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Real zero: an opportunity, not a cost

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About Climate Analytics

Climate Analytics is a global climate science and policy institute. Our mission is to deliver cutting-edge science, analysis and support to accelerate climate action and keep warming below 1.5°C.

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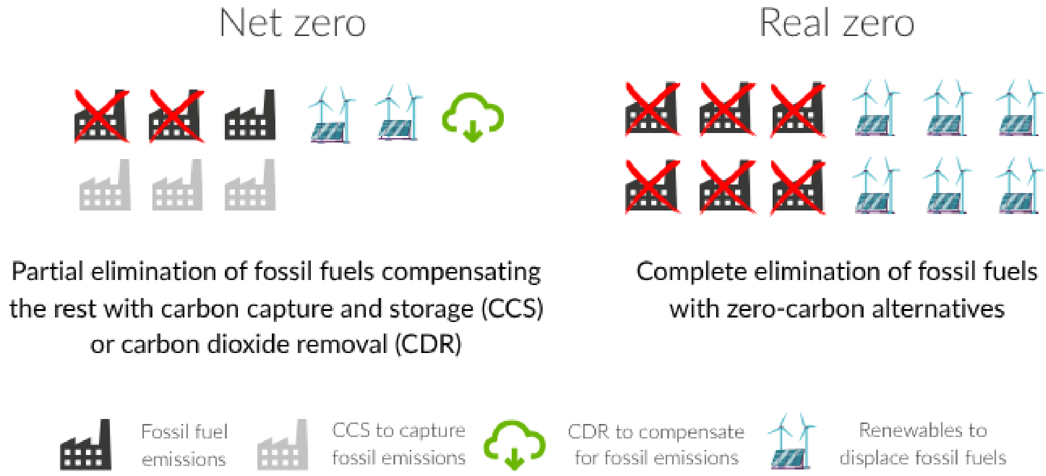
Summary

“Real zero” – the complete elimination of fossil fuels by replacing them with zero-carbon alternatives, rather than compensating for them with offsets, carbon dioxide removal (CDR) or carbon capture and storage (CCS) –also offers economic opportunities across heavy-industry and transport value chains. The evidence assembled here shows that following real zero emissions reduction options can lower total system costs, secure market access, and stabilise firms and economies against policy and fuel-price shocks.

In contrast, “corporate net zero” strategies that rely on offsets or deferred CCS/CDR tend to prolong exposure to volatile fossil inputs, crowd out scarcer removal capacity, and raise execution risk.



Climate action is often framed by a narrow “cost of action” lens, focusing on the perceived burden of mitigation efforts for businesses, industries, and economies. However, while the economic opportunities arising from decarbonisation are now widely acknowledged, pursuing real zero emissions further amplifies these opportunities. The increasing affordability of clean technologies, such as renewables, energy storage, and electrification, positions them no longer as expensive alternatives but as some of the most cost-effective options available. Their deployment reduces operational costs, strengthens efficiency, and provides early movers with a competitive edge in markets that are rapidly shifting toward sustainability.

Instead of a cost, climate action is business can be seen as an investment in efficiency, resilience, and long-term competitiveness.

This report explores the economic opportunities of transitioning sectors of the economy to reach real zero, focusing on three key areas: the potential for increased competitiveness, investment attractiveness, and economic resilience.

The economic opportunities of real zero:

- **Competitiveness and cost leadership:** The frontier of real zero mitigation options is expanding due to the rapidly declining costs of renewables and electrolysers, increases in battery storage and efficiency, and accelerating innovation in reducing process related emissions across so called “hard-to-abate” sectors. Firms moving early to transition to real zero systems will benefit from lower operating costs and first-mover access to low-carbon demand pools.
- **Economic resilience:** Taking fossil fuels out of the production process (both energy and non-energy) reduces exposure to fuel-price volatility and regulatory interventions (e.g., carbon pricing). It can also stabilise opex, and limit stranded-asset risks inherent to strategies dependent on offsets or carbon capture and storage (CCS). In the case of steel, taking fossil fuels out of the mix also enhances supply security by increasing reliance on domestically available energy and circular-material inputs rather than imported combustibles and virgin feedstocks.

Go fast, go early: when it comes to risk and option value, cutting emissions fast up front, outperforms deferral strategies that bank on uncertain CCS/CDR scale-up down the line.

In this context this report explores the economic opportunities of so called “hard-to-abate” sectors of the economy to reach real zero, focusing on these key areas through three case studies: steel in Japan, fertiliser in India and trucking in EU.

Evidence from the case studies

Japan's steel sector: cost-competitive real zero without sacrificing security

Japan's steel sector accounts for up to 14% of the nation's CO_2 emissions. Current plans have Japan targeting a ~30% cut in emissions from the steel sector by 2030 compared to 2013 levels. Policies indicate Japan will rely heavily on CCS to offset emissions from coal-based blast furnace-basic oxygen furnace (BF-BOF) assets to fulfil this goal.

Our analysis finds that transitioning to a real zero steel sector in Japan could be more cost-effective and enhance both economic and energy security compared to the business-as-usual approach. Specifically:

- **Secondary (scrap) steel:** Real zero secondary steel can be produced from scrap via 100% renewables-powered electric arc furnaces (EAF). This method is cost-competitive with fossil fuel powered options and reduces dependence on imported coal and iron ore in favour of domestic scrap and electricity.

- **Primary steel**: Current methods of producing primary steel using BF-BOF fitted with CCS cannot meet ambitious climate benchmarks. This is because CCS carbon captures rates remain low with little indication they will improve, making any carbon they do capture very expensive – limiting how much CCS can be used towards the benchmarks. Real zero primary steel can be produced from direct reduced iron-electric arc furnace (DRI-EAF) , where imported green iron enables production that can beat BAU costs as early as the early 2030s. Fully domestic real zero primary remains costlier, but the end product pass-through to consumers is modest and could be countered by policy instruments (e.g., carbon price, H_2 support, demand pooling).

In Japan, green hydrogen offers a pathway to near-zero steel production but is constrained by cost and supply. The high price of green hydrogen and limited production capacity present substantial barriers that need to be addressed through technology innovation and economies of scale.

Contrary to the prevailing narrative that CCS preserves a lower cost, real zero steelmaking in Japan in the 2030s is a viable, realistic option that is cost-competitive and directly reduces emissions – requiring no need for offsetting.

Green ammonia could transform India's fertiliser production

India is the world's second largest fertiliser consumer and third largest producer. India's current production model for nitrogenous fertilisers relies heavily on "grey" ammonia, which is produced using primarily imported liquefied fossil gas (LNG). This imposes several structural risks; exposure to global gas prices and fiscal burden for subsidies, leading to unpredictable production costs, supply chain risk for the food supply security, and a large climate externality.

A techno-economic comparison of BAU grey, "blue" and "green" ammonia shows that removing fossils fuels from the fertiliser sector and transitioning to real zero is feasible, more cost-competitive and would reduce exposure to price volatility from imported LNG:

- **Green ammonia is viable in the next decade:** the levelised cost of ammonia (LCOA) for green ammonia (ammonia produced using renewable electricity) falls below grey ammonia by 2034 across most of the analysed states of India – sooner in states such as Gujarat and Rajasthan which have high levels of renewables in their energy mix.
- **Blue ammonia is risky:** blue ammonia (ammonia produced from fossil fuels, with emissions captured by CCS) is still vulnerable to fossil fuel prices and depends on the unproven capture performance of CCS and risks increasing residual emissions. Other risks include relying on large-scale CO_2 transport and storage build-outs that are currently without policy and financing traction.
- **Policy tailwinds favour green ammonia:** the National Green Hydrogen Mission and SIGHT incentives are already crowding in private capital, as seen in competitive green-ammonia auction bids. India also continues to support renewable energy deployment.

In India, shifting to green ammonia production could unlock major economic opportunities for the fertiliser industry, yet ensuring affordable, renewable energy supplies and technological advancement will be critical to achieving this shift. Ammonia produced using renewable energy is on track to become cheaper than ammonia produced using fossil fuels in the 2030s, due to the falling cost of renewables. Green ammonia cuts emissions at source, decouples costs and subsidies from gas volatility, and reduces import dependence – all with negligible pass-through to food prices.

Early electrification of EU trucking sector cheaper in the long run

For road freight in Europe, a real zero trucking sector is on the cusp of becoming cheaper than traditional diesel vehicles. Battery electric trucks are almost at the threshold of beating out the current diesel BAU model when assessed on total cost of ownership (TCO) – these should reach parity in 2026, and by 2030 could be 15-22% cheaper than diesel alternatives.

By 2040, battery electric trucks could be up to 24% cheaper, depending on the truck type. Upfront cost parity should follow between 2030–2040.

- **Alternatives:** Other real-zero alternative to diesel, such as fuel-cell and CNG/LNG options, remain more expensive than battery electric trucks. with CNG/LNG trucks 45–58% more expensive to operate than BETs in 2030.
- **Carbon pricing exposure:** Under the next phase of EU emissions trading system (*EU ETS II*), diesel vehicles face rising total cost of ownership over time, with laggards incurring up to 11% higher costs by 2035 versus early battery electric truck adopters.
- **Operational feasibility:** Depot charging and targeted corridor fast-charging can enable high-utilisation duty cycles. Early adopters can harvest savings of tens to hundreds of millions annually for very large fleets by 2030, while achieving ~66% emissions cuts by 2030 from 2020 levels.

In Europe, trucking is moving towards electrification powered by renewable energy. The business case for early, full electrification of the sector with battery-electric trucks (BETs) wins decisively over the continued use of diesel trucks on economics and compliance risk.

It’s plausible that the entire EU trucking fleet could be electrified by 2050, however, scaling the infrastructure required to support this and overcoming deployment challenges remain significant hurdles. The transition will require policy clarity on timelines for electric vehicle charging build-out, supply readiness, and ICE phase-out.

Strategic approaches for achieving real zero

- **For firms:** To get ahead, prioritise real zero energy sources (where technically mature) over fossil fuels that require offsetting. Electrify first; then prioritise green molecules when there is no viable electrification path, then back-solve residuals. This locks in opex stability and market access premiums while minimising stranded-asset risk.

- **For investors**: Treat CCS-dependent extensions of combustion assets as duration-mismatch risk and favour assets whose cash flows ride learning curves (renewables, BETs, electrolysis, scrap/EAF).

- **For policymakers**: Combine carbon pricing with infrastructure and innovation support (grids, charging, H_2 for process-critical uses), produce standards/procurement for low-carbon materials, and design governance that reserves CDR for residuals and potential overshoot, not routine offsetting.

Finally, when supported by the right policy mix, real zero becomes not only viable, but the most efficient and prudent economic pathway. Case studies highlight both the opportunities and the bottlenecks that must be addressed to accelerate the adoption of real zero pathways and realise their full economic potential.

Table of Contents

Real zero brings long-term economic benefits

The need to limit global warming to 1.5°C is more pressing than ever. Achieving this target requires the rapid transformation of industries and sectors to align with a sustainable, low-carbon future. In this context, the concept of real zero – eliminating use of fossil fuels at source by replacing them with zero-carbon alternatives rather than compensating for them through carbon offsets or carbon removal technologies and carbon capture and storage – presents a transformative approach to mitigating climate change while generating long-term economic benefits.

Climate action has often been framed primarily as a cost to businesses, industries, and economies, with emphasis on the burdens of mitigation. While economic opportunity from decarbonisation is now broadly recognised, real zero emissions by eliminating emissions at source rather than relying on offsets, amplifies those opportunities by delivering high-integrity emissions reductions that secure market access, reduce policy risk, unlock structural efficiency gains, and catalyse resilient local supply chains. This report explores the economic opportunities of transitioning sectors of the economy to reach real zero, focusing on three key areas: the potential for increased competitiveness, investment attractiveness, and economic resilience.

The Stern Review (2007) established the foundational economic case for climate action, concluding that the benefits of strong and early mitigation substantially outweigh the costs of inaction (Stern, 2007). At its core, Stern's analysis emphasised two principles: first, that climate change represents the greatest market failure in history, with damages escalating over time and disproportionately affecting the poorest; and second, that delaying action raises costs by locking in high-carbon infrastructure and increasing the scale of future adjustment. Within this framing, the logic for pursuing real zero pathways, direct elimination of fossil-fuel emissions without reliance on speculative technologies and offsets, flows directly from risk-based and welfare economic reasoning. Offsets do not correct the externality at source, while real zero directly reduces cumulative emissions.

The economics of climate action rests not only on expected cost-benefit comparisons but also on risk management under uncertainty (e.g., non-negligible catastrophic tail risks), which strengthens the rationale for front-loaded, real-emissions reductions (Dietz & Stern, 2008; Weitzman, 2009). It is well recognised in scientific literature that overreliance on carbon capture and storage (CCS) and carbon dioxide removal (CDR) is a high-risk strategy. Both options are broadly nascent, with limited deployment and a poor historical track record (e.g., high failure rates in fossil-CCS demonstrations), and they face technical, price, and geophysical constraints, including limited CO_2 storage and water availability. Even if scaled, several CDR approaches carry food-security, biodiversity, and broader sustainability trade-offs. Crucially, if we overshoot the 1.5°C temperature limit of the Paris Agreement, CDR will be needed to reduce peak temperatures, leaving insufficient capacity to also offset large volumes of ongoing fossil emissions (Climate Analytics, 2025). The implication is clear: minimise the need for future removals by cutting gross emissions at the sectoral level and reserve CDR for its most critical roles.

The central question we explore in this report is whether an economic rationale already exists today for rapid, real, elimination of fossil fuels at their source. At the sector level, the challenge of justifying real zero is to identify how it can be achieved in practice, where technologies are already viable, and what targeted policies can accelerate progress. It is essential to situate these figures within the broader economic context (discussed further in the case studies below). The implications extend beyond individual industries, shaping consumer prices, trade competitiveness, fiscal balances, and macroeconomic welfare. Evaluating these systemic consequences is central to understanding not only the feasibility of rapid fossil-fuel elimination but also its distributive and political economy dimensions.

Real zero vs net zero

Both net zero and real zero pathways seek deep decarbonisation but differ in how reductions are defined and pursued. Net zero balances residual emissions at the global level with removals, allowing continued emissions in some critical sectors by negative-emissions technologies (NETs) such as bioenergy CCS (BECCS), direct air capture (DAC), or offseting by large-scale afforestation. Net zero may also use offsets and carbon credits outside the emitter's boundary (Climate Analytics, 2025).

At the global scale, net zero is indispensable as warming stops when CO_2 reaches (net) zero and falls when total GHGs reach and are sustained at (net) zero. Because some non-CO_2 sources are structurally hard to eliminate, global net zero GHGs necessarily entails some removals to counterbalance residual non-CO_2 emissions. Around mid-century, limited removals may also be needed to balance any residual CO_2 on the path to eventual real zero CO_2 (Climate Analytics, 2025; IPCC, 2022).

The widespread corporate interpretation of “net zero” has shifted from a scientific global balance to a firm-level accounting device, often allowing continued fossil energy CO_2 offset by credits, CCS outside the boundary, or future CDR. This “corporate net zero” framing can lock in fossil demand, divert scarce CDR from its highest-value use, and ultimately may undermine whether we can achieve global net zero GHGs (Climate Analytics, 2025). Therefore, pivoting corporate strategies towards real zero wherever technically and economically feasible will be essential for ensuring we meet our climate goals.

In contrast, real zero emphasises achieving actual emissions reductions at the source rather than compensating their continued use. It does not justify ongoing combustion where direct elimination is viable, especially given that full capture is unlikely through CCS. In real zero strategies, CDR is then only reserved for global system-level balancing of unavoidable residuals and, if needed, for bringing temperatures down after overshoot – not for underwriting continued large-scale fossil consumption.

Our analysis situates the economics of real zero within a systemic sectoral lens. This framing is not only environmentally robust; it is increasingly feasible and economically rational. Rapid declines in the costs of renewables and batteries and accelerating innovation across so called “hard-to-abate” sectors, are expanding the frontier of real zero options.

This is illustrated through three case studies that show how real zero approaches are emerging across key sectors in a cost-competitive way. In Europe, trucking is moving towards electrification powered by renewable energy, with supporting infrastructure beginning to play a leading role in decarbonisation, though deployment and scaling challenges remain. In Japan, green hydrogen offers a pathway to near-zero steel production but is constrained by cost and supply. In India, shifting to real zero ammonia production could unlock major economic opportunities for the fertiliser industry, yet requires significant investment in renewable capacity and technology development. Together, these examples highlight both the opportunities and the bottlenecks that must be addressed to accelerate the adoption of real zero pathways and realise their full economic potential.

Economic opportunities of real zero pathways

Increased competitiveness: lowering operational costs and gaining first-mover advantage

One of the most compelling reasons for embracing real zero pathways is the potential to enhance competitiveness. Businesses that transition to low-carbon operations can significantly lower their operational costs by adopting renewable energy sources and energy-efficient technologies, thus gaining a market advantage.

In this context it is important to recognise the role of endogenous technological change, as innovation responds to policy and investment. Well-designed policies and targeted capital can accelerate mitigation without compromising development goals. ~~p~~ Studies have shown that ambitious mitigation could stimulate growth and accelerate cost reductions (Barbier, 1999; Löschel, 2002). Subsequent empirical studies confirm this dynamic: learning rates[1] for solar and wind have consistently driven down costs, with each doubling of deployment reducing prices by 15–25%, with accelerated learning rate of 40-45% in recent years (Bolinger et al., 2022). The past decade has seen the cost of renewable power and batteries fall to become the cheapest sources of new energy in most regions (IRENA, 2024). This cost trajectory strengthens the case for real zero today, not only as an environmental imperative but as economically efficient, given that further delay foregoes innovation spillovers and prolongs reliance on volatile fossil markets.

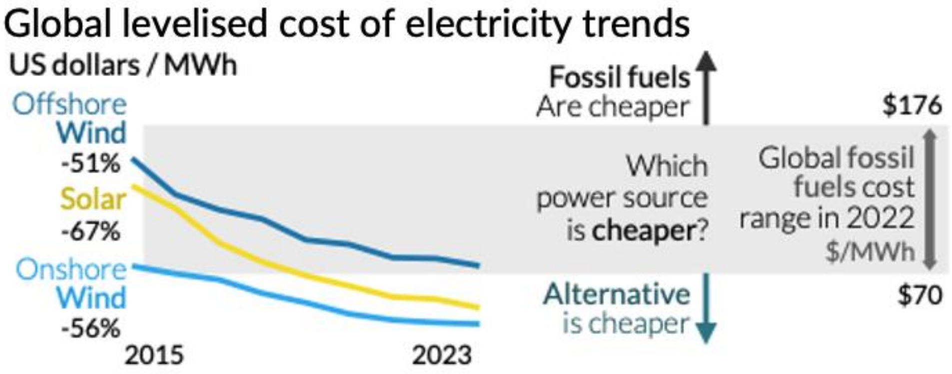


Figure 1: Globally, the levelised cost of solar and wind has declined consistently since 2015, and it is now competitive with the levelised cost of fossil fuel-based power. Data source: (IRENA, 2024)

[1] The learning rate is the percentage reduction in unit cost (or price, as a proxy for cost) associated with each doubling of cumulative experience (most often measured as cumulative production).

Moreover, advances in energy storage technologies, such as lithium-ion batteries, are enabling companies to manage energy fluctuations more effectively and reduce reliance on expensive fossil fuels for backup power. These technological advancements contribute to a reduction in operational expenditures, creating a competitive edge for businesses adopting clean technologies.

In addition to cost reduction, real zero pathways offer a distinct first-mover advantage. Companies that are early adopters of clean technologies and sustainable practices can establish themselves as leaders in the market, thereby gaining brand reputation and securing long-term contracts with consumers who are increasingly prioritising environmental responsibility. By setting the standard for low-carbon practices, early adopters are also able to preemptively adjust to evolving regulatory frameworks, avoiding potential penalties for non-compliance with climate policies.

Economic resilience: mitigating regulatory risks and exposure to volatile fossil fuel markets

Economic resilience is another key benefit of transitioning to real zero . In an era of intensifying climate change impacts, industries must be prepared for both physical and market-related disruptions. By adopting real zero strategies, businesses not only align themselves with global sustainability goals but also build resilience against future climate risks.

One of the primary risks that businesses face is regulatory change. As the global push for climate action intensifies, governments are implementing increasingly stringent environmental regulations, including carbon pricing mechanisms, carbon taxes, and emissions reduction targets. The increasing stringency of climate regulations, such as carbon pricing and emissions reduction targets, means that companies failing to decarbonise will likely face higher operational costs and potential fines. Conversely, businesses that adopt real zero strategies can mitigate these risks by being ahead of regulatory requirements, ensuring compliance with future policies while avoiding associated penalties (Carbon Trust, 2020).

Conversely, those that proactively embrace real zero strategies can benefit from early access to incentives, subsidies, and regulatory support, ensuring their operations remain in line with future climate policies (World Bank, 2021).

The transition to real zero reduces exposure to fossil fuel price volatility, which has become an increasing concern in recent years. As seen during the COVID-19 pandemic and subsequent global supply chain disruptions, fossil fuel prices can fluctuate significantly, creating financial instability for businesses reliant on these energy sources.

By shifting to renewable energy and energy-efficient systems, companies reduce their dependence on fossil fuels, insulating themselves from price shocks and providing greater predictability in their energy expenditures.

Real zero adoption reduces a company's reliance on volatile fossil fuel markets, providing more stability in its financial operations. As fossil fuel prices fluctuate due to geopolitical tensions, supply chain disruptions, or changes in demand, companies dependent on these sources face increased financial uncertainty. By transitioning to renewable energy and energy-efficient technologies, companies can stabilise their energy costs and protect themselves from such market volatility.

Real zero pathways contribute to resilience by ensuring that companies are better prepared for climate-related physical risks, such as extreme weather events and disruptions to supply chains. By decarbonising their operations to reach real zero and adopting sustainable practices, businesses reduce their vulnerability to climate impacts, ensuring continuity of operations and long-term viability in an increasingly volatile world.

The economics of real zero: beyond the cost narrative

Debates around climate action have long been dominated by the idea of a “cost of action,” as if decarbonisation were primarily a financial burden. Real zero pathways call for a different perspective. By looking at the evidence, what initially appears to be a cost is better understood as an investment in efficiency, resilience, and long-term competitiveness.

First, clean technologies such as renewables, energy storage, and electrification are no longer expensive alternatives but increasingly the most cost-effective options. Their deployment reduces operational costs, strengthens efficiency, and provides early movers with a competitive edge in markets that are rapidly shifting toward sustainability. In this sense, the transition is not merely about bearing costs today but about seizing economic opportunities for tomorrow.

The economic case is further strengthened by co-benefits and risk reduction. Mitigation also delivers ancillary gains, notably improvements in health from reduced air pollution. More recent evidence shows that health co-benefits alone can offset a substantial share of mitigation costs, particularly in regions heavily dependent on coal and oil (Shindell et al., 2018). In addition, early elimination strategies minimise the financial risks of stranded fossil assets, which could impose systemic costs in disorderly transitions (Mercure et al., 2018). Real zero therefore contributes not only to climate stability but also to economic resilience by insulating industries and economies from policy tightening and fossil fuel price volatility.

Finally, when supported by the right policy mix, real zero becomes not just viable but the most efficient and prudent economic pathway. Carbon pricing, combined with innovation support, infrastructure investment, and regulation, can accelerate deployment at scale while ensuring that risks are minimsed and co-benefits maximised (Stiglitz & Stern, 2017).

As the global economy charts out pathways forward to a rapid reduction of GHG emissions, hard-to-abate sectors risk slowing down the progress. Hard-to-abate sectors refer to industries where reducing carbon emissions is particularly difficult due to the nature of their processes and their heavy reliance on fossil fuels. These include essential industries like steel, cement, chemicals, and transportation which face significant technological and economic challenges. But these challenges are drivers for accelerated innovation and investment. Aligning their GHG emissions trajectory with the Paris Agreement’s 1.5°C warming limit is imperative. These sectors themselves are crucial: they provide the materials, goods, and connectivity that support housing, healthcare, food security, and even the clean-energy transition itself. It is therefore necessary to maintain these essential services while simultaneously achieving sectoral emissions reductions in line with the Paris Agreement.

These are further explored through three case studies from so called ‘hard to abate” sectors: the steel industry in Japan, the fertiliser sector in India, and the trucking industry in the European Union. Each of these case studies demonstrates how real zero pathways play out in practice, revealing both the opportunities of transitioning industries with different technological, economic, and policy contexts. Together, they provide concrete illustrations of why the economics of real zero represent not a cost to be borne, but the foundation of a more competitive and resilient global economy.

Evidence from the case studies

Towards a real zero transformation of Japanese steel

Japan's climate plans favour a gradual transition away from carbon-intensive steelmaking. The national approach mostly promotes carbon capture and storage (CCS) and other purported solutions to "abate" ongoing emissions. Japanese steelmakers and officials reject an alternative transformation that would see rapid deployment of "real zero" technologies capable of eliminating emissions at-source.

In this report, we show that these preferences are flawed. Japanese stakeholders often present their approach as cost-effective climate action, and aligned with national energy and economic security concerns. However, a "real zero transformation" can be more cost-effective. It can be cheaper than even elements of business-as-usual (BAU) steelmaking. And real zero need not compromise energy or economic security — in some instances, it can better manage Japan's security concerns than BAU production.

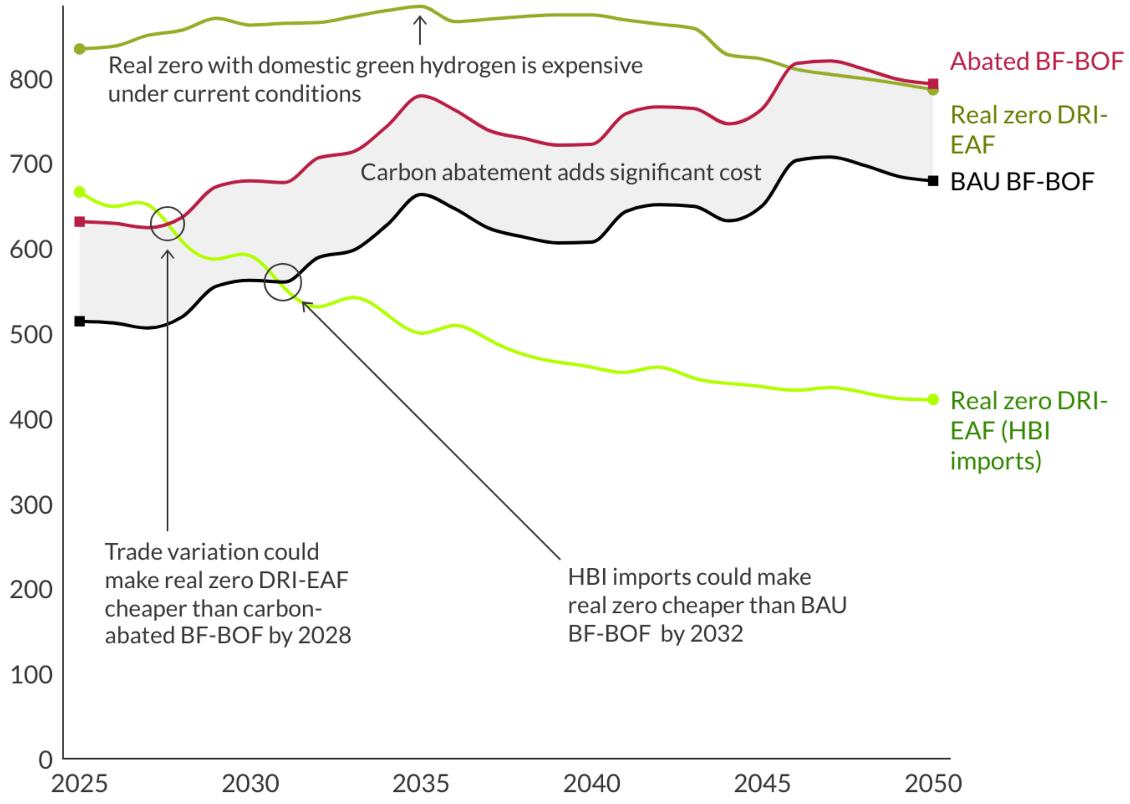
Steelmaking accounts for up to 14% of Japan's CO_2 emissions. Yet the industry's current target is only a 30% emissions reduction by 2030 (from a 2013 baseline), compared with a 45% reduction goal for the broader Japanese economy. Government plans envision most emissions cuts coming from CCS applied to coal-dependent blast furnace-basic oxygen furnaces (BF-BOF), which generate 75% of Japan's steel.

We test whether and how Japanese steel production could be adapted to meet ambitious emissions reduction benchmarks, specifically the International Energy Agency's "near zero steel" definitions, and assess the implications for cost, as well as energy and economic security. Factors shaping our analysis include the comparatively old age of Japan's BF-BOF plants, and the need for steelmakers to decide whether to reinvest in about half the country's BF-BOF capacity by the end of 2030.

We assess potential production pathways for both "primary" (using mainly iron ore inputs) and "secondary" steel (using mainly recycled steel inputs), under ideal conditions.

We find Japan already has a real zero steel pathway capable of meeting our ambitious emissions benchmark in a more cost-competitive manner than its BAU equivalent. Secondary scrap-based steel produced in a 100% renewables-powered electric arc furnace (EAF) can outcompete BAU scrap EAF production drawing power from the grid. Japan could accordingly scale up this route, alongside renewable energy production.

Japan will continue to require substantial primary steel production. However, our analysis finds the BF-BOF route cannot remain cost-competitive against rival modes while meeting our emissions benchmark. There is no viable real zero pathway for BF-BOF production, and a carbon-abated approach relying heavily on CCS would be too expensive. While it would lower costs, CCS retrofitted to existing BF-BOF plants cannot achieve Paris-aligned emissions reduction. Moreover, any apparent future-proofing of BF-BOF production inevitably relies on unrealistic assumptions on CO_2 capture rates.



With iron trade, real zero could quickly outcompete Japan's carbon-intensive BF-BOFs

Levelised cost of steel for real zero DRI-EAF vs BAU and carbon-abated BF-BOF pathways for primary steel production in Japan, USD/t, 2025-2050

Figure 2. Levelised cost of steel for real zero direct reduced iron-electric arc furnace (DRI-EAF) vs business-as-usual (BAU) and carbon-abated blast furnace-basic oxygen furnace (BF-BOF) primary steel production, USD/t, 2025-2050. Source: Climate Analytics/Transition Asia

While other potential options are emerging, the battle over cost-competitive, suitably climate ambitious primary steel production in Japan is currently closest in the alternative direct reduced iron-electric arc furnace (DRI-EAF) route. Japan does not currently use this technology at commercial scale, and fossil gas-dependent DRI-EAF production elsewhere remains too carbon-intensive.

DRI-EAF production can be adapted to meet our emissions benchmark through either carbon-abated or real zero pathways. We consider two carbon-abated pathways: one uses fossil gas for energy and to “reduce” iron, while capturing plant emissions, and the other substitutes “blue hydrogen” for these purposes, with emissions captured from fossil feedstocks. We also consider a real zero pathway using renewables-powered “green hydrogen” for energy and reduction. We also consider trade variations, using imported hot briquetted iron (HBI, an easily shipped and handled form of DRI) for both blue (carbon-abated) and green (real zero) hydrogen-based DRI-EAF.

With the trade variation of imported HBI, real zero DRI-EAF could become a competitive option for Japanese primary steel production — cheaper than BAU DRI-EAF by the early 2030s. Carbon-abated DRI-EAF pathways can more easily reach our emissions benchmark than carbon-abated BF-BOF alternatives. However, these options would again put production on course to be pricier than the trade-varied real zero DRI-EAF pathway (and would still rely on ambitious CCS assumptions).

Under current conditions, more domestically focused Japanese real zero primary steel production, utilising the DRI-EAF route, will remain uncompetitive against alternatives, largely due to Japanese challenges producing affordable green hydrogen.

Nevertheless, the associated “green premium” for domestic hydrogen-based real zero DRI-EAF in Japan could be relatively minor for steel end users, adding only 1-2% to the cost of a domestically produced car. Policy interventions, such as stronger hydrogen subsidies, carbon prices, and coordinated private or public demand could further improve the economics of real zero.

A real zero transformation of steelmaking need not clash with Japan’s stated energy and economic security concerns. The cost-competitiveness of real zero suggests it is best positioned to future-proof Japan’s steel production levels, and the national values attached to these, as the country achieves its climate goals.

Real zero transformation might also deliver discrete energy and economic security benefits. For example, scaling up renewables-powered EAF secondary steel production relative to BF-BOF primary production could reduce demand for imported iron ore and coal in favour of less material- and energy-intensive (and more domestically sourced) scrap and renewable energy. In addition, the trade variation of real zero DRI-EAF primary steel production, using HBI imports, would offshore the most energy-intensive stage of steelmaking, and related security concerns, to other countries.

Contrary to what Japanese steelmakers and officials claim, real zero is preferable to a carbon-abated approach on cost-competitiveness, as well as energy and economic security. It can even improve on BAU conditions in some circumstances.

Road to real zero freight trucking in Europe

Achieving real zero emissions – defined as eliminating tailpipe emissions entirely by or before 2050 – is the most cost-effective and sustainable strategy for European road freight logistics companies. This report demonstrates that early adoption of battery electric trucks (BETs) is not only the best approach for decarbonisation but also delivers the greatest long-term financial savings.

Existing literature shows that from a total cost of ownership (TCO) perspective, cost parity of BETs with diesel trucks has been reached for urban and regional delivery trucks. For long-haul trucks, BETs are expected to reach TCO parity with diesel trucks between 2025 and 2026. In practice, logistics trucking companies typically operate a mix of routes, including urban, regional and long-haul segments. This report analyses the potential financial savings of pursuing a real zero emissions pathway compared to alternative, less ambitious strategies, at a company fleet level. However, to realise these benefits, companies must act quickly and accelerate their adoption of BETs within this decade.

The analysis compares different powertrain transition strategies, including Early Action (real zero), Business-as-Usual with a split powertrain mix, Current Action with full electrification, and Delayed Action towards full electrification.

The findings show that transitioning to BETs under an early action strategy, aligned with real zero emission pathways, offers the lowest TCO across all mission profiles. To align with real zero pathways, companies would need to transition their fleet to a 68% BET share by 2030 and be fully electrified by 2045. By 2030, the TCO of BETs are projected to be 15–22% cheaper than diesel trucks. In contrast, other powertrain options, including fuel cell electric trucks (FCETs) and compressed natural gas (CNG) and liquified natural gas (LNG) vehicles, remain more expensive, with the latter projected to cost 36%–46% more to operate than BETs by 2030.

The upfront costs of BETs are falling and by 2030, are expected to be 34% lower than today, with the retail price dropping to an average of 200,300 EUR. By 2040, this price reduction is projected to reach 65%–75% compared to 2020 prices, making BETs even more economically attractive compared to diesel or hydrogen alternatives. By 2050, these companies are projected to fully electrify their fleets, resulting in 100% emissions reductions.

The Early Action scenario, which aligns with the real zero emissions pathway, achieves significant emissions reductions early on. It represents companies that adopt BETs early and at scale, resulting in faster fleet electrification, lower TCO, and the deepest emissions reductions. By 2030, companies following this path would need to have 68% of their fleet comprised of BETs, achieving 66% emission reductions compared to 2020 levels. By 2045, early acting companies achieve full decarbonisation. An Early Action approach delivers a 16% lower TCO compared to a Business-as-Usual approach in 2030. On the other hand, if companies delay achieving real zero emissions pathway by five years with slower BET uptake, they can still achieve real zero by 2045 but face higher TCO costs. In 2030, TCO costs will be 7% higher TCO costs than that of an early action approach. However, additional actions would be needed to cut the difference in carbon budget that will exist between a delayed action and an early action approach.

Companies following a current action or business-as-usual approach will rely on more expensive and polluting powertrains like diesel and CNG/LNG, which will become increasingly uneconomical under the road transport EU ETS II carbon pricing system. Even without the ETS II, this study shows it will still be more cost-effective for companies to rapidly shift to BETs rather than maintain their existing diesel truck fleets. These companies will also register higher emissions, with a BAU scenario only achieving a 50% emissions reduction by 2050 compared to 2020 levels, far from the full reduction needed to meet EU climate targets.

Our analysis models the transition for a large trucking company operating 10,000 trucks across a mix of regional delivery, return-to-depot long-haul, and cross-border long-haul operations. While most trucking firms are small- or medium-sized enterprises, the largest operators will play a pivotal role in driving the sector’s transition. Their greater resources enable them to adopt BETs early, helping to establish an affordable second-hand market that will make it easier for smaller companies to electrify their fleets.

The financial case for early action is further supported by the substantial savings that early adopters of BETs can expect. These savings will come from cheaper fuel costs, maintenance, compliance with road tolls and charges, and added savings from the EU ETS II which will increase the costs for diesel truck owners.

For instance, by 2030, large road freight logistics companies with fleets above 10,000 trucks and following the early action strategy could save between €49 million and €108 million annually in operational costs compared to slower adopters, without the added cost of the ETS II. By 2040, delayed transition could result in operating costs up to 4% higher compared to early adopters, underscoring the growing economic advantage of adopting BETs sooner rather than later.

For the first time, this report tries to quantify what the added cost impact of the ETS II will mean for trucking companies. Companies relying on diesel trucks will face rising costs as carbon prices increase. In 2030, companies with a high share of diesel trucks could see their TCO increase by up to 7% under a high carbon price scenario, compared to only a 3% increase for early BET adopter companies with a real zero aligned BET share. In relative terms, BAU companies will pay an additional 4% under a high ETS II price, on top of the 16% TCO cost difference compared to early acting companies. In monetary terms, a BAU approach would cost a company an additional 5 to 66 million EUR annually in 2030, due to continued reliance on fossil fuel-powered trucks. By 2040, this cost gap becomes even more significant, with BAU companies facing up to 6% - 10% higher costs. In contrast, companies that adopt BETs early will experience minimal cost increases, ranging from 1% - 2%. Beyond 2040, early BET adopters will not pay any ETS II premiums as their fleet will be fully electrified, making early adoption the most financially advantageous strategy.

Depot charging presents a practical solution for overcoming charging time constraints in long-haul operations. Depot charging allows trucks to recharge when they are not in use, taking advantage of off-peak electricity rates and minimising the impact on daily operations. This model works particularly well for return-to-depot operations, where trucks operate within a predictable range, allowing logistics companies to invest in private charging infrastructure at their depots. This approach reduces the need for public charging stations and mitigates the risk of congestion at high-power charging points.

Companies can implement operational strategies such as dynamic charging, where trucks power-up during mandatory driver rest periods, ensuring that idle time does not disrupt delivery schedules. Additionally, advancements in fast-charging infrastructure at strategic locations along highways can facilitate cross-border operations and inter-city freight movement. These charging stations, placed on key logistics corridors, can provide rapid refuelling opportunities for BETs, complementing depot charging infrastructure and enabling more flexible operations.

To support the transition to zero-emission freight trucking, the EU and member states need to implement several key policy changes, including:

- High-power charging infrastructure should be deployed along key logistics corridors, ensuring the availability of fast and reliable charging for BETs.
- Provide subsidies, grants or tax exemptions to enable logistics companies to overcome the high upfront costs of BETs – especially SME operators.
- Increase the number of megawatt charging systems (MCS), and encourage the development of private depot charging solutions through incentives or subsidies for fleet operators.
- Ensure that EU ETS II revenues are used to support SME truck operators through the uptake of BETs.
- Set strong BET mandates for larger companies through the Green Freight Initiative currently under development.
- Increase the stringency of CO_2 standards for new heavy-duty vehicles to at least a 65% reduction by 2030, coupled with mandates for BET sales for truck manufacturers.
- Send clear policy signals to vehicle manufacturers and logistics companies that fossil gas and biofuels are not suitable and represent costly lock-in investments into technologies that will not be compatible with achieving the EU's net-zero goals.

The EU must provide long-term policy certainty for logistics companies, particularly around emission reduction targets and the phase-out of internal combustion engine (ICE) trucks. Clear deadlines for the end of diesel truck sales and strong regulations on CO_2 emissions will give companies the confidence to make long-term investments in BETs and the required charging infrastructure.

The EU needs to ensure that production and supply of BETs in Europe can meet demand if logistics companies are to take an early action approach. If supply cannot be met, then logistics companies may have no choice but to slow their BET transition while simultaneously absorbing higher costs from keeping their diesel fleets operational. Additionally, the EU risks weakening the strategic importance of its vehicle manufacturing industry if BET production is not meeting domestic demand, as the resulting supply gap would likely be met by imports from third countries.

The early adoption of BETs leads to significant cost savings and emissions reductions, while companies that delay the transition risk being burdened with higher operating costs and missed opportunities for financial and environmental benefits. Early action is therefore crucial to securing a competitive advantage, meeting EU climate targets, and ensuring long-term sustainability in the European freight sector.

Transforming India’s fertiliser production with green ammonia

India's fertiliser sector is a cornerstone of its food security, but its high import dependence and subsidy burden create significant macro-economic strain. India is the world's second-largest consumer and third-largest producer of fertiliser. However, the sector's foundation is increasingly unstable. The current production model for nitrogenous fertilisers relies heavily on “grey” ammonia, which is produced using primarily imported liquefied fossil gas (LNG). This dependency creates a set of interconnected risks for India:

1. **Economic risk:** Exposure to volatile global energy prices, leading to unpredictable production costs and a massive subsidy burden.
2. **Supply chain risk:** Reliance on imports for a critical agricultural input, which creates balance of payment risks and exposes the food supply chain to geopolitical shocks.
3. **Environmental and climate risk:** The high emissions from production jeopardise India's climate commitments, including its net-zero goal.

This report presents a techno-economic analysis of decarbonisation pathways for India's fertiliser sector. It compares the conventional business-as-usual (BAU) grey ammonia pathway with two alternatives: a carbon abated business-as-usual (CA-BAU) pathway using carbon capture and storage (CCS) to produce blue ammonia, and a real zero pathway that uses renewable electricity to produce green ammonia.

The analysis conclusively demonstrates that the real zero pathway is the most viable, economically advantageous, and strategically sound solution for India's future. Among the outlined pathways, the real zero approach is the only one which addresses all three risk dimensions identified above.

Real zero reduces fiscal exposure by decoupling costs (and subsidies) from global gas price volatility, India’s core economic vulnerability in the fertiliser sector. To address the supply chain risk factor, real zero strengthens supply security by lowering dependence on imported LNG and related balance-of-payments/geopolitical risks. And, crucially, real zero is the only pathway that fully cuts process emissions, aligning the sector with India’s net zero ambitions.

Key findings

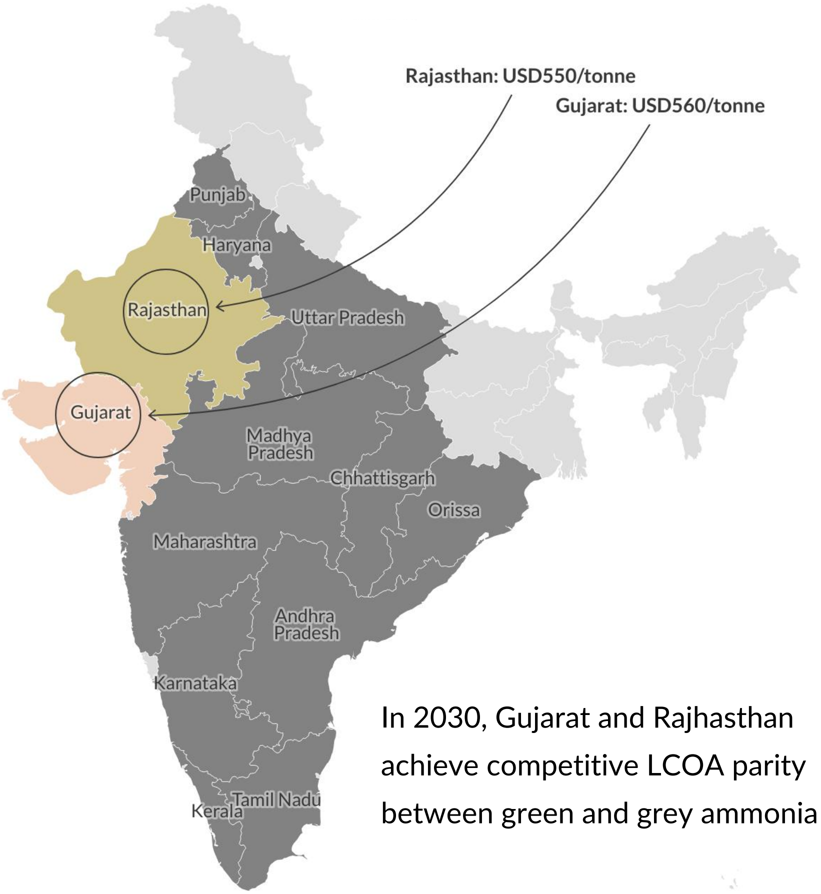
The analysis reveals that while grey ammonia currently holds a slight cost advantage, a decisive economic and technological shift is underway. The real zero pathway is not a distant aspiration but an imminent reality with clear benefits.

- **Green ammonia is on a clear trajectory to cost less:** The primary driver of this transition is the dramatic and ongoing cost reduction in renewable energy and electrolysis technology. Our quantitative analysis models levelised cost of ammonia (LCOA) for green production in 13 of India's 28 states.

  By 2034, our modelling indicates that green LCOA falls below grey LCOA in 10 of these 13 states. In states with high renewable potential, such as Gujarat and Rajasthan, this crossover is expected to happen as early as 2030, establishing them as leaders in a decarbonised fertiliser industry.
- **The real zero pathway is economically advantageous:** The blue ammonia pathway, reliant on LNG and CCS, is found to be less efficient and economically less competitive, and given the imminent competitiveness of green ammonia, would not make sense even as a transitional step. It also fails to eliminate the core problem of dependence on volatile fossil gas prices and upstream emissions.

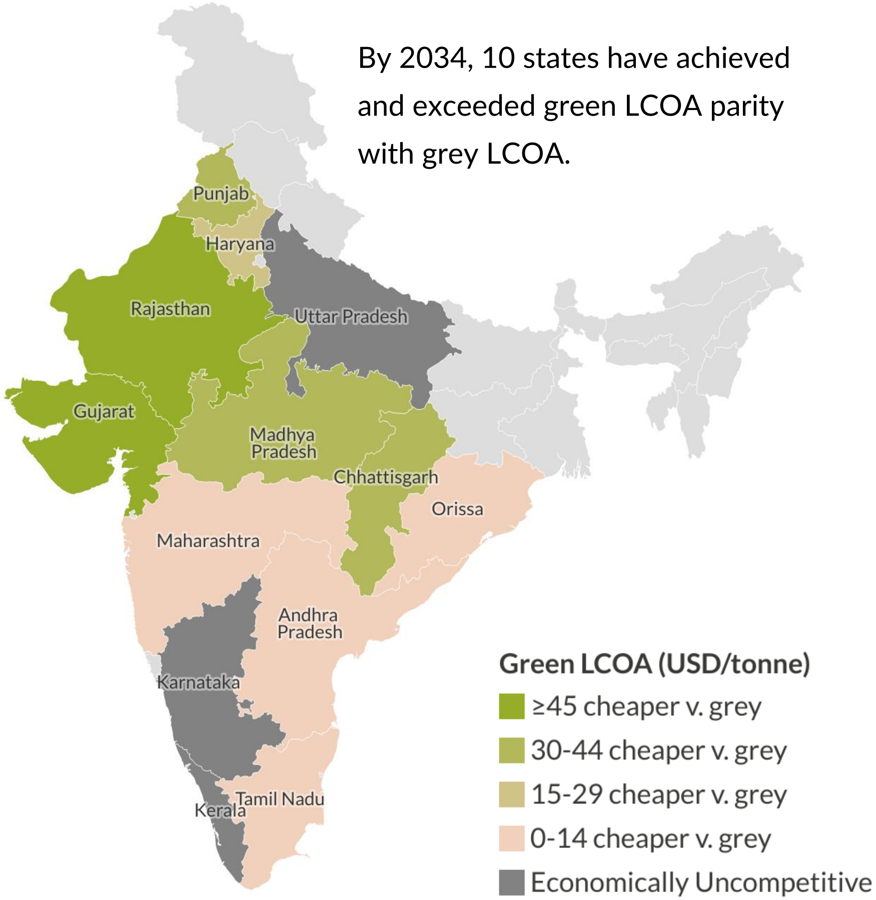
  The economies of scale of CCS technologies is still to be proven and its capture rates are often far lower than claimed. Furthermore, with no significant government investment or policy push for CCS in this sector, it does not represent a viable path for India.

Green vs Grey LCOA by state in India – 2030



In 2030, Gujarat and Rajhasthan achieve competitive LCOA parity between green and grey ammonia

Green vs Grey LCOA by state in India – 2034



By 2034, 10 states have achieved and exceeded green LCOA parity with grey LCOA.

Green ammonia, by contrast, eliminates emissions and fossil fuel dependency at the source.

- **Multiple co-benefits enhance the economic case:** The transition to green ammonia offers benefits far beyond emissions reduction. It will drastically reduce the nation's import bill for LNG, insulate the agricultural sector from global energy shocks, and alleviate the immense pressure of fertiliser subsidies on the national budget. This creates a more resilient and self-sufficient economy.
- **Minimal impact on consumers, maximum impact on sustainability:** Even a significant increase in the cost of ammonia based fertilisers would translate to a negligible price increase for the end consumer of food products. This presents a powerful opportunity for food brands and retailers to decarbonise their supply chains at a minimal cost, meeting growing consumer demand for sustainable products.
- **Supportive policies are accelerating the transition:** The Indian government has already laid a strong foundation for this shift. The National Green Hydrogen Mission (NGHM) and its associated incentive schemes, such as the Strategic Interventions for Green Hydrogen Transition (SIGHT) programme, are effectively de-risking private investment and stimulating the development of a domestic green hydrogen ecosystem. These policies are critical enablers that are already yielding results, with competitive bids in recent green ammonia auctions signalling strong market confidence

India should prioritise and scale investment in states with the strongest renewable resources and existing infrastructure to build large, cost-competitive green ammonia hubs. Policy and financial incentives should be strengthened across the full green hydrogen value chain – from renewable generation and electrolyser manufacturing to storage and transport – including measures to lower the weighted average cost of capital (WACC) for green technologies.

Parallel efforts should foster innovation and domestic manufacturing of next generation electrolysis and other critical components to cut costs, create skilled jobs, and reinforce India’s technological leadership. Finally, India could develop green fertiliser markets by encouraging farmer uptake and creating demand for low-carbon food products at home and for export, with corporations playing an important role.

Conclusion

The evidence assembled in this report is unambiguous: real zero strategies – eliminating emissions at source rather than compensating for their continuation – are achievable with an economic opportunity. Across three very different systems: Japanese steel, Indian fertiliser, and European road freight, real zero pathways deliver lower lifetime costs, tighter control of risk, and stronger security outcomes than offset-heavy or CCS-first approaches. They convert climate alignment into competitiveness, resilience, and option value, while preserving scarce removal capacity for its most crucial.

The Japan steel case shows that the country already holds a cost-competitive real zero route today: secondary steel via 100% renewables-powered EAFs. For primary steel, the contest is not BF-BOF with CCS but DRI-EAF configured for real zero.
Using imported green iron, this option could beat BAU costs from the early 2030s. These crossover points are investment signals, not excuses to wait: because projects take years, decisions today should reflect the coming cost parity and set a timetable to phase out fossil routes by the early 2030s. Even wholly domestic real zero primary production, while costlier, implies only modest end-product pass-through to consumers (≈1% to the cost of a domestic car) and can be further improved via targeted policy. Crucially, real zero steelmaking enhances, not compromises, energy and economic security by shifting reliance from imported coal and ore to domestic scrap, clean electricity, and traded green iron.

In India's fertiliser sector, moving from LNG-anchored grey ammonia to green ammonia resolves a structural vulnerability with high crisis potential. It decouples costs and subsidies from gas volatility, reduces import exposure for a critical input, and cuts process emissions in line with national targets. Our analysis finds the levelised cost of ammonia (LCOA) for green ammonia crosses over below grey ammonia before 2034 in most of the analysed Indian states, and sooner in states with high renewable energy such as Gujarat and Rajasthan. Given multi-year project lead times, this is an investment signal for decisions today and a timetable for phasing out fossil-dependent capacity ahead of that horizon. Blue ammonia does not remove fossil price risk and is not supported by a robust policy or infrastructure base in this sector. This makes blue ammonia a weak transitional bet relative to a direct real zero shift to green ammonia supported by India's NGHM/SIGHT programmes. Consumer-side impacts remain negligible along food value chains, creating room for rapid supply-chain decarbonisation at low pass-through cost.

In the EU, early full electrification with battery-electric trucks (BETs) wins decisively over the business case for continued use of diesel trucks on economics and compliance risk. BETs achieve total cost of ownership (TCO) parity from 2026. This widens to and 15–22% advantage by 2030 and reaches 24% lower TCO by 2040, as the incumbent diesel model becomes increasingly uneconomic under EU ETS II. Operationally, depot charging and targeted corridor fast-charging support high utilisation duty cycles. For very large fleets, early adoption yields annual savings by 2030 and places operators on a credible path to 100% emissions reduction by 2050. These economic and policy signals argue for procurement and infrastructure choices now, and indicate the timeframe by which diesel should be phased out as it becomes progressively uneconomic.

Taken together, these results overturn the assumption that real zero is not cost competitive. Advancements in renewables, batteries, and electrolysers, driven by policy innovation, are pushing the efficient frontier towards electrification and green molecules, here and now. The longer firms defer, the more they forgo economies of scale, lock in exposure to fossil volatility, and accumulate transition and asset-stranding risk.

They also sharpen the governance logic: CCS belongs inside the fence line to manage truly residual process emissions; it does not license continued combustion where direct elimination is viable. CDR should be reserved for system-level balancing of unavoidable residual emissions and potential overshoot drawdown, not as an underwriting facility for ongoing fossil use. This allocation preserves scarce storage and removals capacity for the problems only they can solve, while maximising certainty from concrete, near-term abatement.

From our case studies there are clear and sector-specific strategies that can be enacted now:

- **Steel (Japan):**
    - Scale scrap collection and EAF capacity;
    - enable green-iron trade; deploy targeted hydrogen support where it materially closes the cost gap;
    - retire reinvestment in BF-BOF predicated on high capture rates.

- **Fertiliser (India):**
    - Accelerate contracted renewables and electrolysis build-out for green ammonia;
    - align subsidy reform with green procurement; channel NGHM/SIGHT to bankable offtake.
    - De-emphasise blue ammonia lacking robust economics and policy traction.
- **Trucking (EU):**
    - Lock in early BET adoption with depot charging first, corridor fast-charging next;
    - provide long-term regulatory clarity on ICE phase-out;
    - integrate ETS II trajectories into fleet capex planning to harvest early TCO advantages.

For investors, the lesson is to favour assets whose cash flows ride learning curves and policy tailwinds (renewables, BETs, electrolysis, scrap/EAF) and treat CCS-dependent life-extensions of combustion assets as duration-mismatch risk. For policymakers, the efficient package couples carbon pricing with infrastructure and innovation support, standards and procurement that create demand for low-carbon materials, and removal governance that protects integrity by reserving CDR for residuals.

The central claim we set out to test – does an economic rationale already exist for rapid real zero at source? – is answered in the affirmative. Real zero mitigation options bring more opportunities when compared to BAU in the sectors analysed – on cost effectiveness, on reducing risk, and on enhanced energy and fiscal security. The task ahead is execution: scale what is ready, target support where gaps remain, and keep removals for the jobs only they can do. The sooner firms and governments pivot from relying on ineffective offsets to real zero by design, the faster they unlock compounding economic gains and a more resilient industrial base.

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