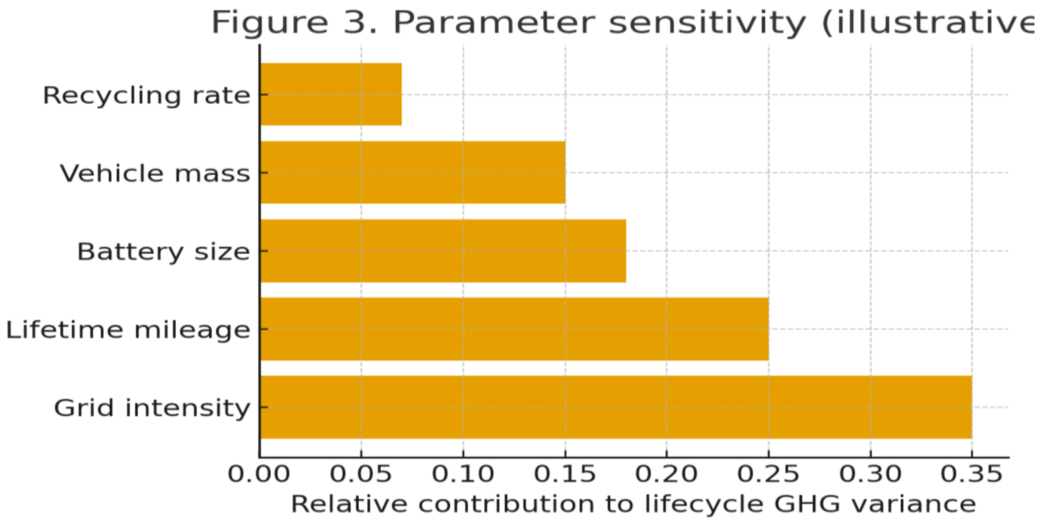

Figure 3. Dominant parameters driving lifecycle results, aligned with ICCT/GREET sensitivities (ICCT, 2024; Argonne National Laboratory, 2025).

Figure 3 illustrates the parameters most strongly influencing lifecycle outcomes—such as grid carbon intensity, battery size, and recycling efficiency—based on ICCT and GREET sensitivities.

Table 3. Battery recycling routes and indicative outcomes

Route	What is recovered	Typical recovery outcomes	Status/notes
Pyrometallurgy	Alloy containing Ni/Co/Cu; Li in slag	Robust, chemistry-agnostic; energy intensive	Commercial; often first step before hydro
Hydrometallurgy	Ni, Co, Mn, Li salts	High yields; chemical inputs/wastewater	Commercial & scaling; design-for-recycling helpful
Direct regeneration	Cathode active material structure	Lower energy; preserves microstructure	Pilots/early commercial; ReCell R&D focus

Table 3 compares recycling routes. Pyrometallurgy is robust and widely used, hydrometallurgy achieves higher recovery yields but requires chemical management, and direct regeneration preserves cathode structure, reducing energy inputs.

4.1 Lifecycle greenhouse-gas (GHG) results

BEVs consistently demonstrate lower lifecycle emissions across scenarios. Under the U.S. 2024 grid, BEV sedans emit 17–19 tCO_2e, while ICE sedans average 38 tCO_2e over 200,000 km. In coal-heavy grids, BEVs remain advantageous due to drivetrain efficiency, though the margin narrows. With deep grid decarbonization, BEV sedans achieve as low as ~12 tCO_2e. SUVs follow the same trend at higher absolute levels, reflecting greater size and weight (ICCT, 2024; IEA, 2024a).

4.2 Upstream impacts: oil vs. lithium

Fossil fuels create systemic upstream burdens. The IEA reports that oil and gas operations release over 120 Mt of methane annually, a potent short-lived climate pollutant (IEA, 2024c, 2024e). The World Bank notes flaring rose 7% in 2023 to 148 bcm, adding ~23 Mt CO_2e (World Bank, 2024). Lithium, by contrast, has localized impacts. Brine extraction can disrupt water balances in arid regions, while hard-rock mining disturbs land. Vera et al. (2023) stress that water recycling, brine reinjection, and careful siting can mitigate these impacts.

4.3 Recycling leverage and circularity

Recycling strengthens BEV sustainability by reducing the need for virgin mining and lowering production emissions. Hydrometallurgy recovers key metals efficiently; pyrometallurgy provides durable preprocessing. Direct regeneration goes further by preserving cathode microstructure, cutting energy use and avoiding resynthesis (Roy et al., 2024; ReCell Center, 2024). Reviews highlight that large-scale recycling in the 2030s will depend on collection systems, automated dismantling, and standardized digital tracking (He et al., 2024; Zanoletti et al., 2024; Sederholm et al., 2024).

5. Discussion

A persistent misconception in public debates is that the environmental burdens of lithium mining cancel out the climate advantages of electric vehicles (EVs). However, evidence from lifecycle assessment studies shows otherwise. The dominant source of climate benefit arises from the high efficiency of electric drivetrains combined with the potential for power sector decarbonization. In contrast, petroleum use is structurally carbon-intensive: most emissions occur during the use phase of combustion engines, and they are compounded by methane leakage and routine flaring in oil and gas production. Efforts to reduce these sources—through methane leak detection and elimination of routine flaring—have been ongoing for decades, yet international progress remains patchy (World Bank, 2024; IEA, 2024c).

For lithium, the relevant policy question is not whether mining should occur, but how it can be conducted in ways that minimize ecological disruption. Three design principles stand out. First, projects must be sited away from high-value hydro-ecological systems to avoid irreversible damage. Second, developers should be required to publish transparent water budgets and demonstrate the effectiveness of reinjection practices in brine operations. Third, facilities must rely on clean electricity and closed-loop water recycling to lower energy and water footprints. Applying these principles substantially narrows local impacts and aligns mining practices with broader sustainability goals.

Technology choices further influence outcomes. Direct lithium extraction (DLE) is often portrayed as a single innovation, but in reality, it comprises diverse processes with varying trade-offs. Some combinations of brine chemistry and sorbent technology result in high energy or water intensity, while geothermal-brine DLE offers promisingly low footprints, though its viability depends on site-specific factors (Vera et al., 2023). This underscores the importance of context-sensitive evaluation rather than blanket assumptions about new technologies.

Perhaps the most decisive factor for long-term sustainability is circularity. Unlike petroleum, whose combustion products disperse irreversibly into the atmosphere, lithium in batteries accumulates in an in-use stock that can, in principle, be recovered and repurposed. As the first generation of EV batteries reaches end-of-life, volumes of recoverable materials will grow substantially. This enables secondary supply to displace a rising share of primary mining, shrinking extraction footprints. Direct regeneration—where battery cathodes are restored rather than dismantled into base materials—holds particular promise for LFP and low-nickel NMC chemistries, which dominate mass-market EV production. Effective recycling not only reduces mining needs but also strengthens supply chain resilience by lowering dependence on geographically concentrated primary resources.

6. Policy Implications

The evidence suggests a multi-pronged policy framework. First, accelerating grid decarbonization while encouraging vehicle right-sizing amplifies the climate benefits of BEVs (IEA, 2024a). Second, methane leakage and routine flaring in the oil sector must be addressed through satellite-enabled leak detection, expanded gas-gathering infrastructure, and enforceable prohibitions on routine flaring (IEA, 2024c; World Bank, 2024). Third, lithium projects should face requirements for water stewardship, ecological siting, and independent monitoring of water use (Vera et al., 2023). Fourth, governments can scale circularity by mandating collection systems, developing digital battery passports, and supporting R&D into direct regeneration methods (ReCell Center, 2024; Roy et al., 2024). Finally, regulators should adopt technology-neutral, performance-based permitting that rewards demonstrable environmental outcomes in both fossil fuel and lithium supply chains.

Together, these measures can align EV adoption with broader decarbonization and sustainability goals, ensuring that climate gains are not undercut by local environmental harms or resource inefficiencies.

7. Conclusion

Viewed through the lens of modern lifecycle assessment, lithium-enabled electrification emerges as a far cleaner pathway than petroleum-based mobility. On the current U.S. grid, battery electric vehicles (BEVs) reduce lifetime greenhouse gas emissions by about two-thirds, with this advantage set to expand as electricity systems decarbonize. In contrast, oil remains structurally carbon-intensive: methane leakage, routine flaring, and unavoidable tailpipe emissions compound its climate burden and have proven difficult to eradicate despite decades of effort.

Lithium extraction, while necessary, brings localized environmental risks—particularly in water-stressed regions. Yet these challenges are not insurmountable. Careful project siting away from sensitive ecosystems, transparent water accounting, reliance on renewable electricity, and strict process accountability can significantly narrow the footprint. Unlike petroleum, which disperses its carbon irreversibly, lithium operates within a recoverable cycle. Recycling and direct regeneration offer a means to progressively reduce reliance on primary mining, strengthening both sustainability and supply security. The policy pathway is therefore clear: accelerate clean power, eliminate flaring and leaks, enforce rigorous water stewardship in lithium projects, and foster a circular battery economy.

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