In collaboration with Accenture

Net-Zero Industry Tracker
2023 Edition

INSIGHT REPORT

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Contents

Foreword

Roberto Bocca
Head, Centre for Energy and Materials; Member of the Executive Committee, World Economic Forum

Muqsit Ashraf
Global Strategy Lead, Accenture

In a decade marked by economic expansion and surging demand for goods and transport, we face a paradoxical challenge: How can we address climate change while fostering economic growth and resilience? This challenge is particularly difficult for companies operating in the steel, cement, aluminium, ammonia, energy and transport sectors. These companies are critical to satisfying future demand and enabling economic growth. Yet, they contribute over 40% of the world's greenhouse gas (GHG) emissions. Their emissions are difficult, but critical to abate.

It is encouraging that many businesses have made significant progress towards their 2050 net-zero goals. Yet most of that momentum is seen in companies with easily abatable emissions, substantial financial resources to invest in decarbonization, public accountability or those operating in advanced economies with supportive policies. A gap remains between those abatement leaders and companies experiencing greater emission intensity, operating in emerging economies or lacking the financial means to embark on a substantial decarbonization journey. The challenges facing these companies and sectors are pernicious – and exacerbated by the fact that their technologies, infrastructures and policy frameworks often fall short.

Through this effort, the World Economic Forum, with support from Accenture, intends to accelerate decarbonization of emission-intensive production, energy and transport industries. Our aim is to ensure that no company is left behind in the transition to a more sustainable and carbon-neutral future, for which timely and consistent monitoring of industrial decarbonization is essential. This practice is crucial to helping companies and industries maintain a steady pace of progress. Still, it first requires a consensus on definitions and thresholds of low-emission products and services from these sectors. Without that, it will be difficult to achieve the transparency needed to build confidence and reinforce the momentum to net zero.

The *Net-Zero Industry Tracker* focuses on production, transport and energy sectors. Decarbonizing these industries' processes and value chains will require more than technological advancements. The effort must encompass business operations, regulations and wider cross-sectoral collaboration. While some countries are issuing supportive policies and financial commitments, the reality is that these sectors are lagging.

We believe a course correction is still possible. It will require industrial leaders to champion innovative business models and shared infrastructures, such as hubs and clusters, that provide greater access to development opportunities and promote equitable sector growth. A successful transition will also require significant financial commitments; we estimate roughly $13.5 trillion will be needed to build the clean power and electrification, hydrogen and carbon capture utilization and storage (CCUS) solutions and infrastructure to meet demand. Bi-directional partnerships and cross-industry collaboration will also be important in stimulating demand for (and adoption of) low-emission products and clean power-based technologies, developing industrial applications and pursuing new market opportunities. Sector-specific policies and regulations are essential. So are cross-regional policies that can help bridge disparities among regions.

Industrial decarbonization remains one of the most daunting challenges of the energy transition. Every country and industry must determine how to incentivize domestic benefits and create quality jobs while ensuring the principles of free trade and open markets. The key findings from the 2023 Global Stocktake of the Paris Agreement confirm that reaching global net zero by 2050 requires much more ambitious actions and far greater support than we have seen. The reality is that the choices and actions taken in this decade will significantly shape the trajectory of our collective futures.

Executive summary

The World Economic Forum's *Net-Zero Industry Tracker 2023 Edition* provides a detailed analysis of the progress emission-intensive industrial sectors are making worldwide, in their efforts to achieve net-zero emissions by 2050. This analysis focuses on sector-specific accelerators and priorities in the harder-to-abate aspects within production (i.e. steel, cement, aluminium and ammonia), energy (i.e. oil and gas) and transport (i.e. aviation, shipping and trucking). Collectively, process- and energy-related emissions from these sectors account for more than 40% of global greenhouse gas (GHG) emissions, which is higher than the emissions of any individual country. For that reason, transparency on the progress these sectors are making is essential for timely and effective interventions to ensure we are on track for net-zero emissions by 2050.

While the pathway to net zero in industrial sectors will differ based on unique sectoral and regional factors, a blend of electrification (clean power), clean hydrogen and fossil fuels abated by carbon capture utilization and storage (CCUS) form the basis of industrial decarbonisation across most sectors. However, a robust enabling environment is necessary to allow them to achieve their respective decarbonization objectives. To help in this, the *Net-Zero Industry Tracker* applies a standardized conceptual framework, including emission drivers and enablers, that not only provides a collective measure of progress and gaps but also highlights opportunities for cross-sector collaboration.

The analysis shows that emission-intensive sectors are not aligned with the trajectory to reach net zero by 2050 – as determined by the International Energy Agency (IEA) and industry specific scenarios and targets. Over the past three years, absolute emissions have grown on average by 8% due to increased activity and demand and all sectors in scope depend on fossil fuels, most with over 90% reliance. Sectors such as cement and steel are facing the most complex decarbonization challenges due to their energy intensity. In fact, their use of energy is equivalent to more than 3 times that of the energy consumed in the US. Transitioning these industries to a net-zero future will require a collective investment of approximately $13.5 trillion, prioritizing the electrification of low to medium temperature industrial processes. That is what's needed to scale up the essential technologies and sustainable infrastructure, but investments aren't enough. They must be complemented by policies and incentives that can help the industries make the switch while ensuring access to affordable and reliable resources that are critical for economic growth.

The tracker reveals an encouraging, though variable, increase in awareness and action among industries towards achieving net-zero emissions. Yet, there is still tremendous opportunity for sectors to come together to drive innovation and address their challenges collaboratively through sharing knowledge and best practices, joint innovation, market access and consumer trust, risk mitigation and resiliency planning.

BOX 1

Definitions

Clean power: A combination of solar, off-shore wind, on-shore wind, nuclear and geothermal energy used to electrify thermal processes in production and as an alternative propulsion source in transport sectors.

Clean hydrogen: Considers both blue hydrogen (produced with natural gas abated by CCUS) and green hydrogen (produced through electrolysis). Though the preference in most cases is towards green hydrogen.

Green premium: Additional products/fuel costs passed to businesses and end consumers, associated with adoption of low-emission technologies.

TABLE 1 | **Five key takeaways from the 2023 tracker**

Technology	**The use of low-emission technologies is growing at a gradual pace; rapid acceleration is needed to support commercial deployment by 2030.** The readiness and adoption of low-emission technology remains low across most sectors. Aluminium and trucking are two sectors showing early promise. Prioritizing material circularity, recycling and transition fuels can help industries bridge the gap until technologies become available.
Infrastructure	**Financing needs for low-emission technologies are significant yet overshadowed by larger infrastructure investments.** Industries are largely reliant on clean hydrogen, CCUS and electrification including recharging infrastructure for transport sectors. While local characteristics like clean power and storage site proximity will drive early technology adoption, shared infrastructure hubs are vital to accelerated decarbonization and improved access in remote locations.
Demand	**Standardized definitions and thresholds for low-emission products are gaining consensus, essential for encouraging first movers.** Early market demand signals are emerging in most sectors. Over the last year, some production sectors have witnessed an increase in low-carbon alternatives. Yet challenges like reporting standards, supply chain instability and transparency gaps persist. In some instances, business to business (B2B) green premiums reaching up to 400%, are largely untested at scale. End-product consumers generally experience relatively modest green premiums, typically 2-5%.
Policy	**The evolving policy landscape, driven by significant industrial policy initiatives in select countries, is bolstering investment in low-emission technologies and infrastructure.** However, this shift may risk concentrating industrial activity in developed nations, necessitating multilateral cooperation to aid major producing regions. Global alignment on emissions reduction requirements is needed, with policies customized to suit individual country needs. Additionally, enhancing market transparency necessitates policy measures to increase emission intensity visibility.
Capital	**Sectors need additional investments of approximately $11 trillion to fund adoption of clean energy technologies and retrofit legacy assets, however most industries lack strong business cases.** Such a shift in capital flows should be supported by market stabilizing policies to enhance investment attractiveness and companies embedding long-term decarbonization solutions into their strategies to targeting growth through sustainable value creation. Capital is also needed to improve emission efficiencies for processes that cannot be fully electrified.

In conclusion, decarbonizing emission-intensive industries across production, energy and transport sectors requires a multi-faceted approach. Aligning the essential components of demand for sustainable products, policy incentives, capital for technology investments and infrastructure expansion is the key to accelerating progress. Positive signals are currently emerging, but much more needs to be done. Recognizing a new and evolving geopolitical context, a new equilibrium needs to be found on how collaboration across countries needs to happen to support this transition that should preserve the conditions for every living being and also create wealth. The 2023 tracker report recognizes that, despite the challenges, the global industrial community is making progress towards achieving net-zero emissions. By pulling the enabling levers and encouraging innovative collaborations, industries can pave the way for a greener, more resilient and prosperous future.

Introduction

The *Net-Zero Industry Tracker* offers a data-driven framework to assess and comprehend the progress of decarbonization across emissions-intensive industry sectors.

Its key objectives include supporting the global endeavour of industry net-zero transformation by providing stakeholders with a detailed framework and methodology to comprehend the driving forces behind industry emissions and the facilitators of net-zero transformation. Additionally, it provides both quantitative and qualitative scorecards to continually monitor industry advancements towards the net-zero goal. Moreover, it identifies priority areas for industries to focus on, promoting actions that accelerate their progress in the journey towards sustainability.

The underlying framework combines two complementary lenses to track industries' progress on the ground – performance and readiness. This year, to increase the overall volume of emissions being tracked, three transport sectors have been included. Consequently, the 2023 iteration of the framework for production and energy sectors remains the same, whereby the field of analysis covers scope 1 and 2 emissions. However, an adapted version has been developed to account for variance in reporting requirements for the newly incorporated transport sectors, which will account for greenhouse gas (GHG) emissions in the fuel supply and operational value chains (well-to-wake emissions) against 2050 targets.

BOX 2

Definitions

"Low-emission" production is defined quantitatively for each industry in terms of product emission intensity (scope 1 and 2).

Targets refer to 2030 and 2050 emission intensity thresholds based on sector net-zero trajectories used for the analysis. These are proposed trajectories based on analysis of data from the International Energy Agency (IEA) *Net Zero by 2050*, Global Cement and Concrete Association (GCCA) Concrete Future, International Air Transport Association (IATA) Net Zero Roadmaps, International Aluminium Institute (IAI) GHG Pathways, International Council on Clean Transportation (ICCT) Vision 2050 and International Maritime Organization (IMO) GHG Strategy. Business as usual (BAU) trajectories have also been considered based on the IEA Stated Policies Scenario and Mission Possible Partnership (MPP) sector trajectories. These trajectories are for this analysis only and not a final recommendation for the industries.

FIGURE 1 | **Net-Zero Industry Tracker framework – performance**

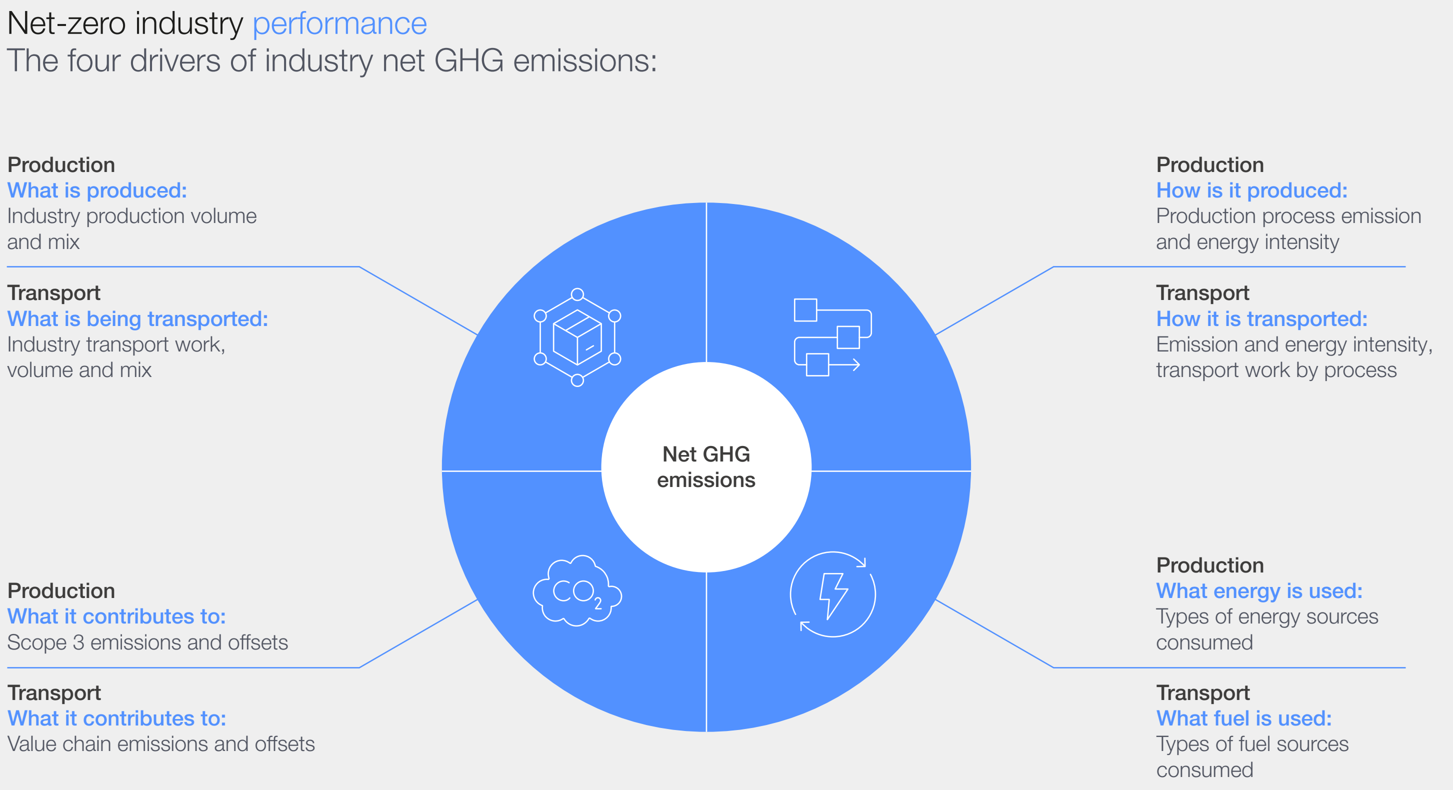
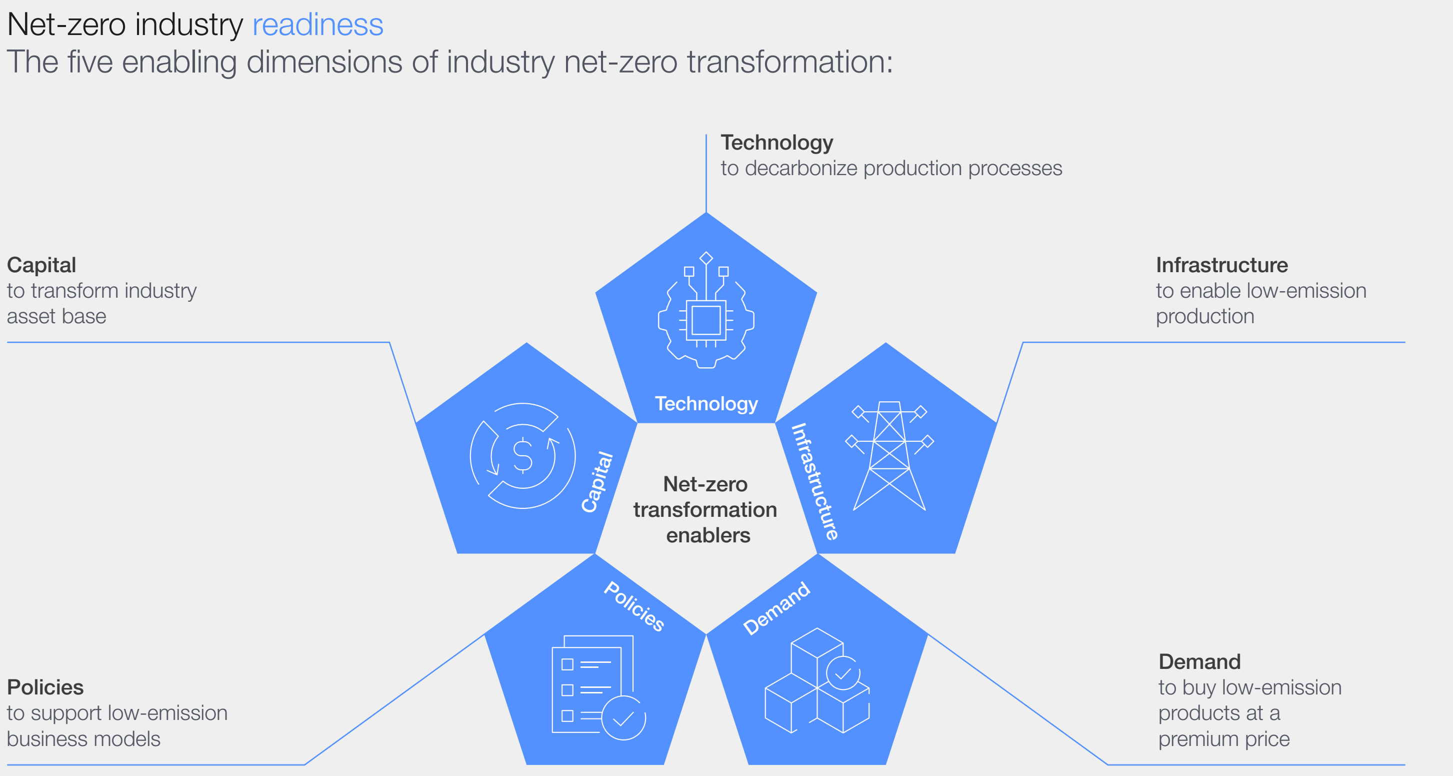


FIGURE 2 | **Net-Zero Industry Tracker framework – readiness**



Each of the enablers is assessed against five stages of readiness, with the assessment criteria outlined in Appendix A2: Mission and methodology.

TABLE 2 | **Scoring matrix for transformation enablers**

Key readiness questions	**Technology** Is the technology to produce a low-emission product at competitive cost available?	**Infrastructure** Is the infrastructure to enable use of low-emission technologies available?	**Demand** Can the market pay the required green premium for the low-emission product?	**Policies** Are the supporting policies to enable the growth of low-emission industry in place?	**Capital** Are returns sufficient to drive investments towards low-emission assets?
Stage 5	The low-emission production technologies are **fully available and competitive with high-emission alternatives.**	The necessary infrastructure required by the low-emission industry **is fully in place.**	**The whole market** can pay the required green premium.	Policies **fully** complement current environment (technology, infrastructure, demand, capital), to support growth of the low-emission industry.	Low-emission investments generate sufficient return for **all** capital expenditure (CapEx) to flow towards low-emission production assets.
Stage 4	The low-emission production technologies are **largely commercial and competitive with high-emission alternatives.**	The necessary infrastructure required by the low-emission industry is **largely in place.**	**Most of the market** can pay the required green premium.	Policies **strongly** complement current environment (technology, infrastructure, demand, capital), to support growth of the low-emission industry.	Low-emission investments generate sufficient return for **most** CapEx to flow towards low-emission production assets.
Stage 3	The low-emission production technologies are **largely demonstrated in commercial conditions.**	The necessary infrastructure required by the low-emission industry is **partially in place.**	**Some of the market** can pay the required green premium.	Policies **moderately** complement current environment (technology, infrastructure, demand, capital), to support growth of the low-emission industry.	Low-emission investments generate sufficient return for **some** of CapEx to flow towards low-emission production assets.
Stage 2	The low-emission production technologies are **largely prototyped at scale.**	The necessary infrastructure required by the low-emission industry **is emerging.**	**A limited portion** of the market can pay the required green premium.	**Limited** policies complement current environment (technology, infrastructure, demand, capital), to support growth of the low-emission industry.	Low-emission investments generate sufficient return for a **minority** of CapEx to flow towards low-emission production assets.
Stage 1	The low-emission production technologies are **largely at concept or early prototype stage.**	The necessary infrastructure required by the low-emission industry **needs to be developed almost entirely.**	**Only very early adopters** in the market can pay the required green premium.	**Very limited** policies complement current environment (technology, infrastructure, demand, capital), to support growth of the low-emission industry.	Low-emission investments generate sufficient return for **barely any** CapEx to flow towards low-emission production assets.

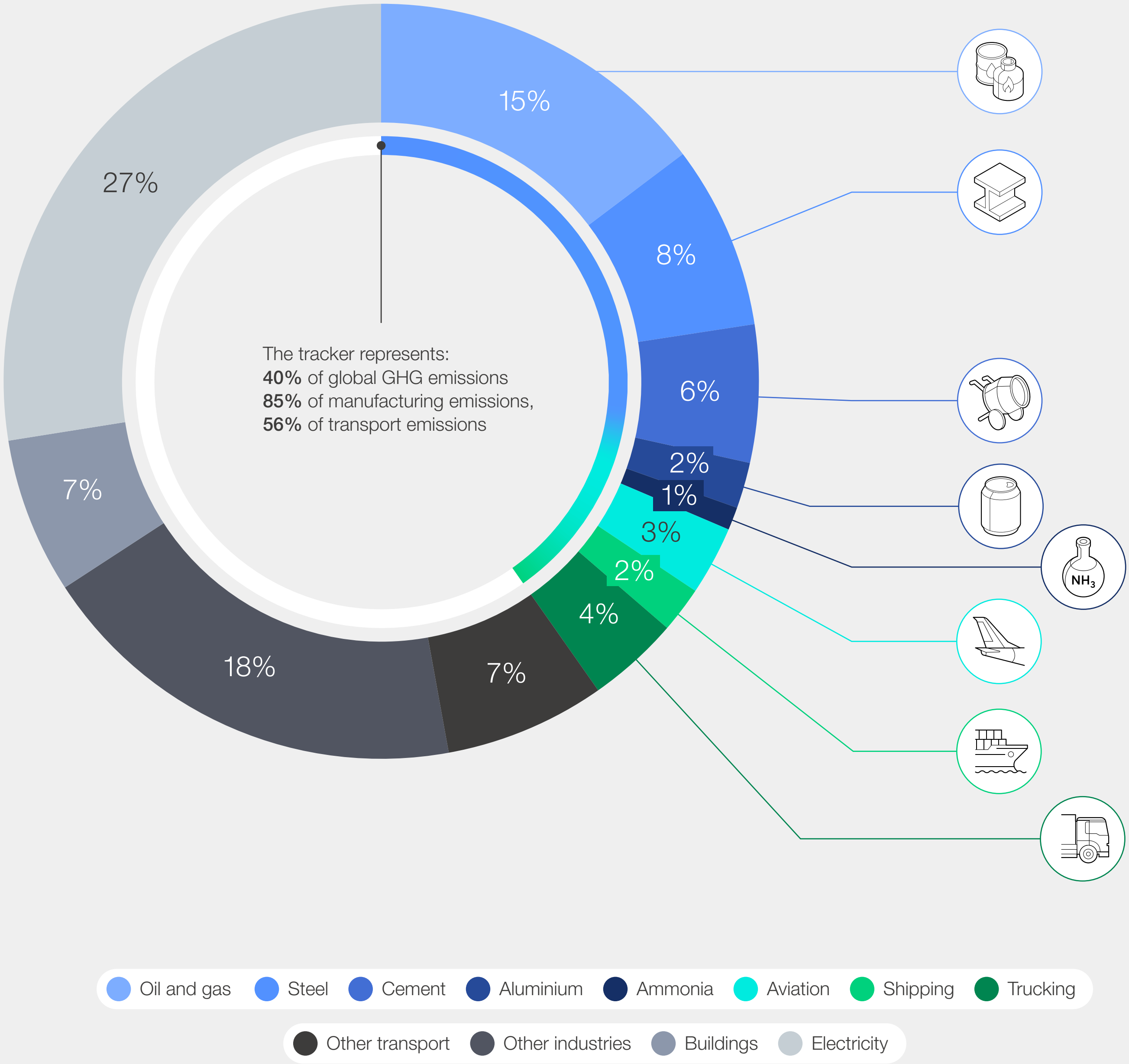
1 Cross industry findings

Industrial sectors, across production and energy, contribute over 30% of global GHG emissions, increasing to over 40% when combined with transport (see Figure 3). Currently, none of these sectors are on course to achieve net-zero emissions by 2050. Progress, in terms of emissions reduction and sector readiness has been limited in most regions over the past year.

Decarbonizing these emissions-intensive sectors is primarily dependent on removing the reliance on fossil fuels as the primary energy source and switching to renewable alternatives such as clean power and clean hydrogen, as well as efficiency improvements and abating emissions from any remaining fossil fuels.

FIGURE 3

Global GHG emissions by sector



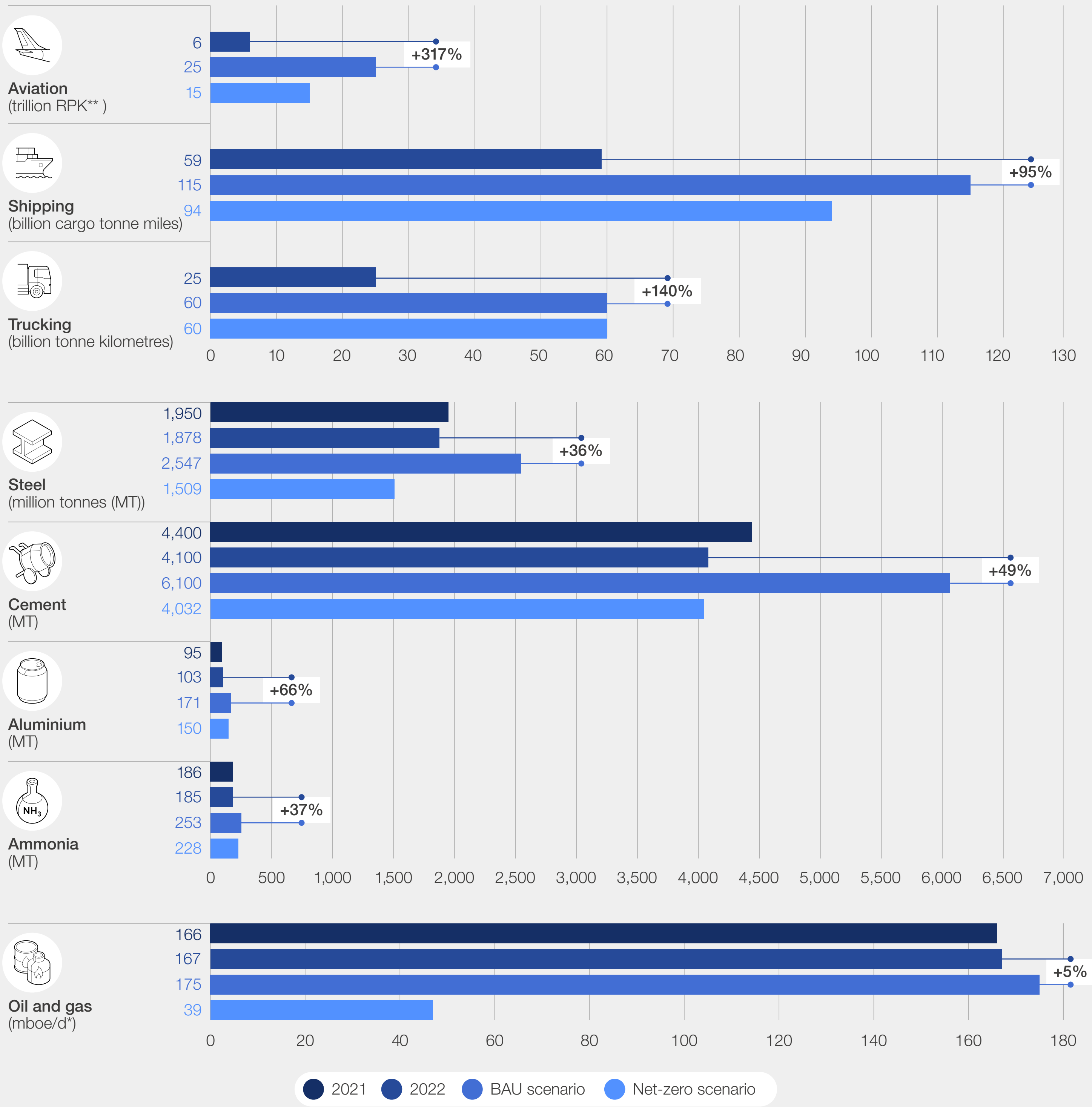
Source: Breakthrough Energy, *The Data, Sectoral Analysis*, n.d., https://breakthroughenergy.org/our-approach/the-data/sectoral-analysis/; IEA, *Net Zero by 2050*, 2021.

Low-emission products, fuels and technologies hold less than 1% market share in most sectors. This is because they are currently costly or hard to scale and many sectors prioritize near-term emission reduction solutions, while there's insufficient regulation, standards and consumer awareness about alternative products and their emission-cutting potential.

Positive advancements are underway in regions such as the US and the EU, where low-emission technologies are projected to gain traction by 2030. It is crucial to implement a customized blend of incentive-driven and mandate-based policies, considering the economic conditions of developing nations. Global companies need to take more substantial actions to expedite the transition.

As population growth, urbanization and economic expansion drive increased demand across all sectors, the carbon-intensive nature of these industries poses a formidable challenge to 1.5°C aligned climate goals. Prioritizing proactive decarbonization, coupled with the creation of employment and wealth, is imperative. However, adopting reactive measures risks higher costs, diminished competitiveness and a failure to meet emissions reduction targets. Industries need to de-couple emissions from demand by embracing innovative technologies, optimizing supply chains, transitioning to cleaner energy sources, encouraging policy collaboration and raising consumer awareness. Energy efficiency and energy savings can often be a quick way to achieve some reductions in emissions and energy consumption. However, there needs to be a complementary tool for developing and scaling technologies that can deliver deeper emissions cuts. Ultimately, in a 1.5°C aligned scenario, demand reduction through efficiency improvements, product diversification and substitution with low-emission alternatives will be needed.

FIGURE 4 **Demand increase from 2021 to 2050 under IEA stated policy and IEA net zero by 2050 scenarios**



*Thousand barrels of oil equivalent per day; **Revenue passenger kilometre

Source: IEA stated policy scenario and IEA net-zero scenario

Performance

Fossil fuels comprise more than 90% of the current energy mix, for sectors in scope. As such, the volume of absolute emissions increases alongside accelerating global demand. Absolute emissions increased by 8% between 2019 and 2022 across most sectors in scope. Though production and transport demand decreases are evident in the data through the course of the pandemic. Most sectors have recovered to or surpassed pre-pandemic demand levels, leading to a subsequent increase in emissions, emphasizing the need to dissociate emissions with demand growth and reduce energy intensity by substituting fossil fuels with renewables, new energy sources and increasing efficiency.

Emissions intensities have shown little reduction over the same time period, suggesting that all sectors require large-scale process and technology improvements. It is crucial to recognize that efficiency improvements that are important to reduce emissions may reach a plateau due to inherent process limitations. Therefore, fossil fuel substitution is equally key to reducing emissions intensities in line with 1.5°C scenarios.

TABLE 3 **Key performance metrics**

Sector	Absolute emissions growth* (2019-2022) (trend)	Absolute emissions growth (2019-2022) (%)	Emissions intensity growth (2019-2022) (trend)	Emissions intensity growth (2019-2022) (%)
Aviation**		-31		
Shipping***				
Trucking		2		-13.7
Steel****				-3.4
Cement		-0.3		0
Aluminium*****		4		-2.9
Ammonia		3		0
Oil and gas******		-4		

Source: IEA World Energy Outlook 2022

*Graph shows movement and trends across sectors, rather than direct unit by unit comparison; **Aviation emission intensity and emissions intensity growth excluded due to extreme outliers across COVID-19 pandemic period; ***Shipping figures from The Fourth IMO GHG study 2020, are based on 2018 data therefore excluded from this assessment; ****Historic absolute emissions data unavailable; *****Data available from 2019-2021; ******Emissions intensity trend not available.

The absence of precise sector-specific definitions for scientifically quantifying thresholds is a prevailing issue. Yet, the significance of establishing these benchmarks cannot be overstated, given that the predominant focus of current endeavours remains centred on high-emission trajectories. Currently, around 7% of production meets the existing thresholds of reduced emission production, defined as a percentage of production aligned with 2030 targets. Similarly, less than 1% meets low-emission thresholds, defined as the percentage of production aligned to 2050 thresholds. The trends over the last four years suggest that none of the sectors are on track to meet 2030 targets, and a significant acceleration of efficiency measures and low-emission technology adoption is needed.

BOX 3

Definitions

Absolute emissions are the total GHG emissions released from a specific source, measured in gigatonnes of CO_2 equivalent ($gtCO_2e$). Industrial production, oil and gas are assessed by scope 1 and 2 emissions. Transport sectors assessed by well to wake emissions.

Emissions intensity refers to the measure of greenhouse gas emissions per unit of activity or output measured in:

- Industrial production: Tonnes of CO_2 equivalent per tonne of output (tCO_2e/t)
- Oil and gas: Kilograms of CO_2 equivalent per barrel of oil equivalent ($kgCO_2e/boe$)
- Aviation: Grams of CO_2 equivalent per revenue passenger kilometre (gCO_2e/RPK)
- Shipping: Grams of CO_2 equivalent per tonne nautical mile ($gCO_2e/t\text{-}nm$)
- Trucking: Grams of CO_2 equivalent per tonne mile (gCO_2e/tnm)

Readiness

Reaching net zero by 2050 across industrial sectors is dependent on advancements in five key areas: technology, infrastructure, demand, policy and capital. This requires strategic actions to bolster technology, upgrade infrastructure, stimulate sustainable and low-intensity energy demand, develop effective policies, and secure the necessary capital investments. Achieving these objectives mandates a pragmatic and coordinated approach to promote sustainable growth and innovation.

TABLE 4

2023 industry enablers scores (arrows depict overall change across industries compared to 2022 scores)

Sector	Technology —	Infrastructure —	Demand —	Policy ↑	Capital ↓
Aviation	Stage 2	Stage 2	Stage 2	Stage 3	Stage 1
Shipping	Stage 3	Stage 2	Stage 2	Stage 2	Stage 1
Trucking	Stage 2	Stage 2	Stage 2	Stage 3	Stage 1
Steel	Stage 2	Stage 1	Stage 3	Stage 2	Stage 1
Cement	Stage 2	Stage 2	Stage 2	Stage 3	Stage 1
Aluminium	Stage 3	Stage 3	Stage 4	Stage 2	Stage 1
Ammonia	Stage 3	Stage 1	Stage 2	Stage 2	Stage 1
Oil and gas	Stage 4	Stage 2	Stage 3	Stage 3	Stage 3

Readiness stages: Stage 1 Stage 2 Stage 3 Stage 4 Stage 5

Technology

The technology landscape remains very similar to last year, with most technologies currently under development expected to reach commercial readiness by 2030. The transformation of emissions-intensive industrial and transport industries, where changes take a long time to incubate, heavily relies on technological innovation, active investments and industrial coordination and collaboration to share and replicate learnings. These sectors encounter distinct challenges, often centred around the imperative to reduce technology costs through strategies such as scaling up production, process optimization and deriving insights from initial deployments. In some instances, genuine technological revolutions are indispensable, as evidenced in sectors like aviation and cement production. As such, three net-zero technologies warrant prioritization for accelerated development:

65% of the 2050 energy mix is expected to be clean power

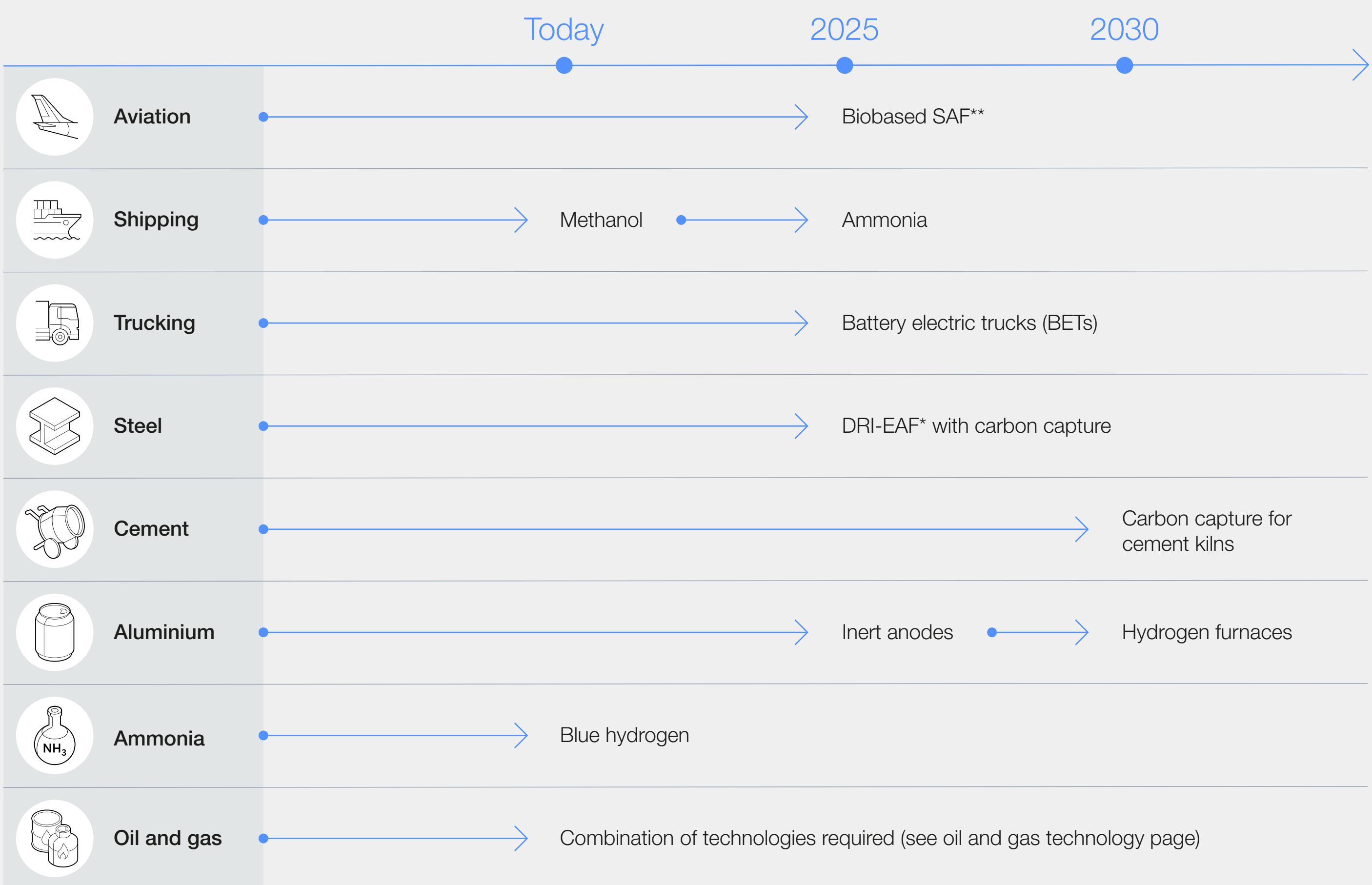
1. **Increase clean power-based technology adoption across all sectors:** Clean power is expected to comprise up to 65% of the final energy mix by 2050 and is the least complex method of driving emissions reductions.

2. **Commercial scaling of carbon capture utilization and storage (CCUS) technology, particularly for cement:** With a lack of viable alternatives for net-zero cement, research and development (R&D), investment and additional projects are needed to improve applications for small and remote facilities and accelerate commercial scaling within this decade.

3. **Accelerated development of green hydrogen technology:** Access to green and blue hydrogen is an important decarbonization solution for several sectors. Despite positive developments in blue hydrogen, it is particularly important to significantly reduce costs and increase supply of green hydrogen to decarbonize and reduce fossil fuel dependence.

Furthermore, sector transition extends beyond the advancement of operational technologies; it equally emphasizes the critical necessity of integrating these innovations with established business systems. To expedite progress towards achieving net-zero emissions, it becomes imperative to prioritize the acceleration of technology readiness levels (TRLs). This goal can be realized through collaborative industry efforts and the development of new cross-industry partnerships.

FIGURE 5 **Year by which industries could commercially deploy technologies enabling them to reach their 2050 low-emission intensity threshold**



Source: Accenture analysis based on multiple sources, including IEA and MPP

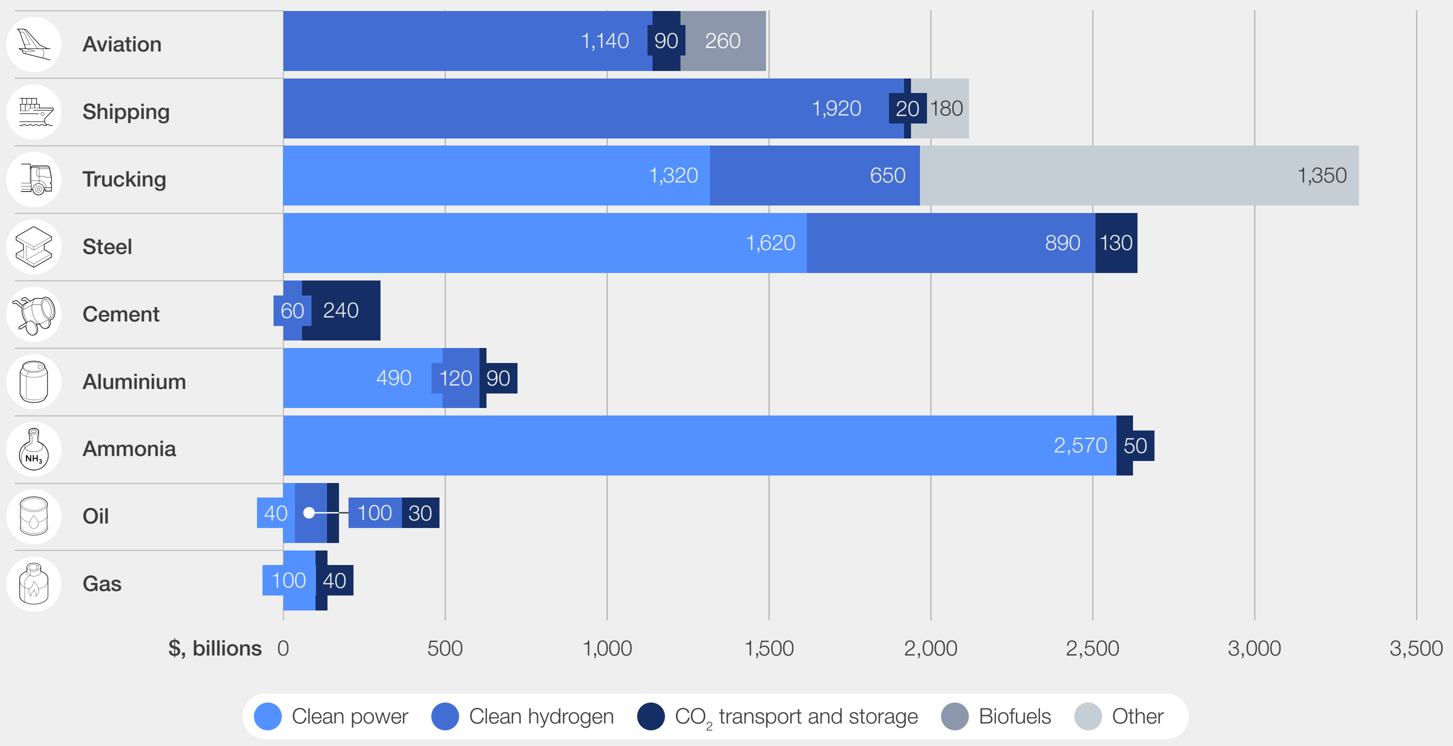
*Direct reduced iron-electric arc furnace **Sustainable aviation fuels

Infrastructure

Clean power, clean hydrogen and fossil fuels abated by CCUS will need to account for over 90% of the final energy mix for net zero by 2050 with applications across all sectors in scope, totalling around $13.5 trillion in investments (see Figure 7). Accelerating clean power generation and energy storage is crucial. The shift towards clean power sources requires significant changes in electricity procurement and markets, placing a growing emphasis on renewable energy procurement strategies, such as access to and coordination of a diverse set of industry players to include solar, nuclear and hydropower. A clean hydrogen economy is vital for industries like cement, steel and ammonia, while sectors like shipping and aviation are exploring hydrogen-derived fuels. Carbon capture capacity may need to increase by 120-125 times by 2050; however, inconsistent CCUS revenue models must be addressed.

With less than 1% of the required infrastructure currently in place, the risk of cross-industry competition for limited resources grows as demand for low-emission products and transport rises towards 2050. **To tackle this, promoting shared infrastructure models like infrastructure hubs and industrial clusters can boost access to development, encouraging more equal sector growth and creating advantages of scale.** Industries should partner with infrastructure and energy providers to develop new contracts and complementary operational models. Bi-directional partnerships between two or more industries hold the potential to drive low-emission product demand through market opportunities and industrial applications.

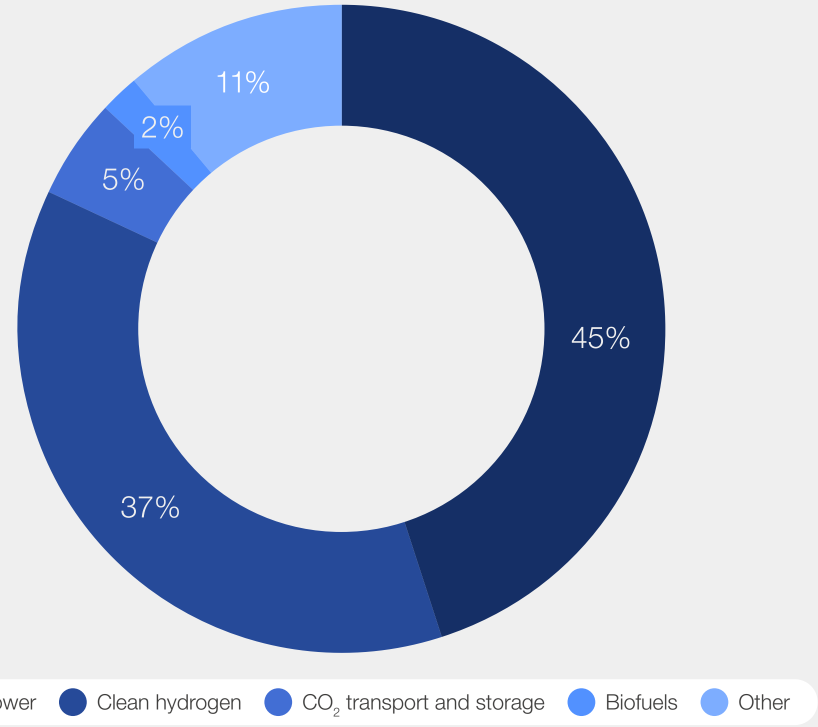
FIGURE 6 **Total infrastructure investments by industry and by enabler by 2050**



Source: Accenture analysis based on multiple sources, including IEA, IRENA, Global CCS Institute and GMF

FIGURE 7 | **Total investments required by 2050 by enabler**

Total investments required = approximately $13.5 trillion



Source: Accenture analysis based on data from organizations including; Global Cement and Concrete Association, International Air Transport Association, International Energy Agency Net Zero by 2050 report and World Economic Outlook.

Demand

Early market demand signals are emerging in most sectors, supported by developing policies and an increase in offtake agreements and green subsidies. Initiatives such as the First Movers Coalition (FMC) have contributed to creating a stronger demand signal for innovative, clean technologies in industrial sectors. **Many production sectors have seen an increase in low-carbon alternatives over the last year. However, a lack of reporting standards, supply chain stability and transparency are consistent challenges across most sectors, with associated green premiums largely untested at the commercial scale.** The current industry dilemma regarding whether to stimulate demand or supply requires immediate attention and resolution. Industry leaders and consortia share a unanimous commitment to developing net-zero pathways, though the absence of reliable customer revenue signals both in terms of price and volume limit execution. This uncertainty poses challenges for businesses looking to invest in and pursue potentially transformative but uncertain opportunities. Industries need to collaborate across the value chain to create transparency around applications of clean technologies, clarify infrastructure demand requirements and prioritize accordingly, reducing the energy intensity of process activities.

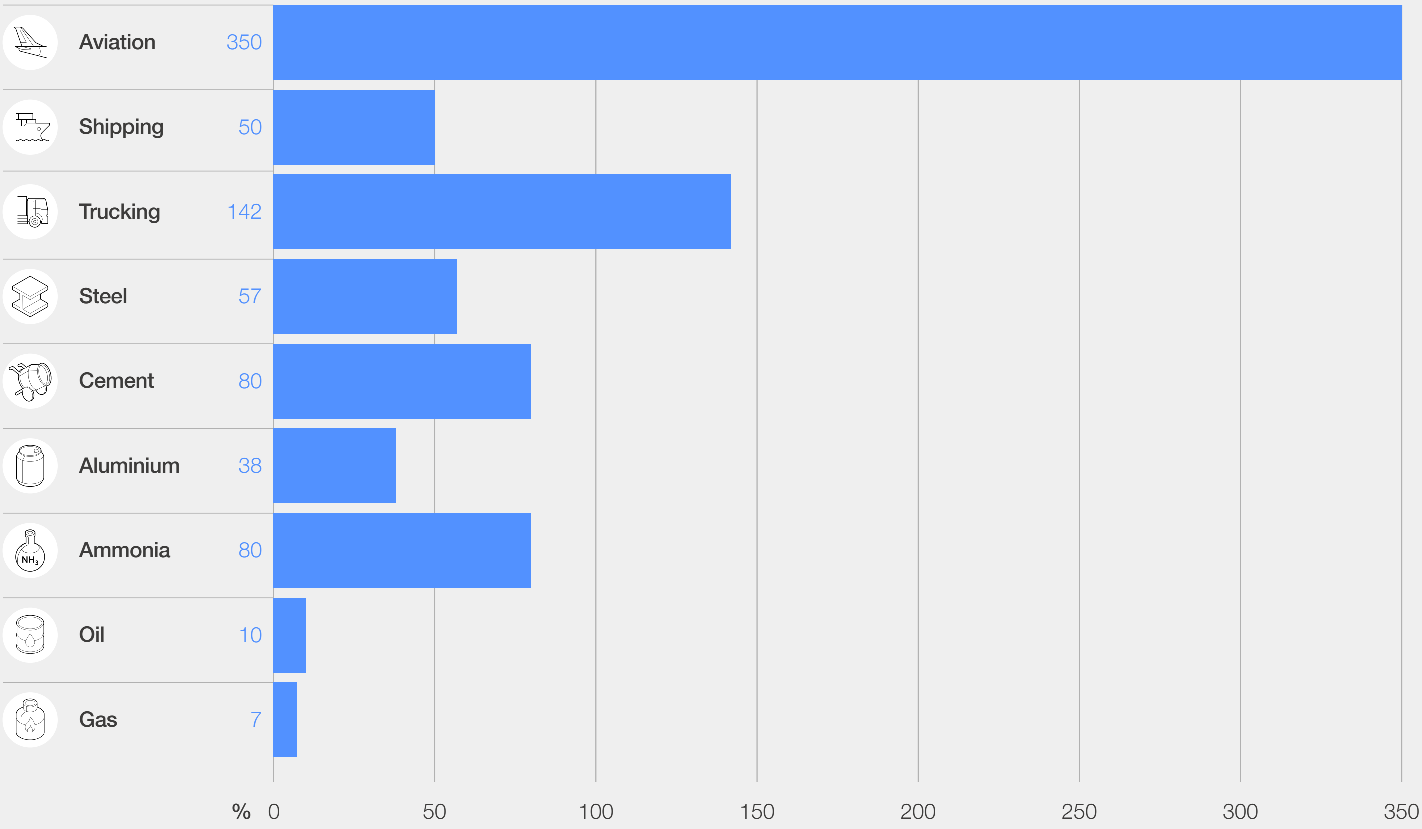
> The industry dilemma regarding whether to stimulate demand or supply requires immediate attention and resolution.

Across various sectors, several key prerequisites have emerged as essential for creating demand for low-emission products and raising consumer awareness of product and service carbon attributes. These prerequisites include:

1. A standardized framework for low-emission products
2. A simple-to-deploy emissions intensity calculator
3. An auditable carbon footprint assessment process.

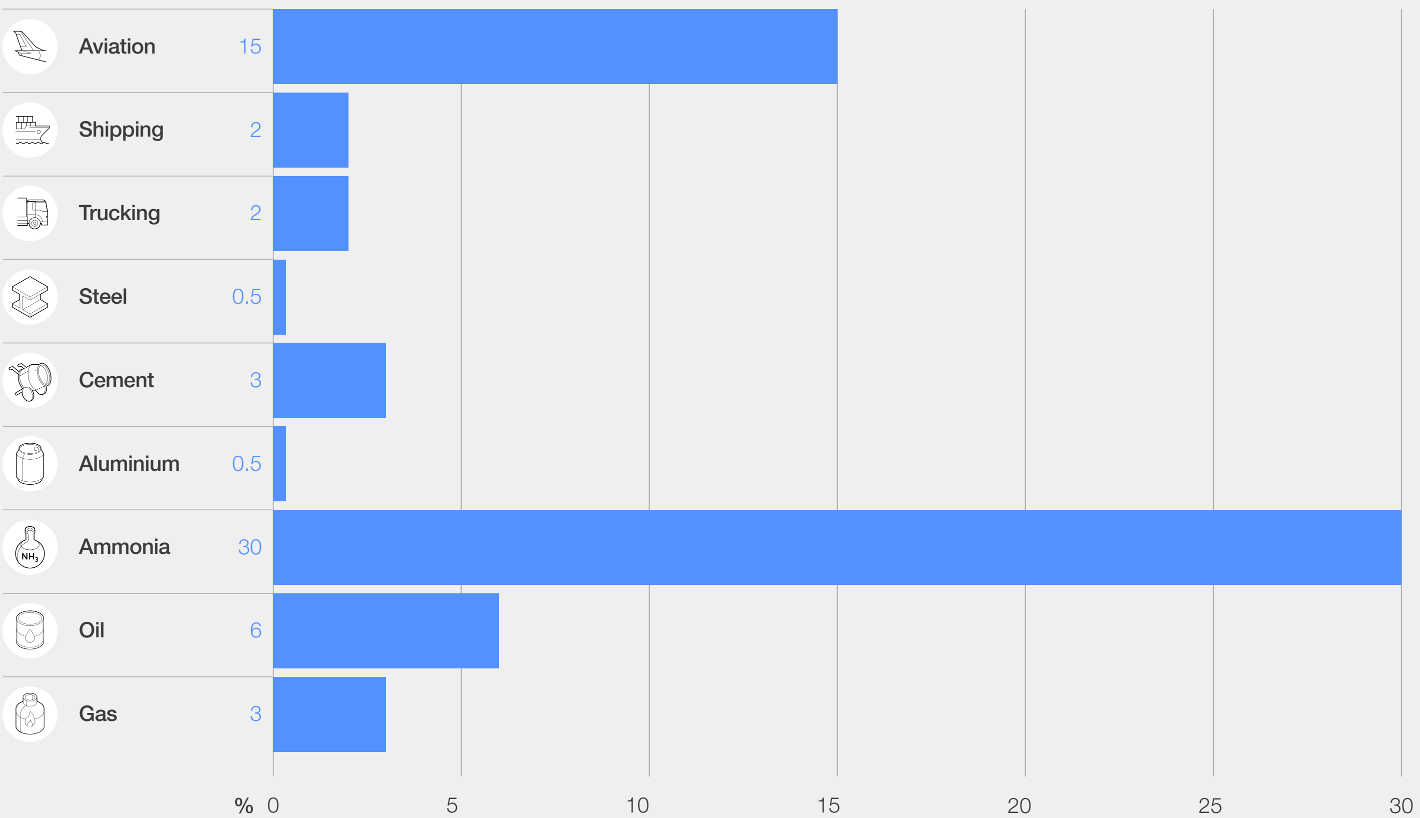
Notably, the aviation sector has made progress in promoting transparency through the use of carbon footprint calculators. Similarly, the construction sector has taken steps to certify green products, especially in the context of low-emission buildings, although it has historically excluded primary materials from these certifications. While these sectors serve as commendable examples, it is imperative for other industries to follow suit and adopt similar measures.

FIGURE 8 | Average business to business (B2B) green premium by current estimates



Source: Accenture analysis based on multiple sources, including MPP, ETC, Bloomberg and IEA

FIGURE 9 | Average business to consumer (B2C) green premium by current estimates



Source: Accenture analysis based on multiple sources, including MPP, ETC, Bloomberg and IEA

Policy

Policy plays a pivotal role in sectoral decarbonization, serving dual objectives: advancing climate goals and bolstering demand and economic resilience. It must also navigate the delicate equilibrium between domestic economic growth and the expenses tied to supply chain onshoring. Major producing countries/regions such as China, India, the US and the EU have now committed to net-zero targets, making it imperative for businesses within their jurisdictions to align their operations and strategies with the evolving regulatory landscape. However, complex and ever-changing policy regimes result in businesses allocating substantial resources towards compliance, impeding progress. Establishing more consistent and stable regulatory frameworks with well-defined timelines is imperative for mitigating these risks.

Emerging signals indicate a range of cross-sectoral policy systems being tested worldwide:

- Currently, 20% of countries have implemented various forms of carbon pricing to incentivize a shift away from emission-intensive production routes.[1] Additionally, import control programmes, like the EU's Carbon Border Adjustment Mechanism (CBAM), complement these measures.

- In countries like China and India, national-level action plans and roadmaps for clean hydrogen have been adopted to encourage investments across the hydrogen value chain that aid large-scale industrial transformation. Also, the G20 member countries have agreed to guiding principles that enable the production, consumption and global trade of clean hydrogen.

- Several countries have introduced policies to enable CCUS technology and infrastructure developments. These include carbon capture and storage (CCS) investment tax credits in Canada, the EU's Innovation Fund for CCS projects, and Japan's commitment to develop a CCS-specific regulatory framework.

- Comprehensive policy packages like US' Infrastructure Investment and Jobs Act (IIJA) and Infrastructure Investment and Jobs Act (IRA) that provide fiscal stimulus to multiple areas of industrial decarbonization have also been deployed.

- While the above policies address the supply side, demand side measures such as green public procurement (GPP) are advancing, with Clean Energy Ministerial's Industrial Deep Decarbonisation Initiative (IDDI) driving global GPP commitments in heavy industries.

While these policy systems show promise, it's important to note that their applicability varies across different sectors, particularly in addressing emissions-intensive sectors across industry, energy and transport. Each sector demands specific, well-defined policies and regulations that align with evolving consumer revenue models. Furthermore, there is an urgent need for effective cross-regional policies that bridge the current disparities among regions, which are impeding global CO_2 emissions reduction efforts.

20%
of countries have carbon pricing mechanisms

Capital

An additional $11 trillion is required by industries to retrofit existing assets with clean technologies and order a new zero-emission fleet outside the BAU asset renewal cycle. For some industries, like cement, this means attracting almost double their annual CapEx to invest in clean technologies. However, the current market landscape lacks sufficient incentives to invest in low-emission technologies and poses a risk to early investors across most sectors.

Industry collaboration is imperative to reduce costs, accelerate learning curves and establish market stability to incentivize greater investment in decarbonization efforts. Industrial decarbonization requires the pooling of collective knowledge and resources across sectors; both start-ups and incumbents have a role to play. Collaboration allows for the efficient exchange of expertise and assets, leading to the development of more economically viable decarbonization technologies. This cooperative approach not only alleviates the financial burden on individual sectors but also creates market predictability. A stable and predictable market environment is paramount in attracting increased investments in decarbonization initiatives and cultivating stakeholder confidence.

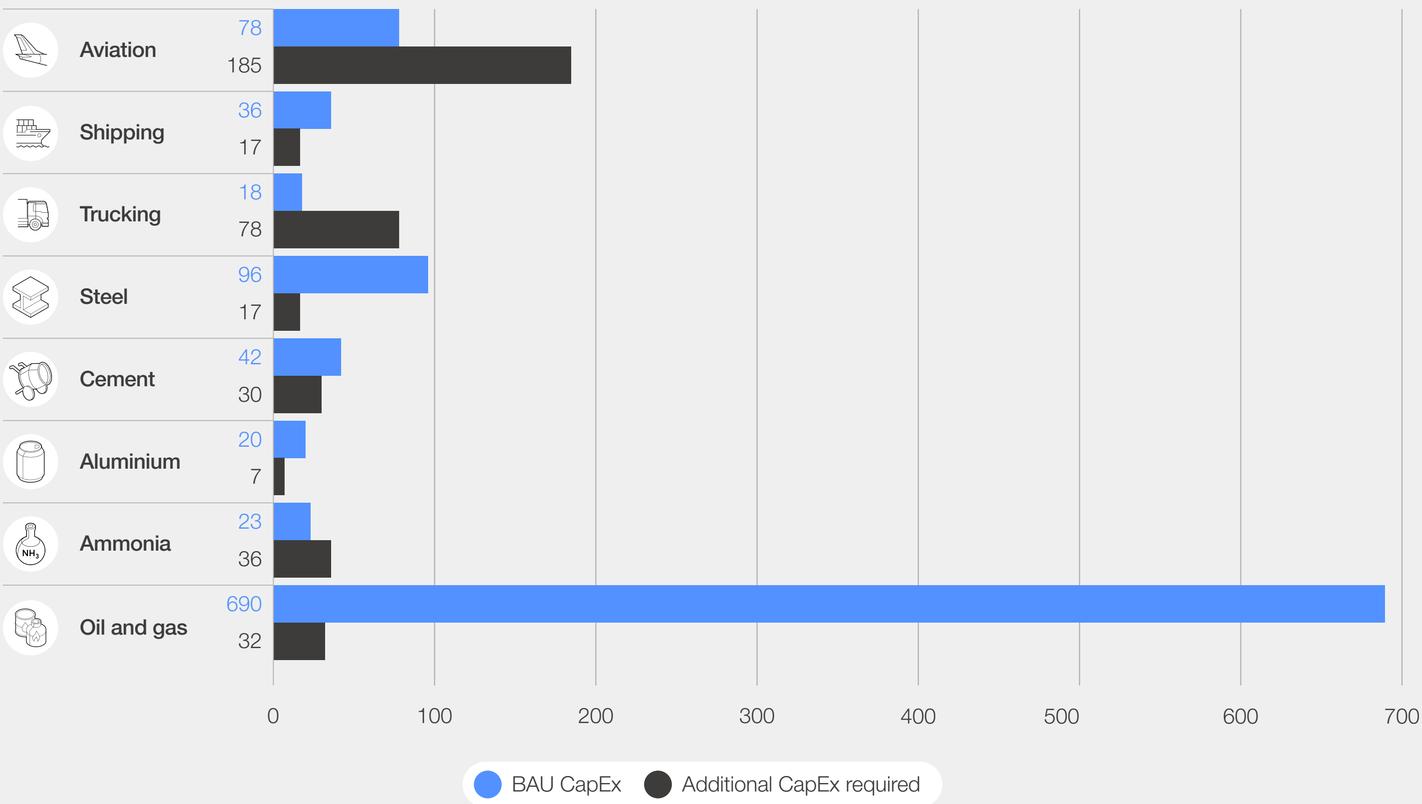
Redirecting capital for industry transformation requires strategic policy interventions, including carbon pricing, technology subsidies, public procurement and a strong business case. Institutional investors and multilateral banks can play a crucial role by providing access to low-cost capital linked to emissions targets. However, adapting financial models to align with the specific needs of various industries and regions is equally vital to mobilizing the necessary capital.

Many companies have demonstrated their commitment to reducing emissions by integrating emission considerations into their decision-making processes. Some companies exhibit a more comprehensive approach, providing detailed emissions reporting and clear emission reduction targets. However, a significant portion of companies lag behind, limited to basic emission reporting and reduction targets, particularly in developing countries.

Current industry profit margins indicate that many industries are ill-prepared to absorb additional costs while generating sufficient returns. To improve access to capital and generate sustainable returns, improved transparency surrounding low-emission and low-carbon alternatives is needed. Strengthening demand signals, particularly for new technology applications, is key. Collaborative infrastructure development across regions can play a pivotal role in mitigating early investor risk, reducing CapEx requirements for individual sectors, and ultimately leading to more substantial and sustainable returns on investment.

To improve access to capital and generate sustainable returns, improved transparency surrounding low-emission and low-carbon alternatives is needed.

FIGURE 10 **Estimated annual CapEx vs BAU annual CapEx ($, billion)**



Source: Accenture analysis based on multiple sources to include IEA, EMSA, MPP and IATA

FIGURE 11 | **Actions to support net zero industrial transformation**

For policy-makers:

1. Implement nationally tailored incentive and mandate-based policies, such as tax subsidies and emissions caps to stimulate demand for low-emission technologies, especially in developing regions. Policy measures need to be tailored to national circumstances and fiscal capabilities.
2. Implement carbon pricing in all major production regions and main transport hubs.
3. Increase green public procurement and public/private partnerships to provide early demand signals for low-carbon products and mitigate early investor risks.

For industry:

1. Support regulations and standards and clarifying net zero and transition technologies to improve transparency for producers, investors and end-consumers
2. Collaborate across sectors for improved infrastructure access and faster development.
3. Increase the number of offtake agreements by 2030 to stimulate early low-emission technology demand.

For companies:

1. Embed measurable net zero targets and pathways into their long-term strategies.
2. Invest in R&D and deployment to accelerate the learning curve for lagging low-emission technologies.
3. Enhance access to infrastructure and implement decarbonisation solutions within this decade.

Decarbonizing industrial sectors requires collective collaboration among policy-makers, industry consortia and companies.

2 Aviation industry net-zero tracker

SAF are considered key to decarbonizing aviation, but current commercial limitations mean that SAF only provides around 40% emissions reduction.

Key emissions data[2,3,4,5]

2%
Contribution to global GHG emissions

0.98 gtCO_2e
Operational and fuel supply chain emissions

-25%
Emissions growth (2019-2022)

>99%
Fossil fuels in the fuel mix (2022)

83 gCO_2e
Emissions intensity emitted per passenger km (2020)

2-5 times
Expected demand increase by 2050

Readiness key takeaways

Technology
Two leading decarbonization pathways have emerged: mature SAF and less mature novel propulsion technologies. However, the most advanced pathway is 2-5 times higher cost than traditional jet fuel.[6]

Infrastructure
$2.4 trillion[7] in infrastructure investment is required to support the development and scaling of aviation technology by 2050.

Demand
Although SAF adoption was less than 1%[8] of flights in 2022, there is a growing shift towards sustainable business models and agreements supporting its use.

Policy
Current policies primarily target developed countries, but further policy advancements are needed, like tax subsidies, direct funding and additional fuel standards, to incentivize biofuels infrastructure.

Capital
The industry needs approximately $5 trillion by 2050[11], far exceeding current airline investments. Low-profit margins and a 7% weighted average cost of capital (WACC) make it hard to attract private capital for low-emission assets.[12]

Stated energy transition goals

- Net-zero emissions by 2050.[9]
- 73%[10] of large publicly traded aviation companies consider climate change in their decision-making processes.

Emission focus areas for tracker

Aviation emissions can be divided into two main categories:

1. **Well-to-tank** mainly upstream emissions from production and distribution of fossil fuels
2. **Tank-to-wake** primarily due to combustion of fossil fuels, predominantly jet fuel, used during flight operations.

Sector priorities

Exisiting transport

Reduce near-term emissions intensity by:

- Increasing the number of operational synthetic fuel projects
- Increasing biofuels refining capacity to support additional commercial scale hydroprocessed esters and fatty acids (HEFA) projects
- Using efficiency and design improvement opportunities at an accelerated pace.

Next generation transport

Accelerate battery electric and hydrogen technology development, to reduce absolute emissions by:

- Investing in next generation transport R&D and accelerating the learning curve
- Developing hydrogen storage capacity and refuelling capabilities
- Investing in clean power infrastructure.

Ecosystem

De-risk capital investment to scale infrastructure capacity by:

- Increasing the number of offtake agreements, strengthening market demand signals
- Accelerating power to liquids (PtL) development, mitigating biofuels supply chain limitations
- Implementing a blend of policies, primarily, tax subsidies, direct funding and additional fuel standards, incentivizing biofuels production.

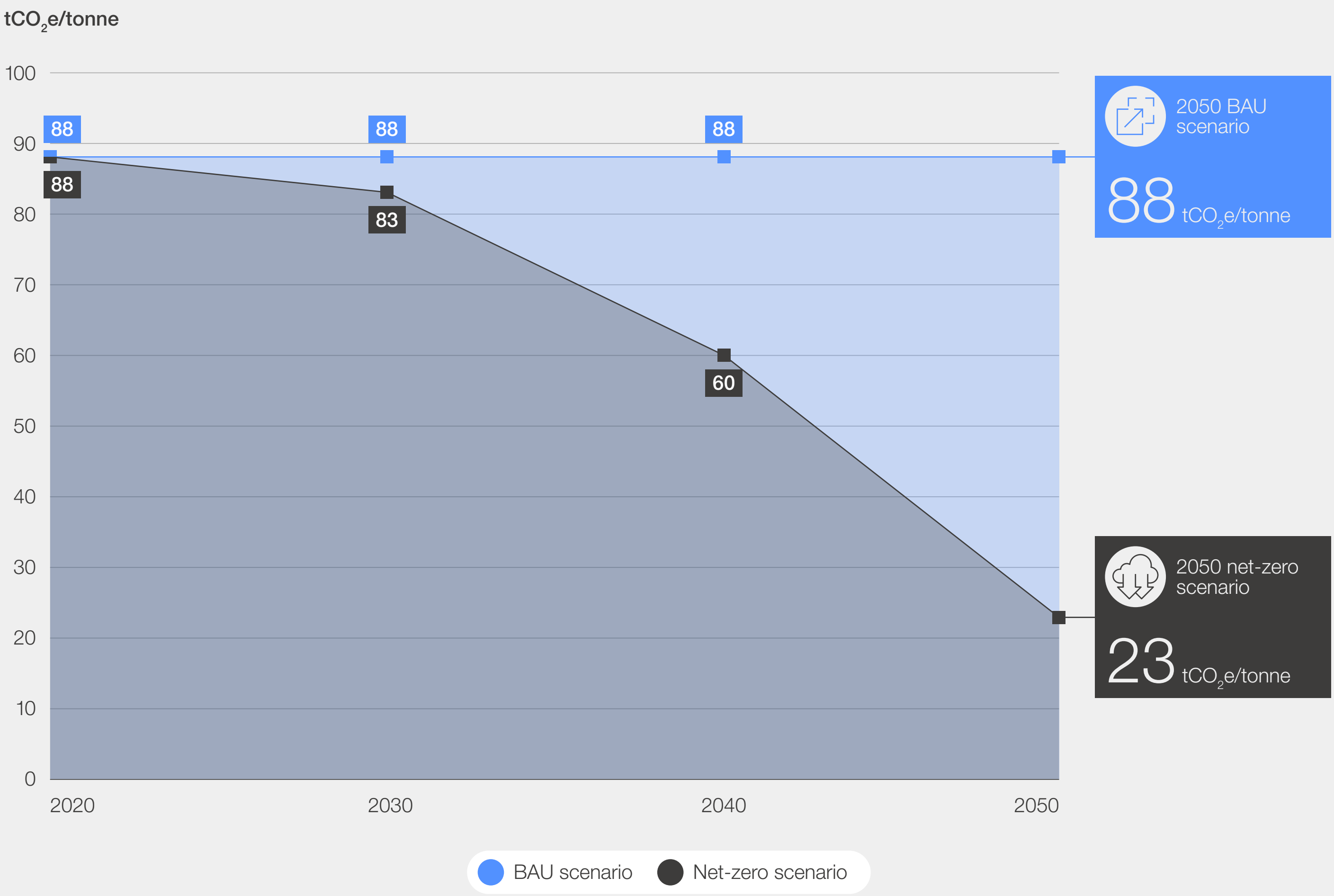
Performance

Emissions profile

Absolute emissions in gigatonnes of CO_2 are impacted by fuel burn, load factors, aircraft type and route operated, among other factors. The most significant emissions reduction, around 65%, is expected between 2030-2040 as SAF becomes more widespread. Further efficiency measures have the potential to enhance fuel efficiency by 30-40% by 2050.[13]

Emissions intensity, measured as CO_2 emitted per passenger kilometre, is influenced by aircraft type and routes. In 2022, emissions intensity per passenger kilometre was higher than pre-pandemic levels due to demand being around 80% of 2019 levels.[14] Emissions intensity is now decreasing in line with growing demand. However, aviation needs to reduce its emissions intensity to net zero by 2050, with over 70%[15] of the reduction expected between 2030 to 2050 as SAF adoption increases alongside increased efficiency measures and offsetting.

FIGURE 12 **Fuel GHG emissions intensity trajectory for aviation**



Source: Accenture Analysis based on ICAO and IEA data

BOX 4 **Offsets**

Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), mandates offsetting CO_2 emissions exceeding pre-pandemic levels (2019) that cannot be reduced by other methods.[16] In 2021, roughly 9% of aviation emissions were eligible for offsets, although precise figures remain uncertain. Although participation is currently voluntary, it is anticipated to increase, alongside associated regulations, as the scheme advances through defined phases. Phase 1 is set to commence in 2024.

Path forward

The key decarbonization strategy involves substituting traditional fuels with SAF to reduce in-flight emissions by 75-95%, coupled with efficiency measures.[17] Achieving 85% SAF adoption by 2050 necessitates coordinated efforts from stakeholders, governments and advisory bodies.[18] Priorities include promoting low-emission fuels, stimulating SAF demand and advancing sustainable feedstock R&D. Despite the current dominance of fossil fuels, projections indicate a 65% emissions reduction by 2030-2040 as SAF scales up to 50% of the fuel mix alongside increased efficiency measures, ultimately reaching an 85% reduction by 2050.[19] Further reductions by 2050 stem from novel propulsion technology, albeit in smaller proportions.

FIGURE 13 **2020 fuel mix**

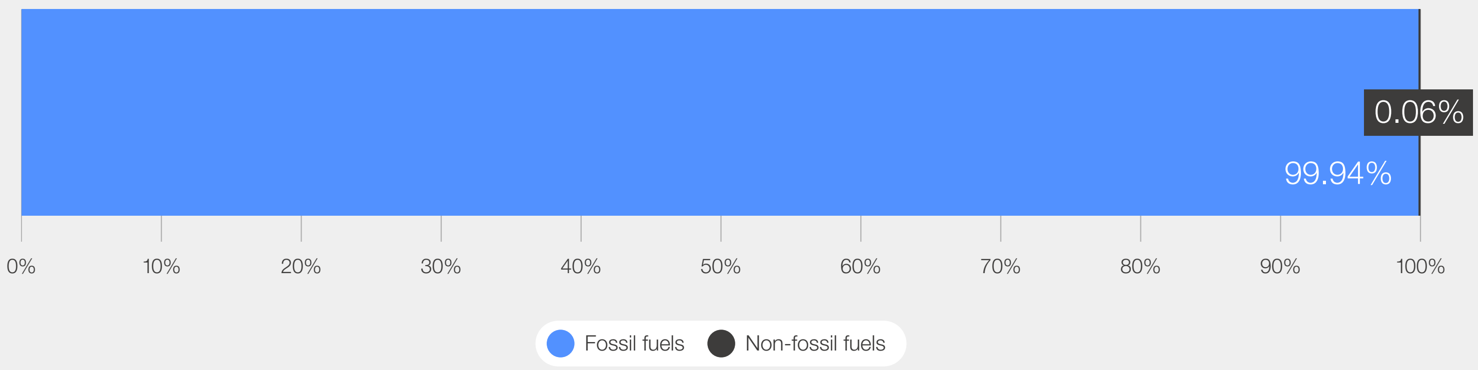
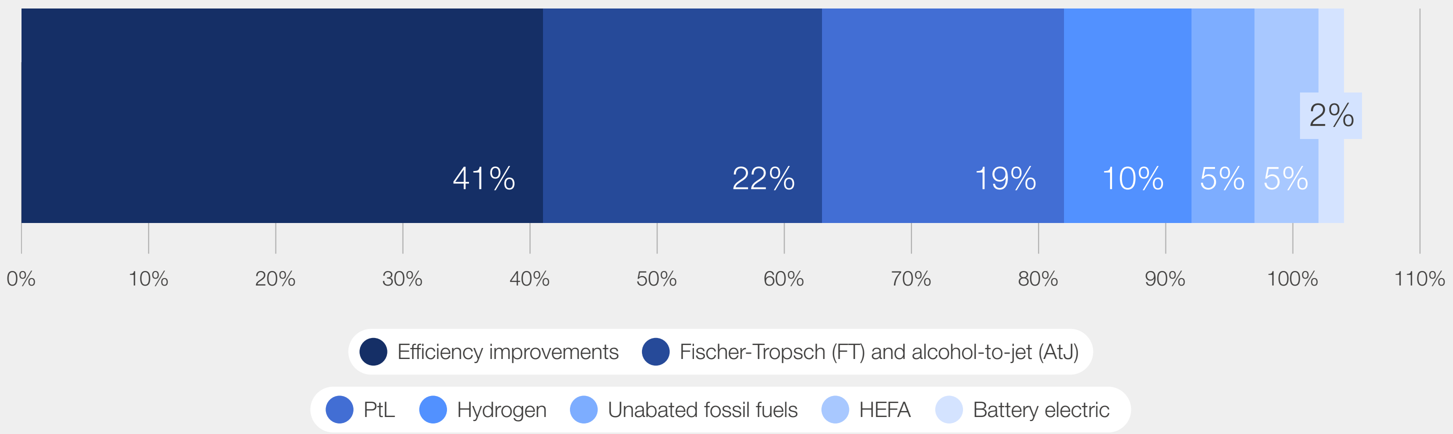


FIGURE 14 **MPP 2050 net-zero scenario**



Note: Totals do not add up to 100% as not a fuel mix

2 Technology

Two leading decarbonization pathways have emerged: SAF and novel propulsion technologies.

SAF includes biofuels made through the HEFA, FT and AtJ pathways, as well as synthetic aviation fuels made from captured carbon and green hydrogen electrolysis, called power-to-liquids (PtL). HEFA is the most advanced and is currently available in small quantities, though increased commercial availability is expected before 2025.[20] Novel propulsion technologies, such as battery-electric and hydrogen, are less mature and anticipated to be commercially ready by 2040.[21] Currently, the total cost of ownership (TCO) for HEFA is 2-5 times higher than traditional jet fuel, and less than 1% of the global fleet uses low-emission technologies.[22]

SAF pathways

Up to **95%** emissions reduction potential

Fuel switching to 100% renewable drop-in fuels has the potential to cut in-flight emissions by 75-95% while matching jet fuel's range (up to 15,000km).[23] However, with SAF currently limited to a 50% blend rate, emissions reduction potential stands at a maximum of around 40%.[24]

HEFA is the most mature, poised for commercial availability by 2025, while other FT and AtJ projects are mostly in large prototype-demonstration stage, also targeting commercial readiness by 2025.[25] However, commercial scalability is limited by the finite nature of bio-based feedstocks, insufficient refining capacity and increased production costs (up to 5 times jet fuel[26]).

Synthetic fuels, though less mature, are advancing, with commercial availability expected around 2025.[27] Despite higher production costs (up to 9 times jet fuel) and lagging clean hydrogen and direct air capture (DAC) infrastructure development, their synthetic nature addresses feedstock availability challenges. Accelerated R&D and adoption of PtL have the potential to alleviate supply chain challenges in SAF production.

Novel propulsion technologies

Battery-electric aircraft and hydrogen aircraft offer the lowest emission alternatives to jet fuel up to 100% emissions reduction. However, their limited range, prolonged safety approvals, high R&D costs and insufficient availability of clean hydrogen and clean power infrastructure delay widespread adoption until the 2040s.

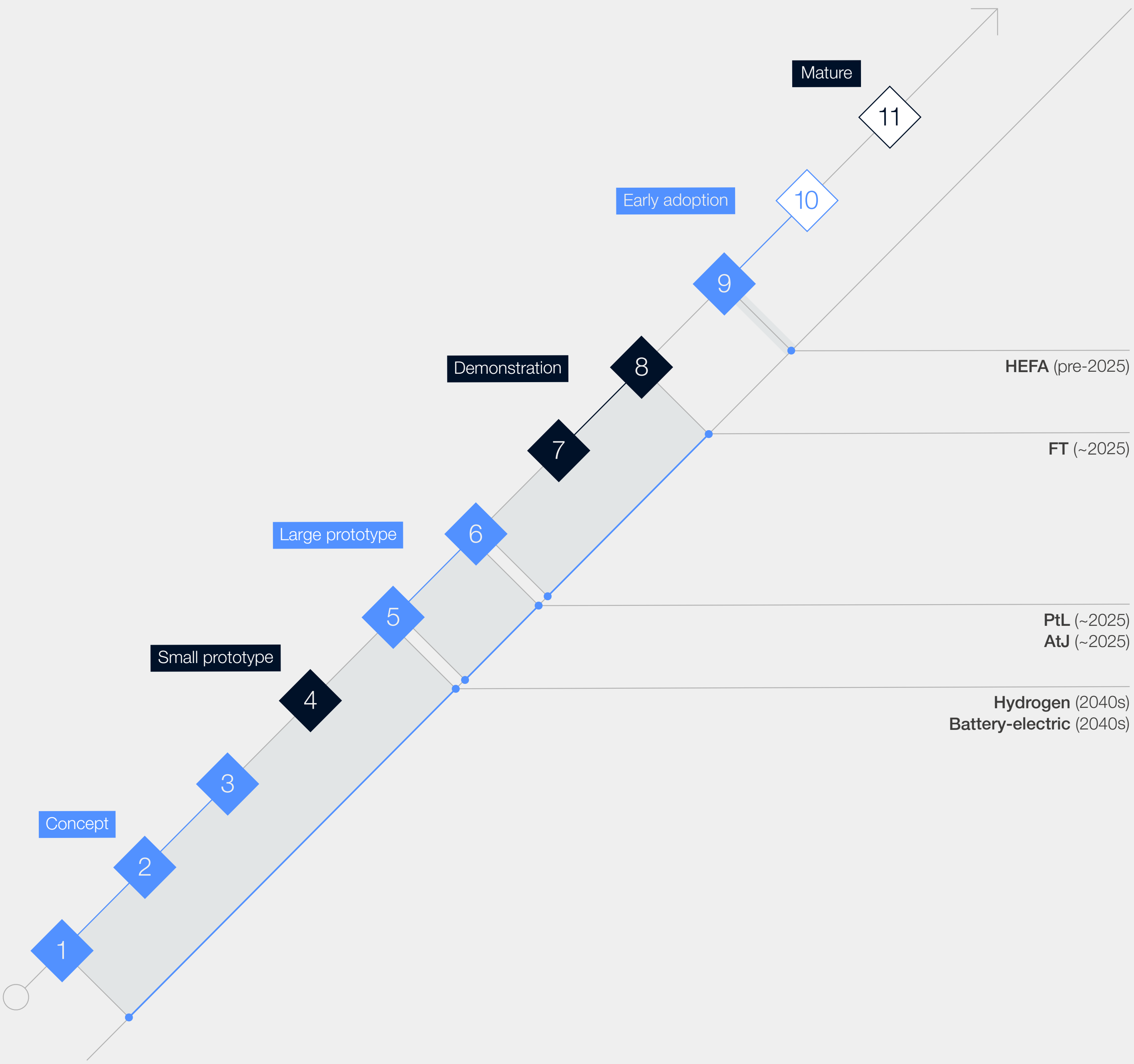
In September 2022, Eviation[28] conducted the first test flight of "The Alice", the world's first commercially scalable fully electric aircraft. Commercial operations are set to begin in 2027, with over 50 orders by June 2023 valued at $4 billion, indicating strong market demand and confidence in electric aviation.

Recharging and refuelling technologies

With on-board battery-electric and hydrogen fuel cell technology limited at prototype stage, technology provisions for fast charging and refuelling technologies are nascent, in line with their required availability. As novel propulsion technologies develop, additional R&D to improve the technical capabilities to match current aviation business models will be needed.

Technology pathways

FIGURE 15 **Estimated TRL and year of availability for key technology pathways**



Source: Accenture analysis based on multiple sources, including IEA and MPP

AVIATION

2 Infrastructure

The current infrastructure is inadequate to support the development and scaling of decarbonization pathways, especially regarding SAF production capacity and feedstock availability for SAF. Less than 1% of the required SAF infrastructure currently exists. It's estimated that $2.4 trillion[29] in infrastructure investments will be necessary to meet SAF demand by 2050, with $0.9-1.5 trillion within the aviation industry's immediate scope.[30]

The majority of these investments should focus on developing upstream SAF production infrastructure:[31] About 18% of total investments should go towards biofuels refining capacity, resulting in establishing approximately 7,000 biorefineries, equivalent to 12 exajoules (EJ) of HEFA and other biofuels by 2050.[32] The remaining 73% should be directed towards creating clean hydrogen infrastructure and implementing DAC, equivalent to 95 million tonnes per annum (MTPA) of clean hydrogen and 490 MTPA of captured carbon as feedstock for PtL production.[33]

As clean hydrogen and clean power technologies advance, downstream infrastructure requirements are expected to emerge, including clean hydrogen storage, charging stations, electrified ground power and grid connection infrastructure or on-site power generation capacity. Industry players are already taking steps in this direction. For instance, in November 2022, Airbus joined HyPort,[34] a venture by ENGIE Solutions and AREC, to develop a pioneering clean hydrogen production and distribution station. The facility is set to commence hydrogen production in 2023, capable of powering up to 50 ground vehicles and scalable for future hydrogen aircraft use.

FIGURE 16 **2050 investment requirements**

Source: Accenture analysis based on multiple sources including IATA MPP, IEA and Global CCS Institute

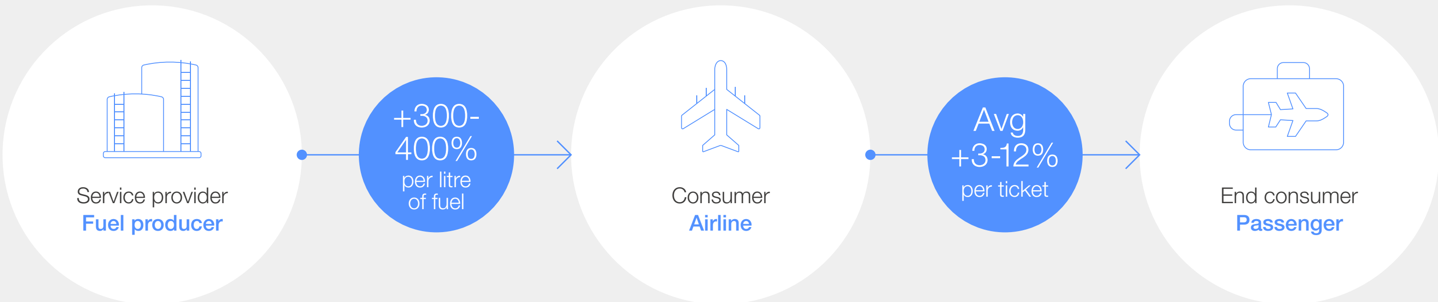
2 Demand

SAF, which represents less than 1% of the current aviation fuel mix, remains untested in terms of its ability to absorb the green premium due to 2022's market demand being less than 1%.[35,36] However, there is a growing shift towards sustainable business models and SAF offtake agreements.

By 2030, SAF production is expected to reach approximately 17.3 billion litres, driven mainly by North America, Europe and Asia. To meet the 2050 target of around 475 billion litres annually, production capacity needs to increase by 27 times from 2030 to 2050.[37]

Comparing the TCO to jet fuel use, the adoption of HEFA carries a 300% fuel cost increase, resulting in a business to business (B2B) green premium of more than 45-60%.[38] HEFA carries an average B2C green premium of 3-12% per plane ticket.[39] Although passengers and airlines currently cover these higher costs, this market scenario is not sustainable and poses risks for early investors, hindering commercial scalability and adoption. Cost reduction is essential to ensure both supply and demand of low-emission technologies.

FIGURE 17 **Estimated B2B and B2C green premium**



Source: Accenture Analysis, based on MPP and Accenture data

The adoption of SAF technologies will require business model diversification in the upstream aviation fuel value chain. There are eight American Society for Testing and Materials (ASTM) certified production pathways,[40] however, the diversity of biomass options and blend rates presents challenges in standardization and supply chain stability. Existing business models are relatively simple. However, sourcing a stable feedstock supply for biobased SAF and access to gas markets to source captured CO_2 and clean hydrogen for PtL will require the creation of new markets, contracts, ecosystems and supply chains. These activities add complexity to the market environment. Still, they are necessary to ensure the stability of SAF supply and provide opportunities for smaller industry players to drive innovation in SAF development.

There are early signs of growing market demand with industry players adopting measures to boost demand. Airlines like Lufthansa offer optional fare increases to offset carbon, while Air-France KLM imposes mandatory green surcharges. In December 2022, Air France-KLM and Total Energies[41] signed a memorandum of understanding (MoU) for Total Energies to supply 800,000 tonnes of SAF to Air France-KLM over 10 years. Moreover, approximately 42 offtake agreements were announced in 2022, totalling around 22 million litres of SAF. However, regulatory incentives and an increase in public-private contracts are required to ensure demand growth, alongside these industry efforts.

Policy

Policies are scarce in developing economies and need to expand to achieve the projected SAF production targets.

Aviation's decarbonization will require a mix of policy tools. Current policies have mainly focused on developed countries, but further policy advancements are needed, such as tax subsidies, direct funding and additional fuel standards, to incentivize biofuels infrastructure.

While aviation operates globally, individual countries handle airline registration, and fuel production extends beyond carrier regions. To effectively drive aviation sector decarbonization, international regulations must be complemented by regional policies.

Developed economies, notably the US, have taken the lead in implementing policies that address various readiness enablers.[42] However, similar policies are scarce in developing economies, and policy coverage needs to expand throughout the 2020s to achieve the projected 2 billion litres of SAF production in Asia by 2030.[43]

Lower carbon aviation fuel (LCAF) is fossil-based jet fuel that is produced with at least 10% fewer emissions compared to the baseline of 89 MJ/kg as defined by CORSIA. While certain SAF alternatives can reach up to 95%, with a minimum threshold of 65% required to qualify for sustainable certification.[44]

Although CORSIA has certified eight SAF production methods, the availability of diverse biomass options, feedstocks and blend rates presents challenges in establishing consistent standards and regulations. As such, the emissions reduction potential of CORSIA-approved fuels can range from 10% with LCAF to SAF, which has the potential to reduce 95% of emissions. The diversity in SAF production also hampers standardization, regulation and traceability of use across the value chain.

To meet ICAO targets, policies should encourage low-emission fuel use and operational efficiency. Key actions include enforcing fuel standards, streamlining approvals, enhancing R&D policies and considering SAF mandates, Carbon Contracts for Differences (CCfDs), book-and-claim systems like Avelia[45] and fiscal incentives.

Existing policy landscape

TABLE 5 **Policy summary**[46]

Enabler	Policy type	Policy instruments	Key examples	Impact
Technology	Market-based	Carbon pricing	– EU-Emission Trading Scheme (ETS)[47]	Incentivizes emission reduction among airlines but is constrained by free allowances and reduced carbon prices. Currently limited to intra-EU flights, expanding to all EU entries in 2024.
		Emissions cap	– CORSIA[48]	Projected emission mitigation potential is around 2.5 gigatonnes of CO_2 equivalent ($gtCO_2$) by 2035 via offsets.[49] Limited to voluntary participation, mandatory offsets from 2027, with increasing emissions reduction as progress continues.
	Mandate-based	Performance standards and certification		Projected to decrease EU aircraft emissions by 66% by 2050[50]
		Direct taxation	– Energy Taxation Directive: Fit for 55 (proposed)[51]	Incentivizes SAF adoption via taxation of jet fuel.
	Incentive-based	Subsidies, tax credits	– US Blender's Tax Credit (BTC)[52]	$1.25-1.75 per gallon tax credits for SAF producers – around 17% higher than other fuels such as biodiesel.[53]
Infrastructure	Mandate-based	Direct regulation	– Alternative Fuel Infrastructure Regulation (AFIR)[54]	Mandatory deployment targets for clean power infrastructure to boost development of battery-electric aircraft.

TABLE 5 | **Policy summary[46] (continued)**

Infrastructure	Incentive-based	Subsidies, tax credits	– Clean fuel production credit[55] – UK: £580 million towards commercialization of SAF plants and fuel testing[56] – Inflation Reduction Act (IRA) clean power and green hydrogen production tax credits[57]	Encourages SAF, clean power and hydrogen infrastructure for advancing technology in developed economies.
Demand	Mandate-based	Fuel standards	– California Low-Carbon Fuel Standard (CALCFS)[58] – ReFuelEU Aviation: SAF blending mandate for fuel suppliers at EU airports[59]	Proposed regulation to penalize jet fuel use and boost SAF demand.
Capital	Incentive-based	Direct funding	– Clean Aviation Joint Undertaking (CAJU)[60]	Public-private partnership that funds technologies that reduce aviation emissions by 20-30% per aircraft. Targets regional/short-medium haul flight technologies; not applicable to long-haul flights.
		Technical roadmap	– SAF Grand Challenge[61]	Incentivizes SAF production through $4.3 billion in investments. Projected to reduce 20% of US aviation emissions by 2030.[62]

1

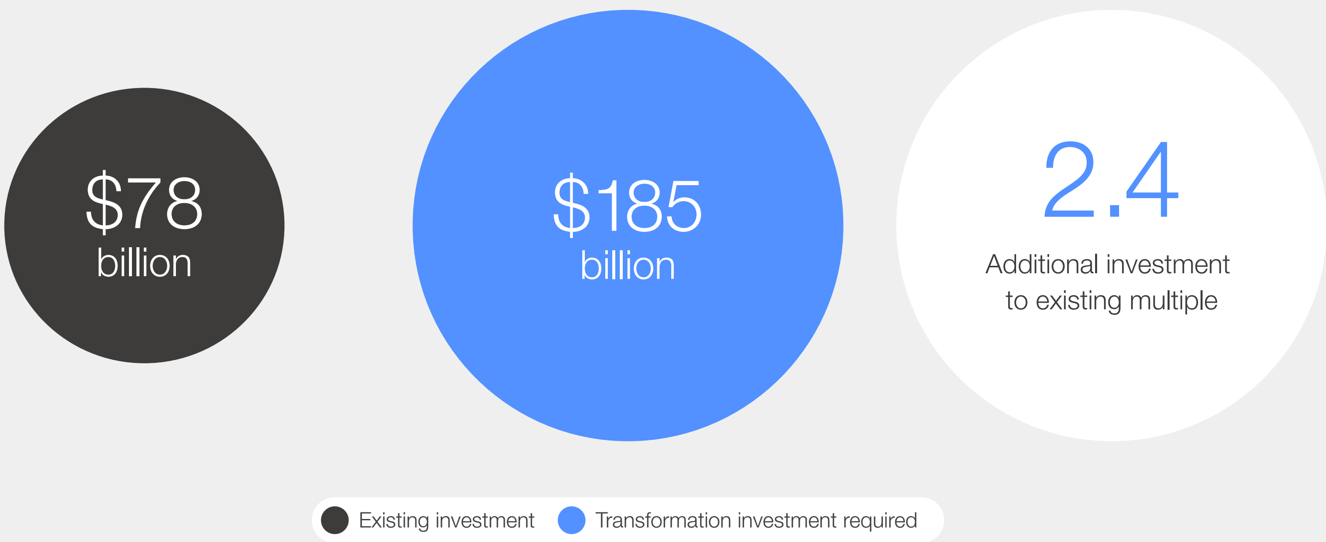
AVIATION

Capital

The aviation industry faces a $5 trillion[63] CapEx requirement for its 2050 net-zero transformation, necessitating an annual investment of approximately $185 billion, 2.4 times the current passenger airline investments.[64]

The argument in favour of investing in aviation assets with low emissions continues to lack strength. Given the aviation industry's tight profit margins and a weighted average cost of capital (WACC) at 7%,[65] the sector isn't ready to assimilate these extra expenses and generate satisfactory returns exclusively from internal funds or to allure private investments.

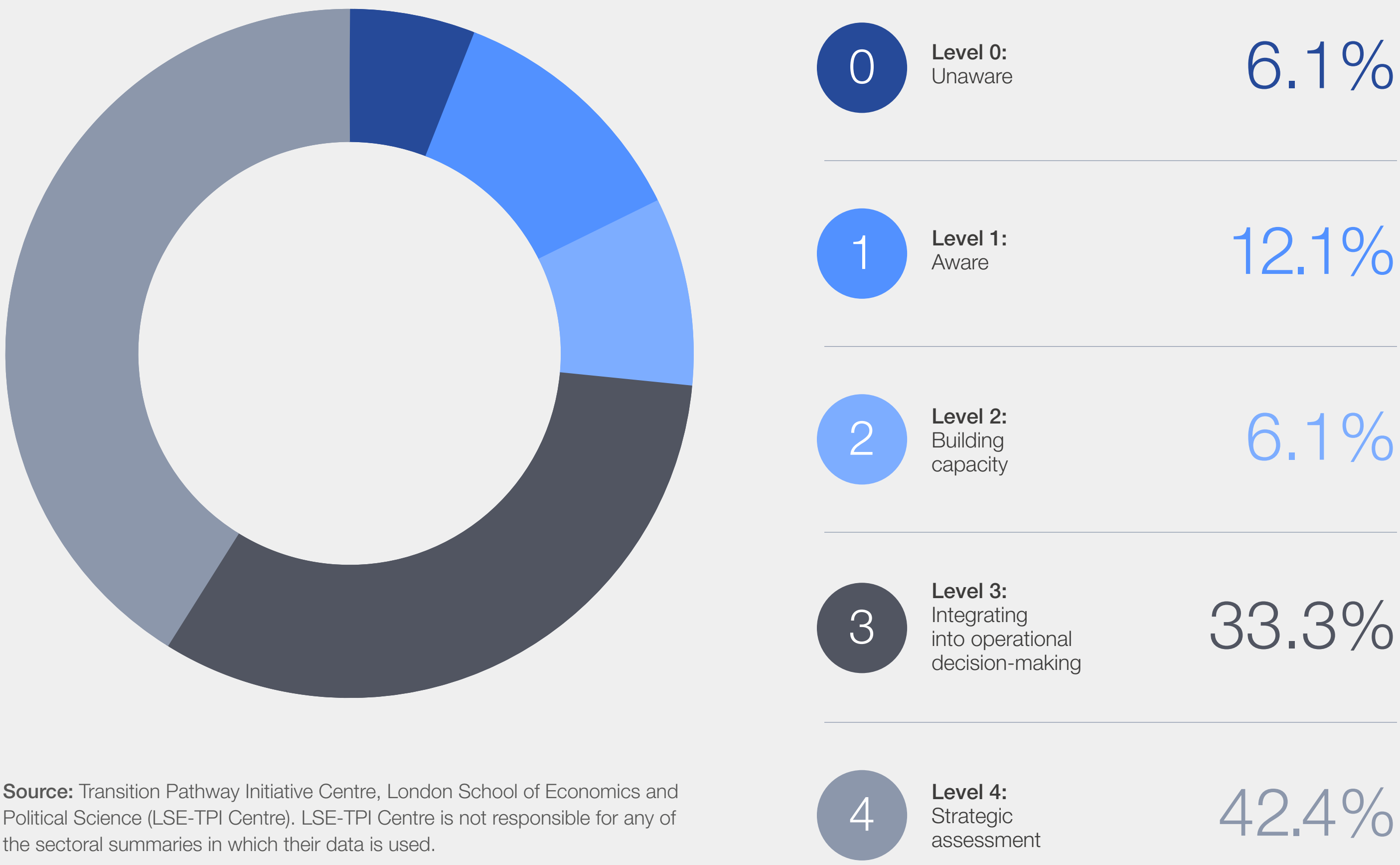
FIGURE 18 | **Additional investment required to existing investment ratio**



According to IATA, actors involved in investing in aviation's net-zero transition will require access to different funding and financing mechanisms depending on the maturity of the investment opportunity. This is because the risk is the highest at the R&D stage and decreases as the commercial viability of the solution grows.[66] In order to channel funds into revolutionizing the industry, policy measures such as carbon pricing, incentives for technology development and the promotion of SAF adoption become essential to ensure profitable returns. The pivotal role played by banks and other financial institutions is to grant access to affordable capital aligned with sustainability objectives.

Approximately 74% of large publicly traded aviation companies consider climate change as a key consideration for their strategic assessment and integrate it into their operational decision making.[67] Meanwhile, 9% of companies are building basic emissions management systems and process capabilities. Finally, 12% of companies acknowledge climate change as a business issue.

FIGURE 19 **Distribution of companies in the airlines sector according to the management of their GHG emissions and of risks and opportunities related to the low-carbon transition**



Source: Transition Pathway Initiative Centre, London School of Economics and Political Science (LSE-TPI Centre). LSE-TPI Centre is not responsible for any of the sectoral summaries in which their data is used.

3

Shipping industry net-zero tracker

Despite the rise in emissions, a more ambitious IMO strategy and industry actions towards technology adoption positions shipping on a positive track for a net-zero pathway.

Key emissions data[68, 69, 70, 71]

2%
Contribution to global GHG emissions

0.76 $gtCO_2e$
International shipping GHG emissions (2018)

11.7 $gtCO_2e$
Emissions intensity (emitted per tonne nautical miles, 2018)

99%
Fossil fuels in the fuel mix (2021)

2 times
Expected demand increase by 2050

Readiness key takeaways

Technology

Transitioning to clean, hydrogen-based, zero-emission fuels (ZEF) like methanol and ammonia, could nearly eliminate shipping emissions. However, uptake faces costs and infrastructure challenges.

Infrastructure

Currently less than 1% of the necessary infrastructure exists, requiring about $0.4-0.6 trillion investment to support the development and scaling of shipping technology by 2050.[72]

Demand

Growing demand for low-carbon shipping faces uncertainty as B2B green premium of 30-80% remains mostly untested at scale.[73]

Policy

To meet IMO targets, policies should encourage low-emission fuels and operational efficiency through measures like carbon pricing, fuel standards and incentives for infrastructure.

Capital

Adopting ZEF propulsion for ships by 2050 requires up to $450 billion investment,[76] adding 47% to annual fleet owner costs, which are currently around $36 billion.[77]

Stated energy transition goals

- United Nations (UN) specialized agency IMO aims for at least 20%, striving for a 30% reduction in absolute emissions by 2030 (vs 2008) and net-zero emissions by or around 2050.[74]
- 51% of large publicly traded shipping companies consider climate change in their decision-making processes.[75]

Emission focus areas for tracker

Shipping emissions can be divided into two main categories considering well-to-wake:

1. **Operational emissions are** primarily due to the combustion of fossil fuels during maritime operations.
2. **Fuel value chain emissions** are mainly upstream emissions from the production and distribution of fossil fuels.

Sector priorities

Existing transport

Reduce near-term emissions intensity by:

- Accelerating design and efficiency improvements aligned with IMO guidelines
- Increasing share of fleet capable of running on alternate fuels supported by technology standards
- Explore feasibility of complementary solutions in the interim (e.g. wind-assisted propulsion).

Next generation transport

Accelerate clean hydrogen-based fuels development, to reduce absolute emissions by:

- Investing in next generation fuels and propulsion technology R&D
- Ramping up the required clean hydrogen-based fuels production capacity
- Developing the required bunkering capacity, with storage and refuelling infrastructure.

Ecosystem

De-risk capital investment to scale infrastructure capacity by:

- Implementing green corridors in major routes supported by clean hydrogen hubs
- Bridging the cost gap between ZEFs and conventional fuels through increased number of projects
- Implementing a blend of policies, primarily carbon pricing and fuel standards.

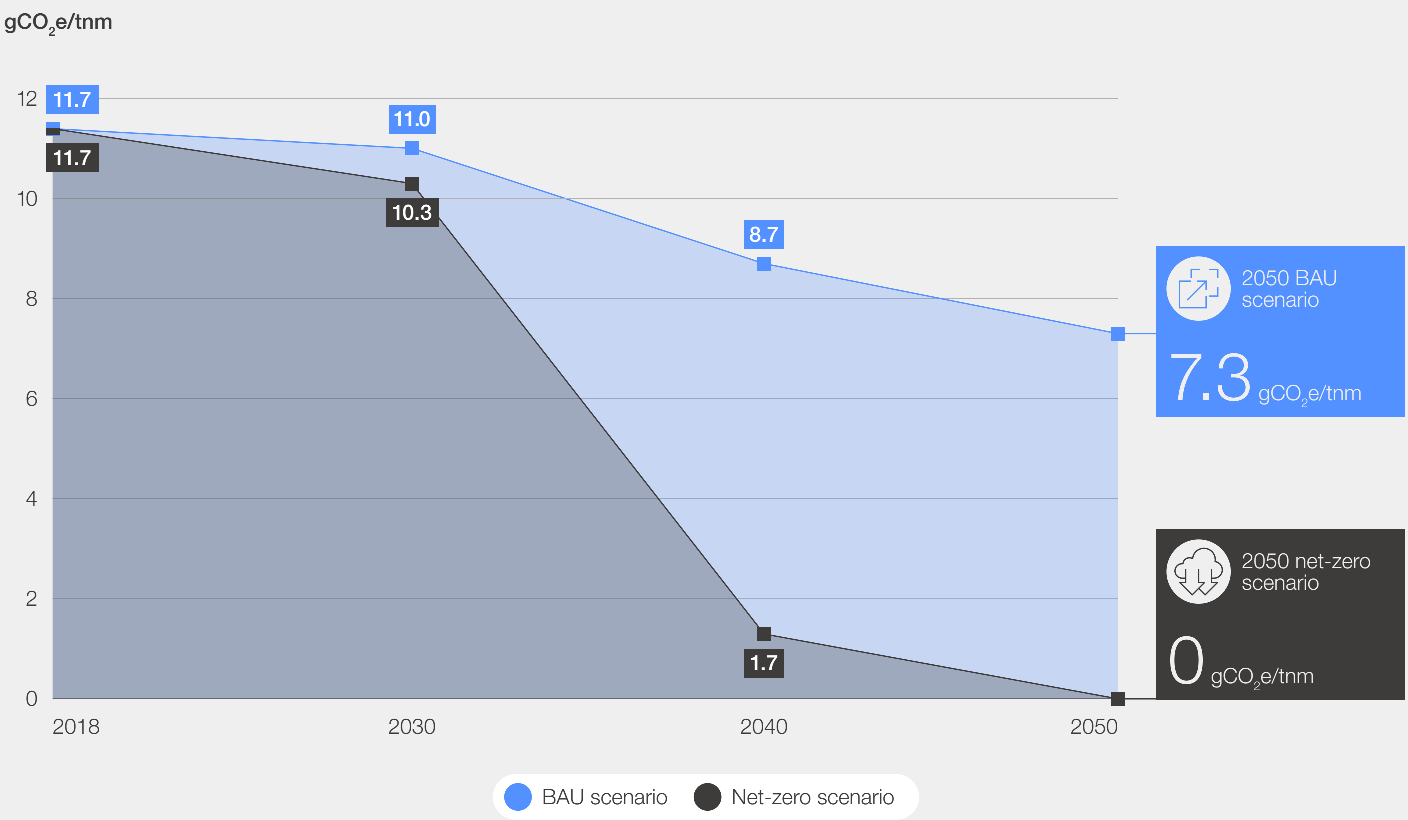
Performance

Emissions profile

Fuel combustion in maritime operations accounts for over 80% of the total shipping life cycle emissions, primarily due to the current reliance on fossil fuels.[78] Bulk carriers, oil tankers and container ships are responsible for 65% of these emissions.[79] As per IMO targets, absolute emissions need to be reduced by at least 20% by 2030 and at least 70% by 2040 compared to 2008.[80] As past trends show, shipping emissions continue to exceed the 2008 benchmark.[81]

Shipping emissions intensity varies based on factors such as fossil fuel use, vessel load use, size, speed and route characteristics. For example, in the case of container ships, the South-East Asia to/from North-East Asia shipping lane has the highest emission intensity among the top 10 trade lanes by activity, 35% above the average emission intensity levels.[82] To meet the IMO targets, carbon intensity trajectory has been considered (see Figure 20). This trajectory requires a 40% reduction in intensity levels (vs 2008) and near-zero intensity levels in 2050.[83]

FIGURE 20 **Emissions intensity trajectory, net-zero vs BAU scenario. Possible net-zero trajectory as per IMO targets**

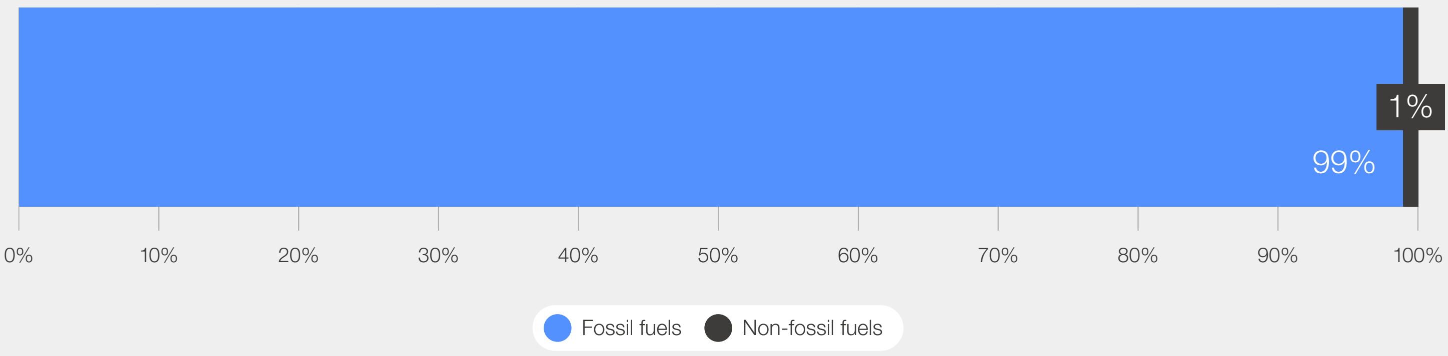


Source: Accenture analysis based on IEA and IMO data

Path forward

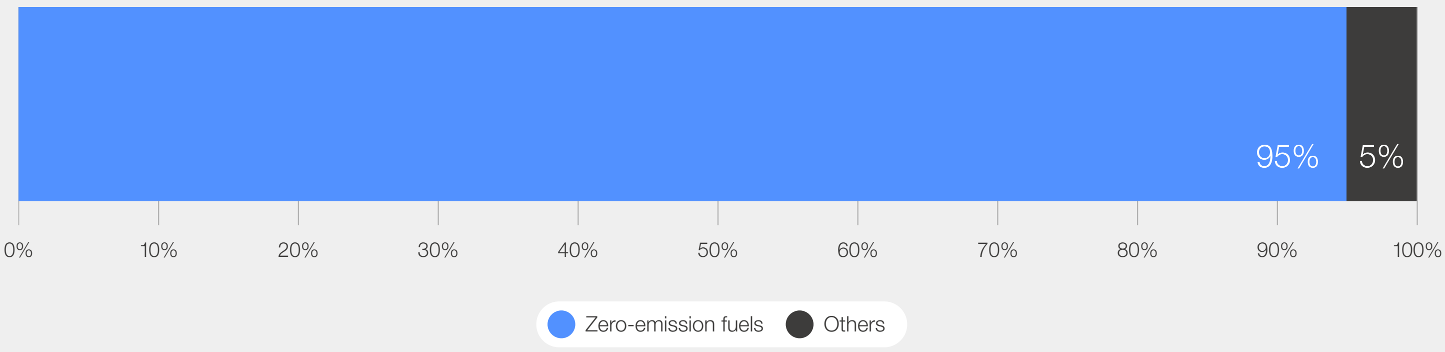
Meeting the IMO net-zero target by or around 2050 demands substantial collaboration from governments, industry stakeholders and research institutions. The industry's primary focus should centre on advancing clean hydrogen-based ZEFs and incentivizing their widespread adoption, to align with Global Maritime Forum (GMF) transition strategy. ZEFs are expected to occupy more than 90% of the 2050 energy mix, facilitating the achievement of net zero.[84] While these fuels develop, biofuels – and, to a limited extent, liquified natural gas (LNG) – will serve as transition fuels. In addition to fuel-switching, emissions can be further reduced through operational efficiency enhancements and design improvements, which are crucial for meeting the near-term 2030 IMO targets.

FIGURE 21 | **2021 fuel mix**[85]



Source: IMO

FIGURE 22 | **2050 net-zero scenario**



Source: GMF

SHIPPING
3 Technology

Up to **80%** increase in total ownership costs expected

Switching entirely to clean hydrogen-based ZEFs, such as methanol, ammonia and liquid hydrogen, holds the potential to achieve near-zero well-to-wake shipping emissions. While methanol-fuelled ships are available, they currently rely on natural gas-based feedstock. Commercial availability of ammonia and liquid hydrogen propulsion technology is expected by 2025. However, transitioning to these fuels may increase total ownership costs by 30-80%.[86] Key barriers to their adoption include higher vessel ownership costs, limitations in the fuel supply chain, the absence of global bunkering infrastructure, and the need for modifications in onboard storage configurations. The TRL of ZEFs can be considered in terms of the maturity of the fuel production process, the maturity of propulsion technologies and the readiness of bunkering technologies. Globally, there are over 200 R&D projects dedicated to advancing these fuels and related technologies.[87]

Production technologies

Currently, ammonia, methanol and hydrogen are derived from natural gas feedstocks. Clean hydrogen-based production for shipping applications is currently limited to demonstration projects. In addition to clean hydrogen, methanol production will require CO_2, which can be sourced from industrial point sources or via DAC technologies. Clean hydrogen production facilities and carbon capture technologies need to be sufficiently scaled at an industrial level to advance the production of ZEFs.

An example of progress is Danish energy company Orsted's construction of Europe's largest clean methanol plant in North Sweden, set to commence operations by 2025. It is expected to supply 50,000 tonnes of clean methanol annually.[88]

Propulsion technologies

Methanol engines have been successfully demonstrated and are in the early adoption stage of development. Currently, there are around 30 vessels running on methanol.[89] In 2023, Maersk will start operating the world's first container ship powered by clean methanol, with further ships in the order book.[90] Ammonia and liquid hydrogen engines are still in development and are expected to mature after 2025.[91]

Bunkering and onboard storage technologies

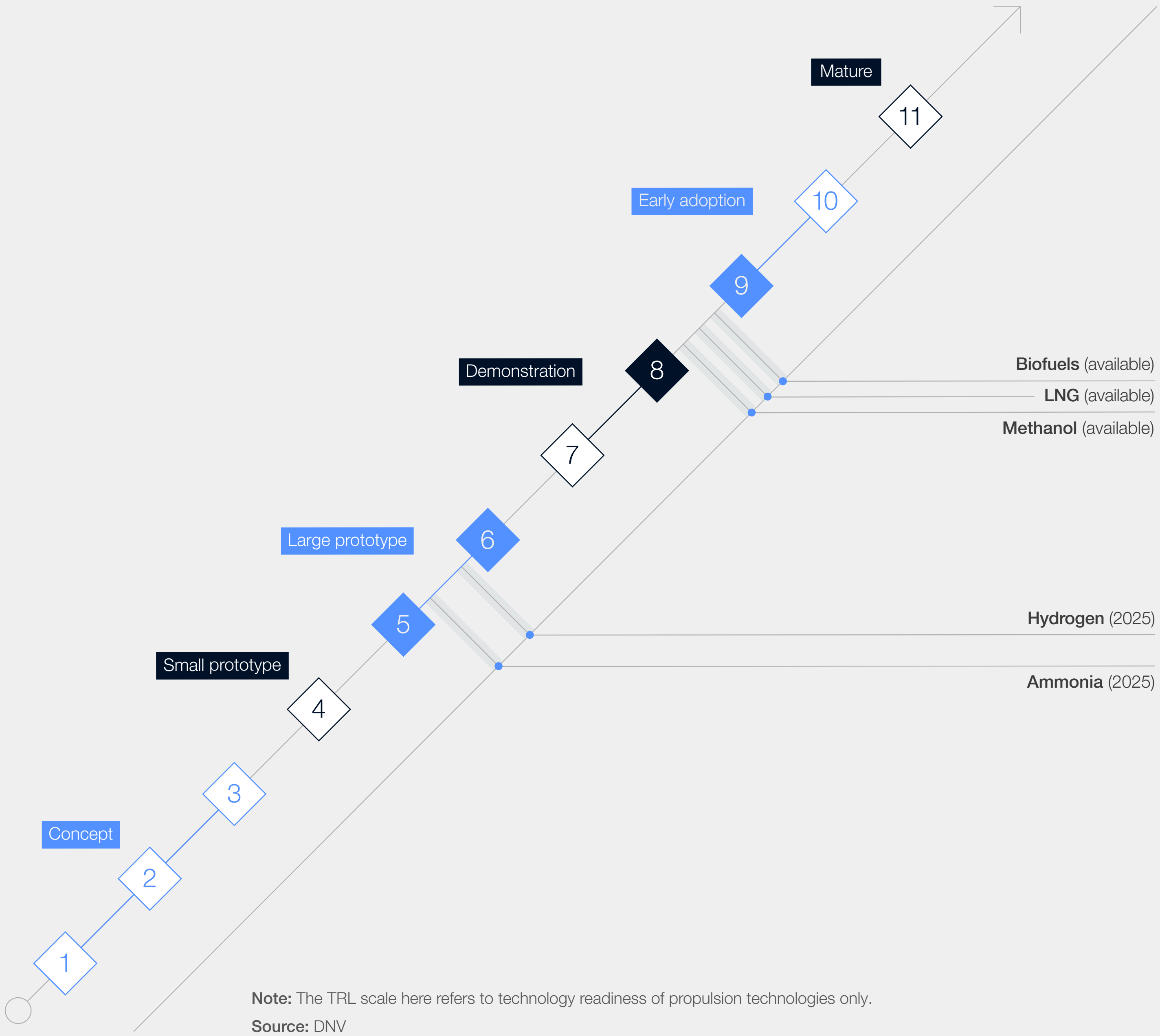
Methanol bunkering and onboard storage/handling technologies have been successfully demonstrated. For ammonia and liquid hydrogen, these technologies need to be progressed beyond the prototype stage.[92]

Other intermediate measures

Additional decarbonization pathways are essential to ensure that the shipping industry meets the near-term IMO targets for 2030. Transition fuels, such as biofuels, can be considered as potential options. Moreover, achieving decarbonization in shipping necessitates improvements in operational and technical efficiency. For instance, optimizing routes and enhancing vessel use can result in emission reductions of up to 10%.[93] Additionally, innovative systems, such as wind-assisted propulsion, are under investigation to further contribute to emissions reduction.

Technology pathways[94]

FIGURE 23 **Estimated TRL and year of availability for key technology pathways**



Note: The TRL scale here refers to technology readiness of propulsion technologies only.

Source: DNV

SHIPPING

2 Infrastructure

Adopting ZEFs hinges on scaling clean hydrogen, CO_2 handling and bunkering infrastructure, however less than 1% currently exists.[95] Investments of up to \$0.8-2.1 trillion will be needed by 2050,[96] mainly for clean hydrogen-based fuel infrastructure. To meet the 2050 net-zero scenario, clean hydrogen production capacity of 160 MTPA is required,[97] necessitating an investment of \$0.6-1.9 trillion.

By 2050, up to 130 MTPA of CO_2 will be needed as a feedstock for producing ZEFs.[98] If the CO_2 is sourced from industrial point sources not co-located with the ZEF producing facility, adequate CO_2 transport infrastructure must be established. This is projected to require investments in the range of \$10-23 billion.[99]

ZEFs need to be supported by bunkering infrastructure, which will require an additional \$132-176 billion in investment.[100] Notable efforts include Yara International and Azane Fuel Solutions partnering to create a "zero-emission" ammonia fuel bunker network in Scandinavia, backed by around \$9 million in public funding. This network will supply "zero-emission" ammonia to ships as early as 2024, expediting fuel adoption.[101] Also, Clean Energy Marine Hubs, a public-private platform between energy, maritime, shipping and finance stakeholders, has been recently launched to de-risk investment into the necessary ZEF infrastructure and accelerate pace of deployment.[102]

FIGURE 24 **2050 investment requirements**

	Investments required	Percentage of total investments	Capacity required
Clean hydrogen production	Up to \$1.9 trillion	91%	160 MTPA
CO_2 transport and storage	Up to \$20 billion	1%	130 MTPA
Bunkering	Up to \$170 billion	8%	880 MTPA

Source: Accenture analysis based on multiple sources to include; GMF, GTZ and Global CCS institute

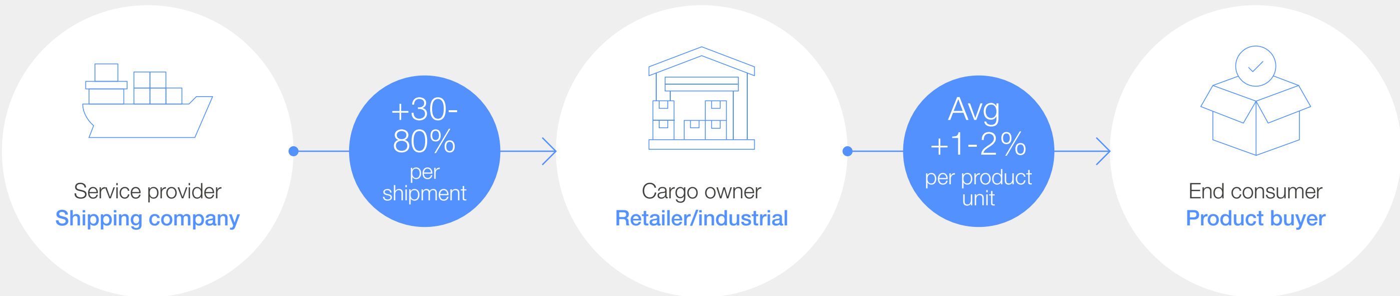
SHIPPING

2 Demand

Demand for decarbonized shipping services is rising as nations and businesses pursue strict environmental, social and governance (ESG) goals. However, the feasibility of cargo owners absorbing the estimated green premium of 30-80% remains untested on a large scale.[103] As an industry working on narrow margins, passing the costs on to cargo owners will be challenging and hence, increased policy interventions may be necessary to reduce the green premium.

While the increase in shipping costs is expected to have a minor impact on end-consumers, resulting in an approximate 1-2% green premium (see Figure 25), it's important to note that shipping costs represent only a small fraction of the final retail price of products.[104] Nonetheless, this premium can result in significant absolute cost increases for essential commodities like oil, grains and metals, particularly affecting emerging and developing economies.

FIGURE 25 **Estimated B2B and B2C green premium**



Source: Accenture analysis based on DNV and GMF data

The ability of shipping companies to pass on or profit from the green premium of decarbonized shipping services depends on the demand from industrial or consumer segments and the location. For instance, low-income countries that heavily rely on maritime trade for essential commodities may feel a more significant impact. As the market progresses, regulatory measures could help reduce green premiums and promote the adoption of decarbonized shipping services, thereby driving increased uptake of ZEFs.

The adoption of ZEFs may also need business model changes across the upstream shipping value chain. For example, existing ammonia producers should move beyond traditional demand applications and build supply capabilities to support the increasing need for ammonia from shipping. Similarly, shipbuilders will need to develop ships capable of running on ZEFs as part of their product portfolio. Stable and predictable policy frameworks will be required to create these new markets, build sustained demand and reduce the risk of stranded assets for early movers.

With growing customer emphasis on climate considerations, decarbonized shipping is gaining popularity as a viable alternative. Industry leaders are actively promoting their offerings to meet this demand. For instance, Maersk ECO Delivery, using fatty acid methyl ester (FAME) biofuels, provides CO_2-saving certificates.[105] Hapag-Lloyd's Ship Green enables "climate-friendly container shipping" to reduce ocean shipment emissions. The FMC shipping members have committed to ZEF targets by 2030,[106] with fleet operators pledging 5% of deep-sea shipping and cargo owners committing at least 10% of goods volume via ZEF-powered vessels.[107] These commitments across the value chain have the potential to drive global demand for decarbonized shipping.

To enhance consistency and comparability of GHG emissions data, the industry should adopt standardized quantification and reporting, exemplified by the introduction of ISO 14083 in March 2023.[108] Standardized reporting empowers industry players to strategically target GHG emissions collectively while also creating stricter policies to encourage low-emission fuel adoption, further boosting market demand. The implementation of IMO regulations, Energy Efficiency Design Index (EEXI) and Carbon Intensity Indicator (CII) is anticipated to improve vessel performance transparency and further stimulate the demand for decarbonized shipping.

> Low-income countries that heavily rely on maritime trade may feel more of the green premium impact.

2

SHIPPING

Policy

The global shipping industry operates under selected flag states subject to international regulations led by the IMO. These regulations are bolstered by supporting regional policies that regulate ships entering territorial waters.

To meet IMO targets, regional policies should incentivize ZEF adoption and improve operational efficiency. Key measures include carbon pricing, fuel standards, green corridors, fiscal incentives for low-emission fuel infrastructure, bunkering standards and performance standards.

Existing policy landscape

TABLE 6

Policy summary

Enabler	Policy type	Policy instruments	Key examples	Impact
Technology	Market-based	Carbon pricing	– EU-ETS[109] – US International Maritime Pollution Accountability Act: $150 per tonne of CO_2 emissions proposed[110] – IMO economic measure, 2023 strategy[111]	$2.2 billion under EU-ETS to fund shipping decarbonization innovation.[112] The proposed US carbon pricing is projected to bring in $250 billion in low-emission funding, over the next 10 years.[113] Carbon pricing under IMO is still under discussion and will not be in effect before 2027.
	Mandate-based	Performance standards and certification	– Energy Efficiency Design Index (EEXI)[114] – Carbon Intensity Indicator (CII)[115]	Mandatory standards that ships must comply with, driving continuous technical and operational improvements.
Infrastructure	Incentive-based	Taxes and subsidies	– IRA clean power and green hydrogen production tax credits[116]	50% reduction in green hydrogen production costs that can boost scaling of green hydrogen capacity required for low-emission fuels.[117] The feasibility of such subsidy-driven policies for developing economies is uncertain.
	Mandate-based	Direct regulation	– EU Alternative Fuels Infrastructure Regulation mandate for major EU ports to provide shore side electricity to vessels[118]	Reduces emissions at ports by providing cleaner electricity as an alternative with a specific timeline for ports to action upon (by 2030).[119]
Demand	Incentive-based	Green corridors	– Clydebank Declaration: 22 countries as signatories to create six green corridors by 2026[120] – Green corridor pledges at COP27 between the US, the UK, the Netherlands and Norway[121]	Reduces risks of adopting low-emission fuels by deploying at a local scale and mobilizing demand. 21 green corridor initiatives announced so far, involving over 100 stakeholders.[122]
	Mandate-based	Fuel standards	– FuelEU Maritime initiative[123] – US Clean Shipping Act[124] – IMO technical measure, 2023 strategy[125]	Provides predictable pathways for low-emission fuels that encourage adoption and drive demand.
Capital	Incentive-based	Direct funding	– Public funding for green shipping projects in India[126]	Funds 30% of costs of new "green" ships.[127]

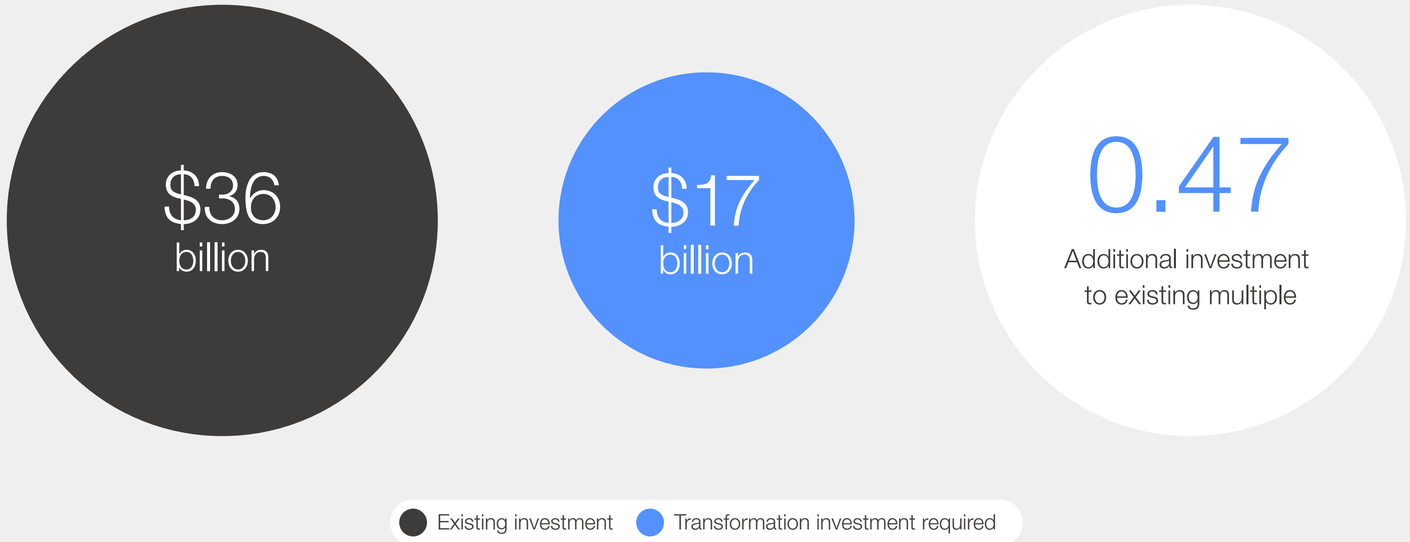
SHIPPING

1 Capital

In the shipping industry, retrofitting the current fleet and upcoming ships orders with ZEF propulsion technology necessitates an estimated $450 billion in investment by 2050.[128] This breaks down to an annual extra cost of $17 billion for fleet owners.[129] Given the current annual CapEx for shipping firms, which stands at approximately $36 billion, this represents an added 47% investment load annually.[130]

Recent data suggests the business case for zero-emission shipping investment remains weak due to high costs and uncertain returns. Current industry profit margins of around 32%[131] and WACC of 8-10%[132] suggest the industry is not positioned to absorb additional costs and generate sufficient returns solely from internal cash flows.[133] Fortunately, with the expansion of technology and the realization of economies of scale, it is anticipated that the financial demands for investment will diminish.

FIGURE 26 **Additional investment required to existing investment ratio**



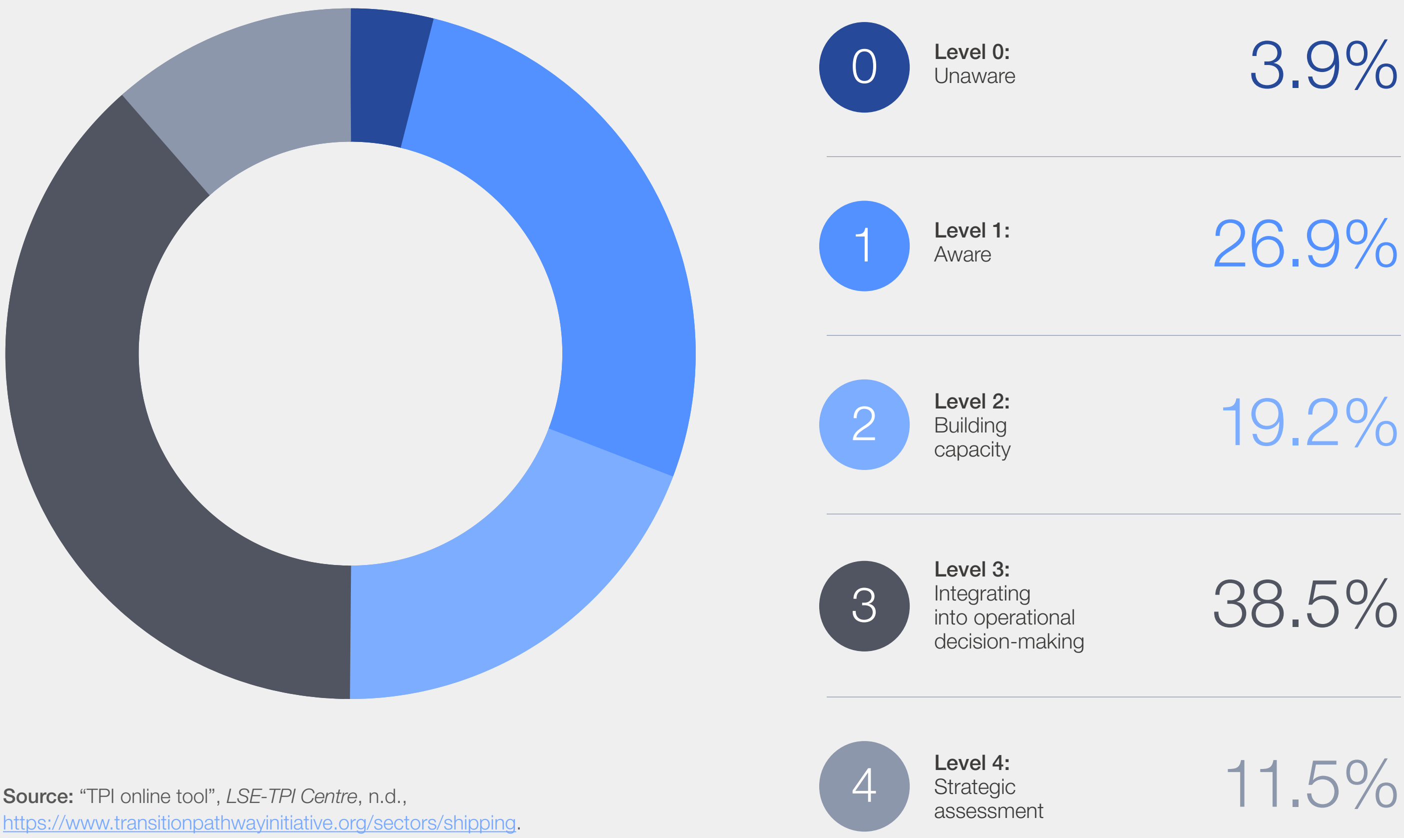
Source: Accenture analysis based on multiple sources, to include EMSA, DNV and UNCTAD

Historically, commercial bank loans have served as the primary source of financing for the shipping industry. Nevertheless, for the sector to achieve its net-zero objectives, there is a growing need for increased involvement from the public sector. This involvement can take the form of direct subsidies or blended finance mechanisms, both of which are designed to incentivize private sector engagement in sustainable shipping initiatives. The International Chamber of Shipping (ICS) set out a Fund and Reward proposal to the IMO for shipowners to make mandatory contributions per tonne of CO_2 emitted to create a new IMO fund to be established by 2024, which will reward uptake of low and zero-carbon fuels and provide billions of dollars of funding annually for alternative fuel production and bunkering infrastructure in developing countries.[134]

Approximately 50% of large publicly traded shipping companies consider climate change as a key consideration for their strategic assessment and integrate it into their operational decision-making.[135] Meanwhile, 19% of companies are building basic emissions management systems and process capabilities. Finally, 27% of companies acknowledge climate change as a business issue.[136]

FIGURE 27

Distribution of companies in the shipping sector according to the management of their GHG emissions and of risks and opportunities related to the low-carbon transition



Source: "TPI online tool", *LSE-TPI Centre*, n.d., https://www.transitionpathwayinitiative.org/sectors/shipping.

4 Trucking industry net-zero tracker[137]

Battery and hydrogen-powered electric trucks are considered vital for net-zero trucking, but adoption depends on region, duty cycle and supporting policies.[138]

Key emissions data[139, 140, 141]

5%

Contribution to global energy related GHG emissions

1.6 gtCO_2e

Operational and fuel supply chain emissions

2%

Emissions growth (2019-2022)

108 gCO_2

Emissions intensity (emitted per tonne miles, 2020)

96%

Fossil fuels in the fuel mix (2021)

2-2.5 times

Expected demand increase by 2050

Readiness key takeaways

Technology
Two key zero-emission pathways are emerging, battery electric trucks (BETs) and hydrogen-electric trucks (HETs), which can nearly eliminate tailpipe emissions. Adoption is limited to around 1% partly due to increased ownership costs (33-133%[142]).

Infrastructure
Insufficient infrastructure, less than 1% of the needed amount, hinders technology scaling. Meeting 2050 goals requires a $2-$3.2 trillion[143] in investment, primarily into clean power infrastructure.

Demand
Zero-emission vehicles (ZEVs) held 1% of the market in 2022. A B2B green premium of 10-15% may be necessary, with about 1-3% affecting consumers.[144] However, this remains untested at scale.

Policy
Public policy encourages ZEV adoption, with the EU taking the lead, but the industry is diverse and regulated at various levels. More policies are needed to support infrastructure development.

Capital
Additional capital requirements, including retrofitting the existing fleet requires a $2.1 trillion[146] in investment. However, the business case remains weak due to high costs and uncertain returns, given 6% industry profit margins and a 10% WACC.[147]

Stated energy transition goals

– Industry bodies propose an emissions reduction of 14% by 2030 and 92% by 2050.[145]

Emission focus areas for tracker

Trucking emissions can be divided into two main categories:

1. **Well-to-tank** mainly upstream emissions from production and distribution of fossil fuels.
2. **Tank-to-wake** primarily due to combustion of fossil fuels, predominantly diesel, used during trucking operations.

Sector priorities

Exisiting transport

Reduce near-term emissions intensity by:

– Accelerating the adoption of drop-in biofuels and synfuels in the interim
– Introducing standards and regulations around legacy vehicle decommissioning cycles
– Making use of efficiency and design improvement opportunities at an accelerated pace.

Next generation transport

Accelerate clean power infrastructure development, to reduce absolute emissions by:

– Investing in R&D to accelerate ultra-fast charging infrastructure deployment
– Investing in clean power infrastructure to increase access to renewable energy sources
– Accelerating development of hydrogen-electric technologies for long-haul applications.

Ecosystem

De-risk capital investment to accelerate technology adoption by:

– Increasing incentive-based policies such as tax subsidies to drive charging infrastructure deployment
– Implementing a blend of policies to incentivize accelerated fleet renewal outside BAU cycles.

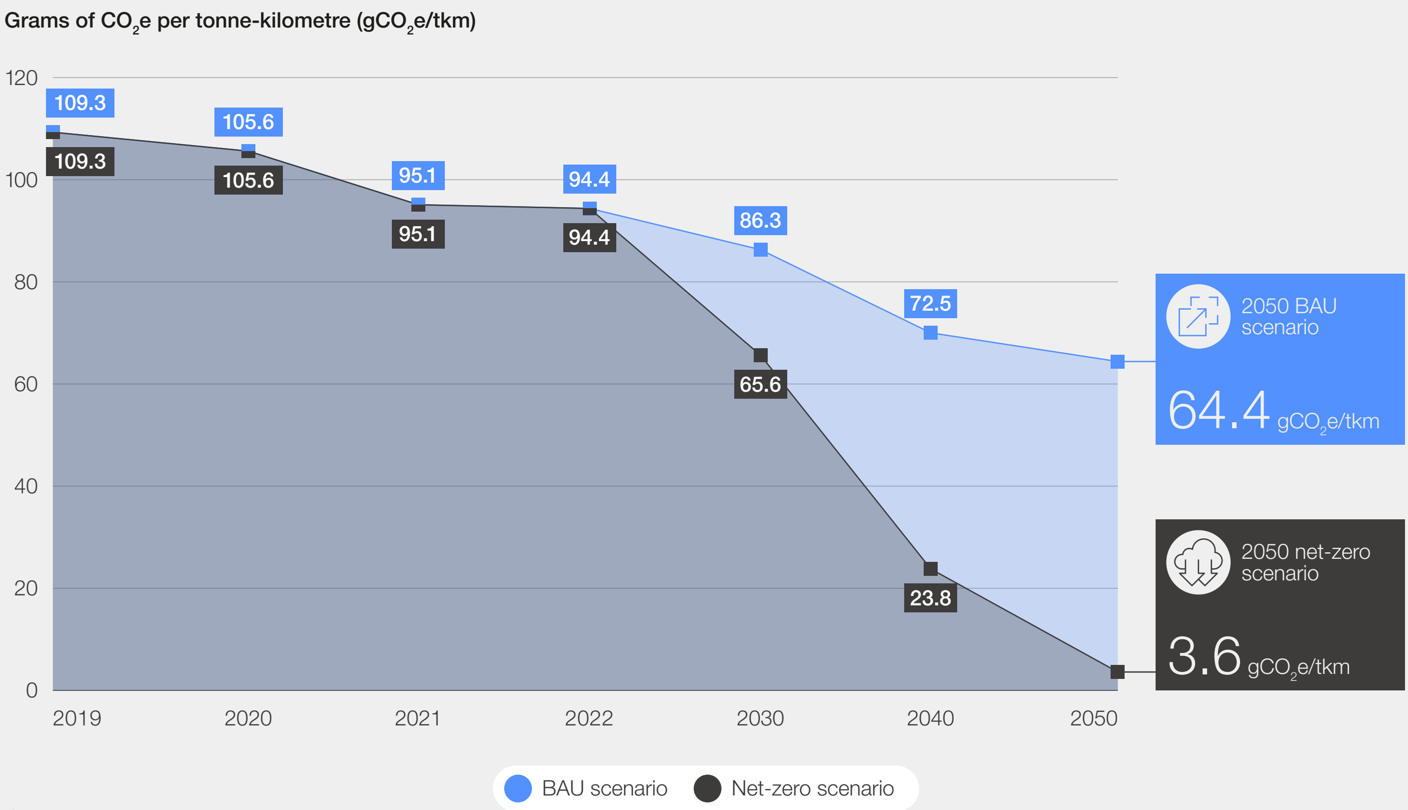
Notes: 1 The scope of analysis covers the hard-to abate aspect of the Trucking industry, primarily heavy-duty trucking **2** Regions in scope for trucking analysis, based on MPP framework; US, China, India, EU

Performance

Absolute emissions, measured by gigatonnes of CO_2 equivalent, are influenced by various factors such as fuel burn, load factors, vehicle type and route type. Currently, around 64% of the industry's total life cycle emissions arise from day-to-day operations, including vehicle use, maintenance and repair.[148] Addressing long-haul emissions could potentially decarbonize 86%[149] of the fleet in the EU. As BETs and hydrogen-electric trucks (HETs), scale up commercially, absolute emissions are expected to reduce almost equally between 2030-2040 and 2040-2050.

Emissions intensity in the trucking industry measures the amount of CO_2 released per gigajoule of energy generated through fuel combustion. This intensity is influenced by vehicle types and combustion rates. Over the last four years, emissions intensity has reduced by around 14% due in part to efficiency measures, operational improvements and an increase in biofuels in the fuel mix. Currently, BETs have a high emissions intensity due to the reliance on coal and other fossil-based fuels for power generation. However, as clean power scales up, emissions intensity is expected to approach zero by 2030. To achieve net-zero targets, the trucking sector should aim to reduce emissions intensity by roughly 30% by 2030 and approximately 80% by 2050.[150]

FIGURE 28 **Emissions intensity trajectory for trucking**



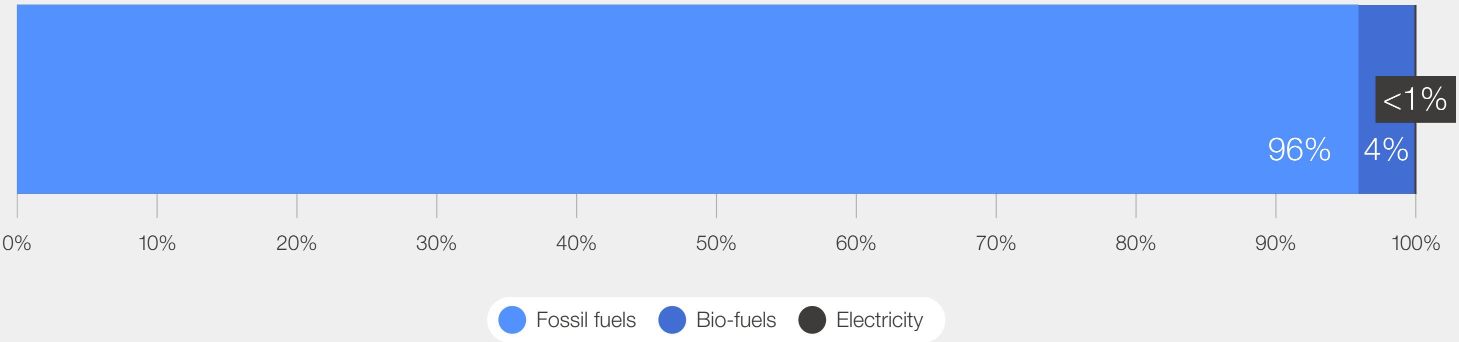
Source: IEA

Path forward

> **Industry should prioritize investment in charging and refuelling infrastructure, R&D and stimulating market demand.**

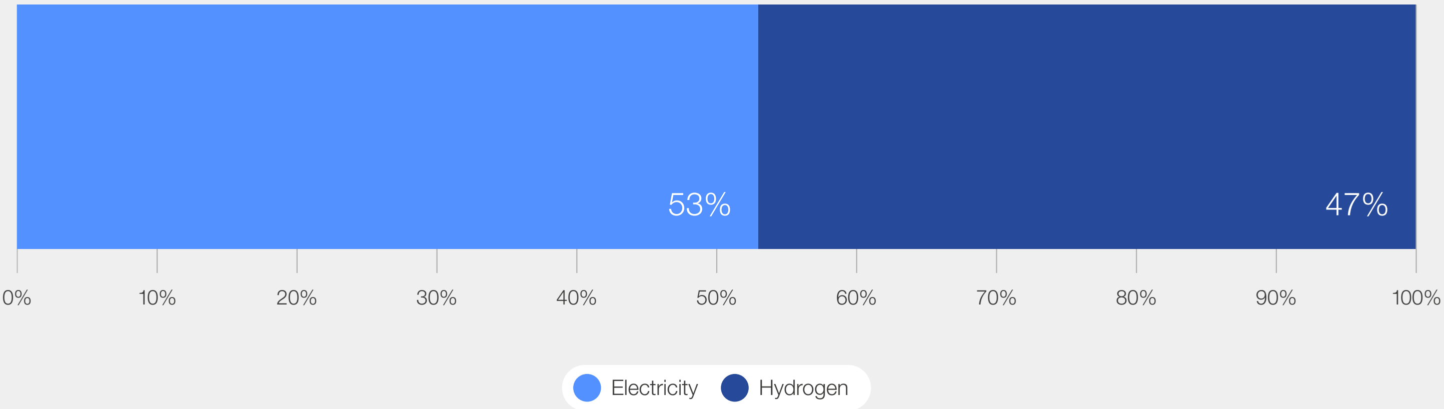
The key decarbonization strategy is to replace diesel combustion trucks with BETs, with HETs playing a smaller role. Immediate measures to accelerate emissions reduction include increased operational efficiency in transport and distribution, fuel efficiency measures and modal shift from trucking to rail. Achieving a predominantly ZEV fleet by 2050 requires collaboration among industry stakeholders, government and global advisers.[151] Priorities include investing in charging and refuelling infrastructure, advancing R&D for long-haul BETs and HETs, and stimulating market demand for zero-emission trucks (ZETs). These coordinated actions aim to accelerate infrastructure development and reduce overall ownership costs, promoting adoption throughout this decade. Despite the current dominance of fossil fuels in the fuel mix, a 53% emissions reduction is projected between 2030-2040 as commercial-scale BETs become widespread.[152]

FIGURE 29 | **2021 fuel mix**



Source: IEA

FIGURE 30 | **Proportion of new trucks sold in 2050 – MPP accelerated zero-emission scenario**



Source: MPP

Technology

Two leading zero-emission pathways have emerged, with BETs being more advanced. HETs are expected to become commercially available by 2025. Both BETs and HETs have the potential to reduce in-transit emissions to near-zero. However, adopting these technologies could increase TCO by 33-133%,[153] depending on duty cycle and range.

The main challenges to widespread adoption include limited range, challenges in charging and refuelling infrastructure, and onboard storage restrictions, especially for long-haul applications. Consequently, adoption remains limited to around 1%.[154]

Propulsion technologies

1%

of the global fleet are BETs

BETs and HETs have the potential to reduce life cycle GHG emissions by up to 84%[155] and tailpipe (tank-wheel) emissions to around zero. BET technology is currently commercially available for light and medium duty trucks, though adoption is low, at around 1%[156] of the global fleet. Hydrogen-electric trucks are not available at commercial scale, with expected availability around 2025.[157] However, sufficient onboard storage of clean hydrogen and large lithium battery capacity requires additional vehicle length, restricting the applicability to long-haul applications. While Adani Enterprises,[158] for example, signed an agreement with Ashok Leyland and Ballard Power to launch a pilot project in 2023 to develop a 55-tonne hydrogen fuel cell electric truck for mining applications, most projects are limited to the demonstration stage.

The implementation of BET and HET technologies includes a TCO increase of up to 1.3 times[159] due to the retrofitting requirements, fleet renewal requirements and necessary modifications to the existing fleet.

Charging and refuelling technologies

Ultra-fast charging stations could reduce recharging from 8 hours to 45 minutes.

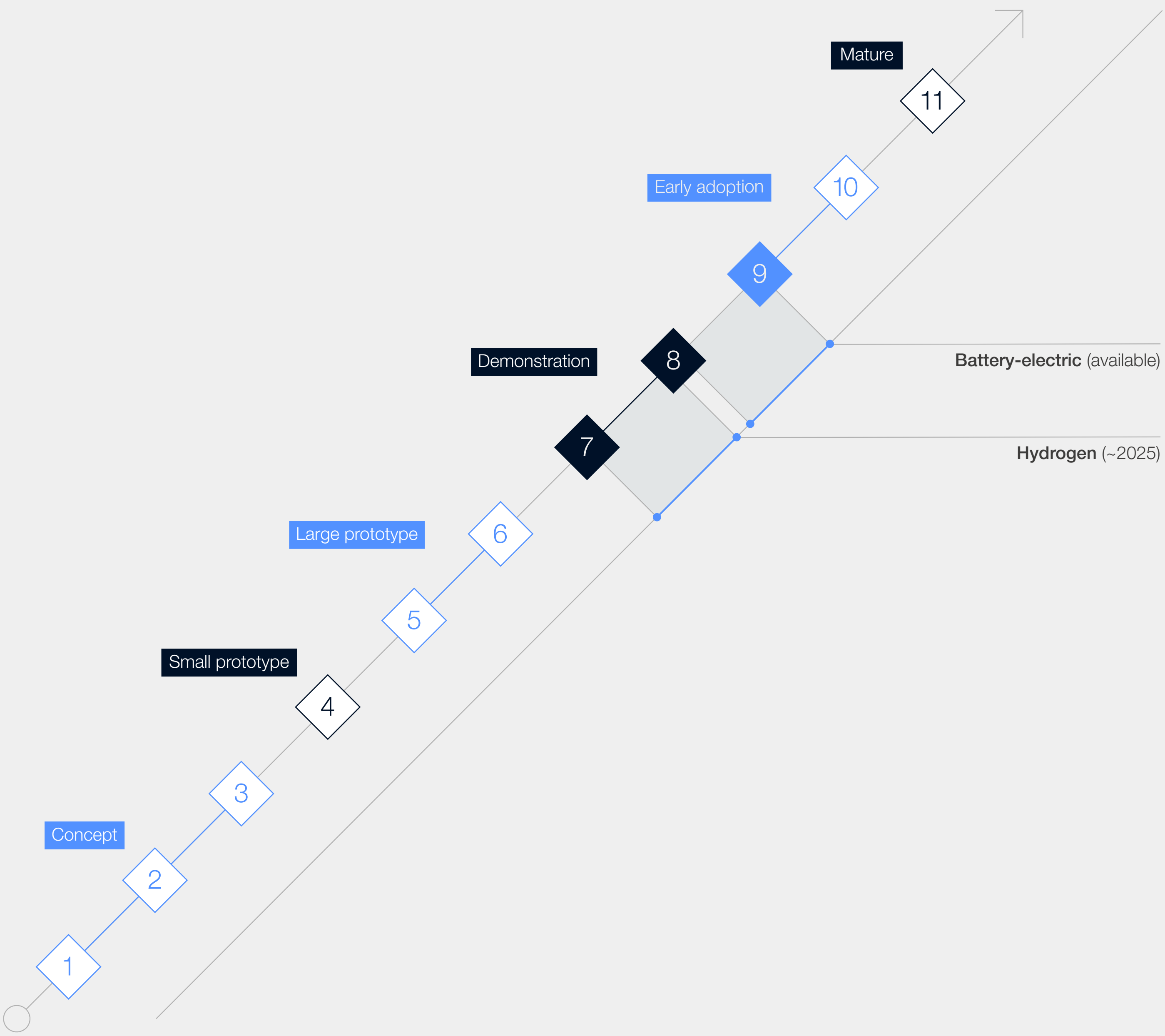
Recharging of BETs has yet to achieve commercial parity with the speed and convenience of refuelling diesel vehicles, charging can take up to 8 hours. While technology advancements have been made, with companies like bp announcing their first ultra-fast charging station aimed at recharging a heavy-duty truck (HDT) in 45 minutes, similar projects are generally limited to the demonstration stage.[160]

In comparison, refuelling with compressed hydrogen takes less than 20 minutes, which is almost comparable to existing diesel refuelling. However, applications are limited by onboard storage requirements.

Other intermediate measures

Transition fuels are less carbon intensive than legacy fuel sources, with emissions reduction potential ranging from 70-75%.[161] Renewable gas, synfuels and biofuels are commercially available today and are being adopted at a higher rate than low-emission technologies. However, these fuels are more emissive in terms of both absolute emissions and intensity than BETs and HETs, and in some cases are blended with fossil-based diesel.

FIGURE 31 Estimated TRL and year of availability for key technology pathways



Source: IEA

TRUCKING
2 Infrastructure

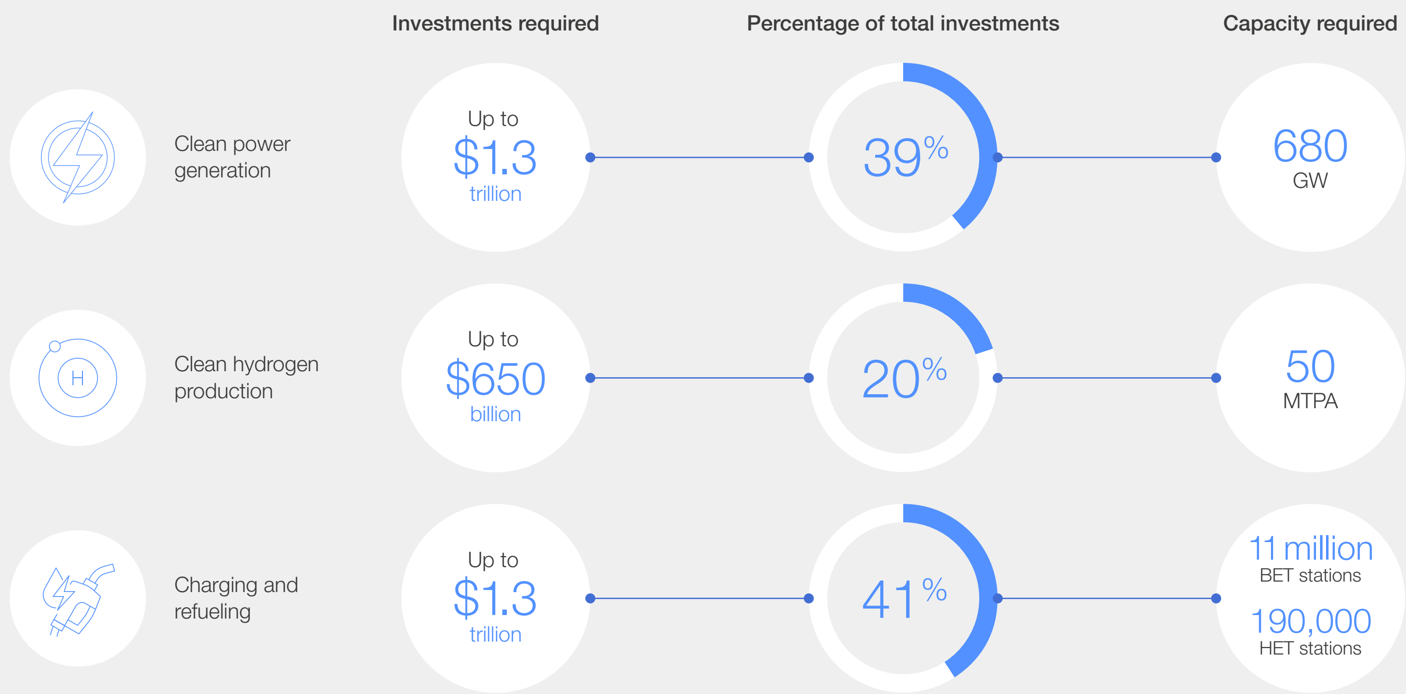
The commercial scaling of BETs and HETs hinges on the availability of crucial infrastructure. Currently, less than 1% of the necessary infrastructure is in place,[162] falling short of what's needed to enable the adoption of BETs and HETs. To enable the industry to meet 2050 targets, substantial investments ranging from $2.1 to $3.3 trillion[163] must be allocated within the trucking industry.

To support the projected target of 53% BETs and 47% HETs on the road by 2050,[164] the trucking industry will require a significant boost in clean power capacity. Specifically, this translates to approximately 8.5 times the current clean power capacity of the entire UK annually and a 54-fold increase in global clean hydrogen capacity.[165] The associated costs for this are estimated to be up to $1.3 trillion.[166]

For BETs to become feasible for medium and long-haul transport, they need access to charging infrastructure, both on-site and roadside. By 2050, an estimated 11 million charging stations will be required to meet the rising demand for BETs.[167] Some promising initiatives are under way in Europe, exemplified by Milence,[168] a joint venture between Volvo, Daimler and Traton, aiming to install at least 1,700 ultra-fast charging points across Europe by 2025. Companies like Siemens[169] are exploring alternative solutions to traditional wired charging, including overhead catenary charging and in-transit wireless charging,[170] which may provide a variety of options for future charging requirements.

HETs require access to onsite hydrogen refuelling infrastructure. To meet the demand for HETs by 2050, an estimated 190,000 refuelling stations will need to be established, incurring costs from $0.3-0.7 trillion.[171]

FIGURE 32 **Investments required for enabling infrastructure**

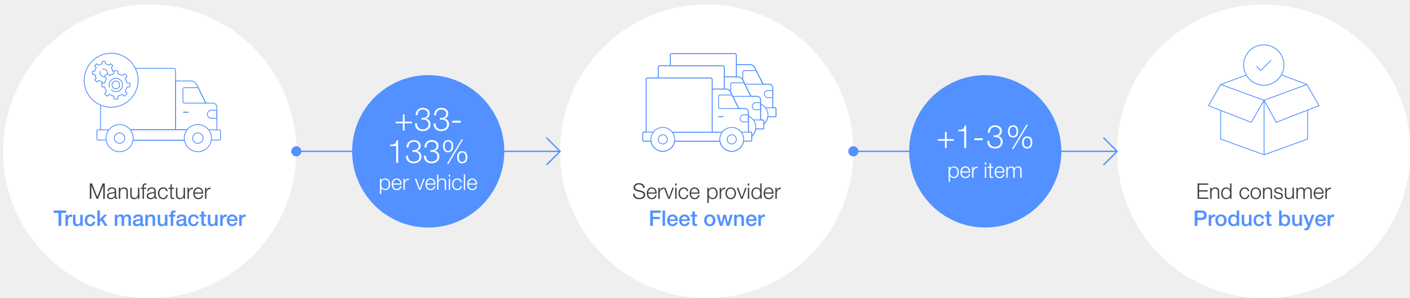


Source: Accenture analysis based on data from multiple sources to include MPP, IEA, IRENA and BloombergNEF

Demand

In 2022, the market demand for ZETs stood at approximately 1%.[172] As such, the ability to absorb a 33-133% green premium for BETs and 100-300% HETs remains untested at scale, with HDTs attracting the higher end of this range.[173] The tight margins in logistics suggest the industry would struggle to absorb these premiums at commercial scale. Present adoption rates fall short of the industry's net-zero trajectory, where ZET sales are expected to constitute 100% of the 2050 net-zero scenario.[174] To stimulate demand, estimates suggest a green premium of 10-15% would be necessary to maintain ZETs affordability in the market. However, only a small portion of the price premium, around 1-3%, is expected to be passed to end consumers due to transport costs accounting for around 5% of a product's retail price.[175]

FIGURE 33 **Estimated B2B and B2C green premium**



Source: Accenture analysis based on MPP data

> Emerging business models like TaaS and BaaS may help manufacturers create new revenue streams.

Efforts to increase demand-side market measures include near-term ZEV sales mandates in countries like China, Canada and Norway, which are anticipated to accelerate adoption towards 2030. Some major carriers, including DPD, have imposed green surcharges ranging from 14-27% on fossil fuel use.[176] However, the uneven development of clean captive and grid-based power infrastructure poses a risks of temporary emissions intensity spikes in regions where power sources primarily rely on fossil fuels, until clean power capacity catches up. Additionally, slower policy development to support the growth of charging and refuelling infrastructure, crucial for maintaining regular business operations, may result in cost penalties for fleet owners, and oversupply issues for original equipment manufacturers (OEMs). However, emerging business models like trucks-as-a-service (TaaS)[177] may help OEMs mitigate these risks, creating an additional revenue stream to ease the impact of high green premiums, while reducing CapEx and on-site charging requirements for fleet owners.

Currently, few manufacturers have successfully demonstrated models of zero-emission HDTs for long-haul application.[178] With limited availability of ultra-fast charging infrastructure, operators are exploring alternative business models such as battery-as-a-service (BaaS) to meet growing ZET demand.[179] Under the BaaS model, fleet owners purchase the truck body, while batteries are owned and maintained by service companies. Fleet owners subscribe to a monthly fee, and their drivers can quickly swap HDT batteries at charging stations in as little as 2-3 minutes.[180] The Chinese State Power Investment Company (SPIC) has already sold 10,000 BaaS-enabled trucks and established 100 charging stations.[181] Private companies like Golden Concord Group (GCL) are advancing this effort, with 10 stations along the Beijing-Shanghai highway by year-end, and an additional 175 planned stations in China.[182]

TRUCKING

3 Policy

Trucking policy has evolved to incentivize the adoption of ZEVs with sales targets and purchase subsidies, notably led by the EU. The trucking industry is highly fragmented, with a mix of both large and small players, truck types, services, duty cycles and load types. It is usually regulated at supra-national (EU), national and sub-national levels, depending on regional dynamics. While tailpipe emissions have been a focus, addressing GHG emissions is equally important.

Effective public policies should facilitate ZEV adoption by developing essential clean power, hydrogen generation and charging infrastructure. The EU stands out with comprehensive policies, while other regions also implement measures such as ZEV sales targets, fleet decommissioning incentives and purchase subsidies to drive adoption.

Existing policy landscape

TABLE 7 **Policy summary**

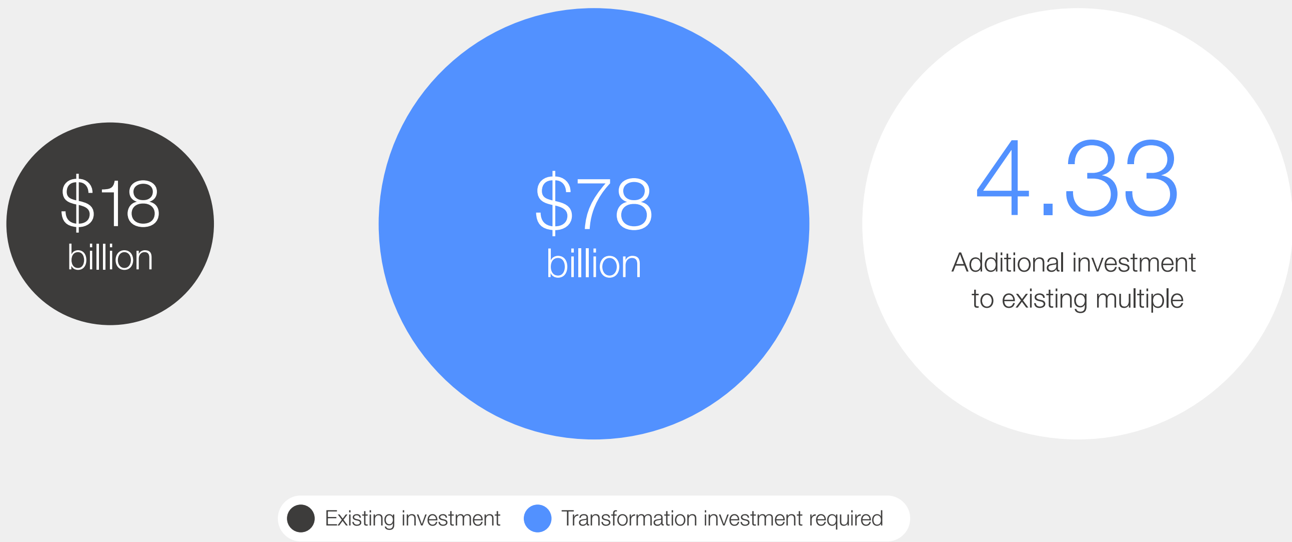
Enabler	Policy type	Policy instruments	Key examples	Impact
Technology	Market-based	Carbon pricing	– EU-ETS proposed expansion to include road transport[183]	Incentivizes gradual adoption of ZEVs by increasing operating costs of diesel trucks. The proposed EU-ETS expansion comes into effect only after 2027.
	Mandate-based	Fuel tax	– Canada's federal carbon tax on diesel[184]	10-13% increase in diesel costs.[185]
		Fuel efficiency standards	– India's fuel consumption standards for heavy duty vehicles[186]	Aims to reduce the consumption of diesel from the trucking sector, which contributes to 33% of India's transport sector emissions.
		Bans on new sale	– Ban on diesel truck new sales in California by 2036[187]	Gradual phase out of diesel trucks leading to reduction in 25% of transport emissions.[188]
Infrastructure	Incentive-based	Taxes and subsidies	– IRA clean power and green hydrogen production tax credits as well as alternative fuel refuelling infrastructure tax credits[189]	Incentivizes build-out of clean power and green hydrogen capacity as well as the required charging and refuelling infrastructure.
	Mandate-based	Direct regulation	– EU Alternative Fuels Infrastructure Regulation mandate for charging stations across the Trans-European Transport Network (TEN-T)[190]	Aims to equip 100% of the TEN-T core network with fast charging stations for trucks at a distance of at least 60km.[191]
Demand	Mandate-based	ZEV sales targets	– 2030 targets for countries including Canada and select EU nations like Norway[192] – 2025 target for China[193]	35% and 50% of new heavy-duty vehicle sales to be ZEV by 2030 for Norway and Canada respectively. For China, 25% of logistics stock to be ZEV.
Capital	Incentive-based	Purchase subsidies	– Complementary policies across several countries like Australia, Canada, Finland, Italy, Japan, the US etc.[194]	Incentivizes switch to ZEV fleet due to lower upfront capital costs.

TRUCKING
Capital

The trucking industry will require an estimated $2.1 trillion by 2050,[195] requiring $78 billion in additional annual investments for fleet owners for fleet owners to retrofit their trucking fleet with battery electric powertrains. This represents four times the current annual expenditures in the trucking industry of $18 billion.[196]

Recent data suggests the business case for investing in zero-emission trucking remains weak due to high costs and uncertain returns. The industry's current profit margins of roughly 15%[197] and WACC of 10%[198] suggest it may struggle to absorb these extra costs and generate adequate returns solely from internal cash flows.[199] As technology scales and economies of scale take effect, investment requirements are expected to decrease.

FIGURE 34 **Additional investment required to existing investment ratio**



Source: Accenture analysis based on Global Drive to Zero data

Facilitating the funding necessary to support this transformation in developing nations will play a pivotal role in enabling a zero-emission trucking sector. International multilateral finance institutions should adjust their investment portfolios to align with the requirements of the trucking industry. In the United States and Europe, where internal combustion engine (ICE) trucks are substantially more expensive than in India and China, the upfront net capital investment required to achieve net zero is 25% to 30% more than continuing to use mostly diesel. However, in India and China, where ICE trucks are cheaper, the incremental costs of ZETs and their infrastructure are more significant.[200]

The existence of ZETs depends on both the supply of these vehicles and the demand for them, which are interconnected with the upstream value chains facilitating their production and use. Policy-makers should focus their attention upstream by addressing concerns like the ethical sourcing of essential raw materials for ZET components by OEMs. Additionally, investing in the infrastructure required to distribute electricity and hydrogen to areas where trucks will require these resources is crucial.

Worldwide, governments are stimulating both the desire for and availability of ZETs by enforcing more stringent emissions goals, fuel criteria or both. Prominent logistics firms and major truck purchasers are pledging to reduce carbon footprints and cut emissions, thus creating growing demand for ZETs. Established OEMs and emerging players are making substantial investments in the advancement of ZET models, while fleet operators are channelling investments into acquiring vehicles and establishing on-site infrastructure. An example of innovative ZET deployments includes Shihezi industrial park in China, a fleet of 100 BETs serve business based in the park. The trucks typically make trips of about 100km and swap batteries at a facility in the industrial park.[201]

The fragmented nature of the industry makes aggregating data on net-zero commitments by companies challenging.

> Worldwide, governments are stimulating both the desire for and availability of ZETs by enforcing more stringent emissions goals, fuel criteria or both.

5 Steel industry net-zero tracker

For primary steelmaking clean hydrogen-based DRI-EAF has emerged as the main decarbonization pathway, whereas secondary steel needs to switch to clean power sources.

Key emissions data[202, 203, 204, 205]

8%
Contribution to global energy related GHG emissions

3.7 $gtCO_2e$
Scope 1 and 2 emissions

1.41 tCO_2
Emissions intensity (per tonne of steel, 2022)

22%
Reduced emission production

>85%
Fossil fuels in the fuel mix (2022)

1.4 times
Expected demand increase by 2050

<1%
Current low-emission production

Readiness key takeaways

Technology
Primary steel[206] can use both clean hydrogen and CCUS for decarbonization. Secondary steel[207] can use EAF with renewable electricity. However, costs are 40-70%[208] higher than traditional methods.

Infrastructure
Inadequate infrastructure requires $1.8-2.4 trillion[209] for clean hydrogen and clean power development. Regions with steel capacity and access to affordable renewables and CO_2 storage should be prioritized.

Demand
Near-zero-emission steel held less than 1% of the market in 2022. A B2B green premium of 40-70% may be necessary, with about 1-2% affecting consumers.[210] However, this remains untested at scale.

Policy
Early-stage steel decarbonization policies are needed especially in Asia-Pacific (with 70% global steel production). Policies should focus on clean power, hydrogen, R&D and green procurement for low-emission steel.

Capital
$372 billion[213] is required by 2050, with 60% directed towards retrofitting existing assets. However, the business case remains weak, given 8.5% industry profit margin and 10.1% WACC.[214]

Stated energy transition goals

- The industry targets a 45% reduction in intensity for primary steel and a 65% reduction for secondary steel by 2030, and net-zero emissions by 2050.[211]
- 70%[212] of large publicly traded steel companies consider climate change in their decision-making processes.

Emission focus areas for tracker

Steel emissions can be divided into two main categories:

1. **Energy-related emissions** are primarily due to coal use in the blast furnace-basic oxygen furnace (BF-BOF) and EAF processes to produce molten steel for primary steel production.
2. **Process-related emissions** emanate from the use of coke or natural gas as a reducing agent to convert iron ore into iron for primary steel production.

Sector priorities

Existing assets
Reduce near-term emissions intensity by:
- Deploying energy efficiency improvement techniques
- Shifting to transitional technologies such as DRI-EAF in regions where natural gas is affordable and available
- Switching to clean power sources for secondary steel production, where cost competitive renewables are feasible.

Next generation assets
Accelerate infrastructure development to drive absolute emissions reduction by:
- Investing in clean hydrogen generation capacity to support transition for primary steelmaking
- Retrofitting assets with CCUS where access to CO_2 transport and storage is economical
- Enabling access to grid-based clean power for secondary steel.

Ecosystem
Enabling access to grid-based clean power for secondary steel by:
- Implementing a blend of policies, principally product standards and incentivizing low-emission production
- Reducing near-zero-emission production costs through an increased number of clean hydrogen projects
- Enabling shared infrastructure and supply chain stability through strategic partnerships.

Performance

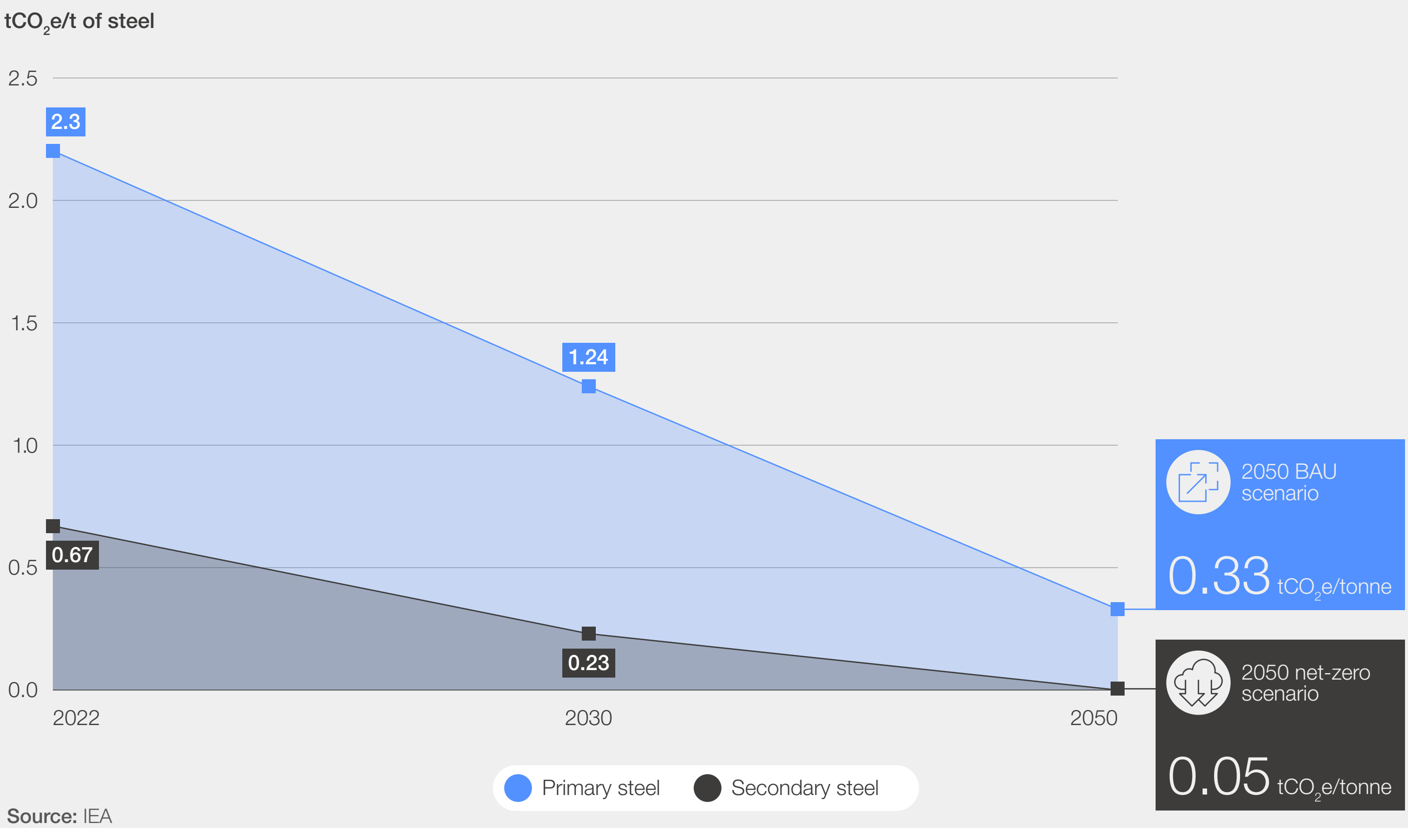
75%
of steel's fuel mix comes from coal

The production process of steel is energy intensive and generates high CO_2 emissions, accounting for up to 95% of its emissions. The current fuel mix heavily relies on fossil fuels, predominantly coal, occupying around a 75% share. The coal dependency has remained consistently between 70-75% over the decade,[215] substantially contributing to steel's absolute emissions.

Over the last decade, steel CO_2 emissions rose 2.5% annually, due to rising production driven by demand growth in emerging markets. Currently, 78%[216] of steel is produced using primary methods, while the remaining portion comes from secondary production. However, this distribution varies globally, with China predominantly using primary processes - mainly BF-BOF – for 90% of their steel, whereas North America relies on secondary processes for 70%[217] of its steel production. Other major steel-producing regions like India and the EU exhibit a more balanced distribution between primary and secondary steelmaking.

Energy intensity in steel production has remained relatively stable, averaging between 19-20 gigajoules per tonne (GJ/t) of steel over the past 5 years,[218] due to improved energy efficiency and increased secondary steel production. Primary steel production is particularly energy-intensive due to the high temperatures required to melt iron. Both primary steel production methods, BF-BOF and DRI-EAF, require up to 25 GJ/t of energy. In contrast the secondary steel method (EAF), reduces energy intensity by 2.5 times, down to 10 GJ/t, as melting scrap steel requires much less energy.

FIGURE 35 **Emissions intensity trajectory for primary and secondary steel**



Source: IEA

Path forward

The industry targets a 45% reduction in intensity for primary steel and a 65% reduction for secondary steel by 2030.[219] The 2050 net-zero compliant fuel mix will require disconnecting steel emissions from the growth in market demand. This entails reducing non-abated fossil fuels from their current dominant share of 86% in the fuel mix to 30%,[220] which will require a substantial increase in CCUS deployment. For primary steel production, accelerated investments are needed, together with the commercialization of clean hydrogen fuels, coupled with implementation of CCUS-enabled technologies. In the case of secondary steel production, expediting the adoption of clean power through EAF processes is paramount.

FIGURE 36 | **2021 fuel mix**

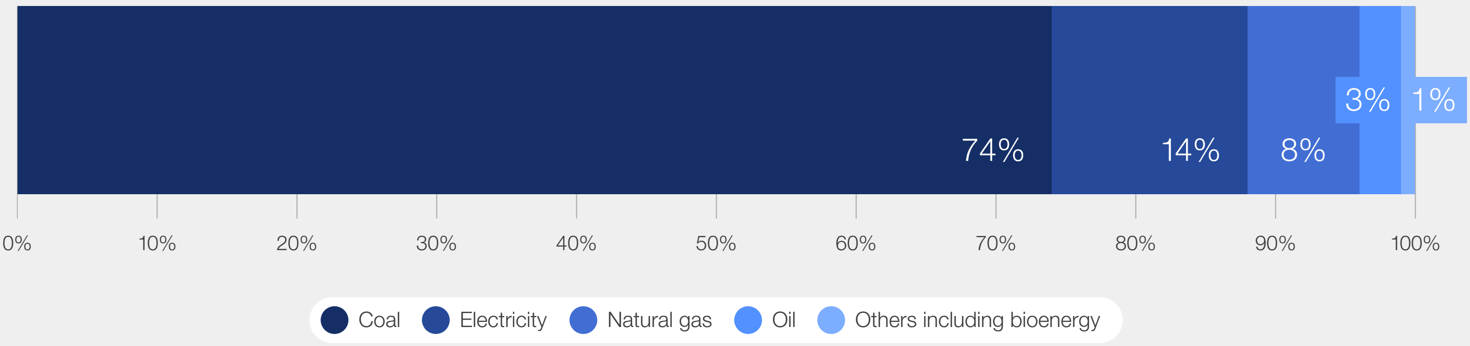
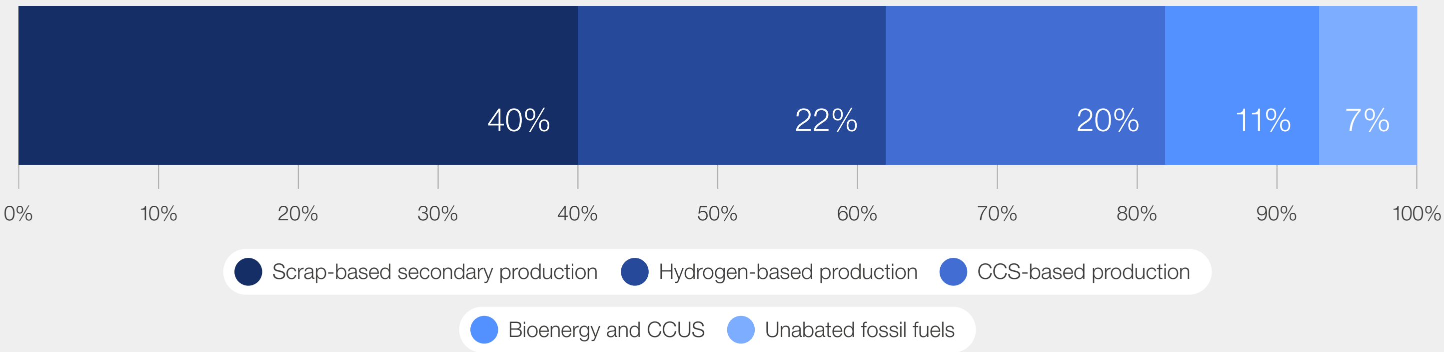


FIGURE 37 | **Estimated share of production in 2050**



Sources: IEA, *Iron and Steel Technology Roadmap*, 2020, https://iea.blob.core.windows.net/assets/eb0c8ec1-3665-4959-97d0-187ceca189a8/Iron_and_Steel_Technology_Roadmap.pdf; "Steel: Pathways to net zero", *MPP*, n.d., https://dash-mpp.plotly.host/mpp-steel-net-zero-explorer/.

Technology

Two leading decarbonization pathways have emerged for primary steel: clean hydrogen-based DRI-EAF is the most developed (TRL 6-8), and CCUS is rapidly developing (TRL 5-8). For secondary steel decarbonization, EAF-based production using 100% renewable electricity is a mature and available technology. Production costs for these technologies are 40-70% higher[221] than traditional steelmaking processes.

Process emissions abatement measures

Clean hydrogen potential for primary steel: Using clean hydrogen in production processes has the potential to reduce emissions by up to 97%,[222] however, it comes with an expected green premium of 35-70%[223] when compared to conventional BF-BOF processes. However, constraints around the capacity of EAFs in comparison to larger blast furnaces and deployment at smaller facilities impact the applicability of this technology.

CCUS technologies for primary steel: Most CCUS-based technologies are projected to become commercially available after 2028. These CCUS technologies have the potential to decrease emissions by up to 90%[224] compared to BF-BOF. Bioenergy carbon capture and storage (BECCS), a modified CCUS technology, can achieve up to negative emissions from BF-BOF, though results are dependent on the source of bioenergy. However, all CCUS technologies entail a significant green premium in the range of 65-120%.[225] Although DRI-EAF with CCUS is currently accessible, its carbon capture efficiency is limited. CCUS technology is most suited for decarbonizing BF-BOF assets, especially given the higher concentration of CO_2 in blast furnace gases.

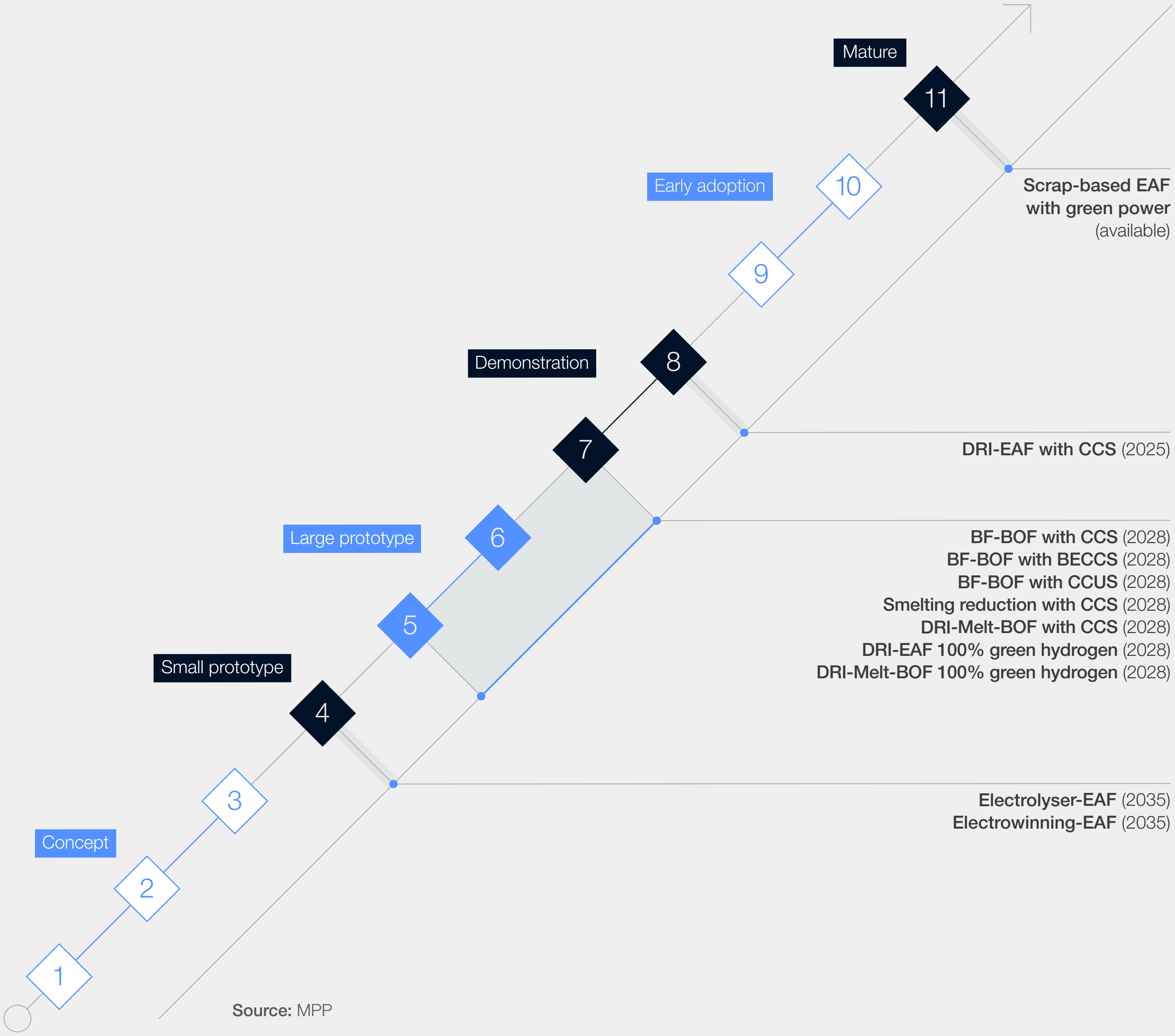
Energy emissions abatement measures

> Steel decarbonisation is likely to be faster in regions where competitively priced clean power and scrap steel are readily available.

EAF-based secondary steel production: Powered by 100% renewable electricity, this method offers a promising pathway towards near-zero-emission steel at low cost. EAF technology can reduce emissions by 90-95% compared to BF-BOF, with only a marginal cost premium of 8-13%.[226] Yet, there are limits around the applications for secondary steel due to variances in the quality of available scrap. Adoption is likely to be faster in regions where competitively priced clean power and scrap steel are readily available. China, for instance, is expected to witness an estimated 70% growth in EAF production by 2050 compared to 2020 levels.[227] Additionally, SSAB, the largest steel manufacturer in Scandinavia, launched SSAB Zero™, produced from emission-free recycled steel. One of its main advantages is its near-zero-carbon emissions throughout the company's operations, contributing to an emission-free value chain for end-users. However, this sustainability comes at a higher cost due to the manufacturing process.[228]

Technology pathways

FIGURE 38 **Estimated TRL and year of availability for key technology pathways**



Source: MPP

STEEL

1 Infrastructure

Steel decarbonization relies on the availability of clean hydrogen, CCUS and EAF-based secondary steel production. Establishing infrastructure for near-zero-emission production requires significant investments, estimated between $1.8-2.6 trillion.[229] Of this, 90% should be directed towards creating clean hydrogen and clean power generation capacity, with the remainder for CO_2 transport and storage. Around 50%[230] of current steelmaking capacity is in regions with access to low-cost renewables or CO_2 storage and should be prioritized for transition.

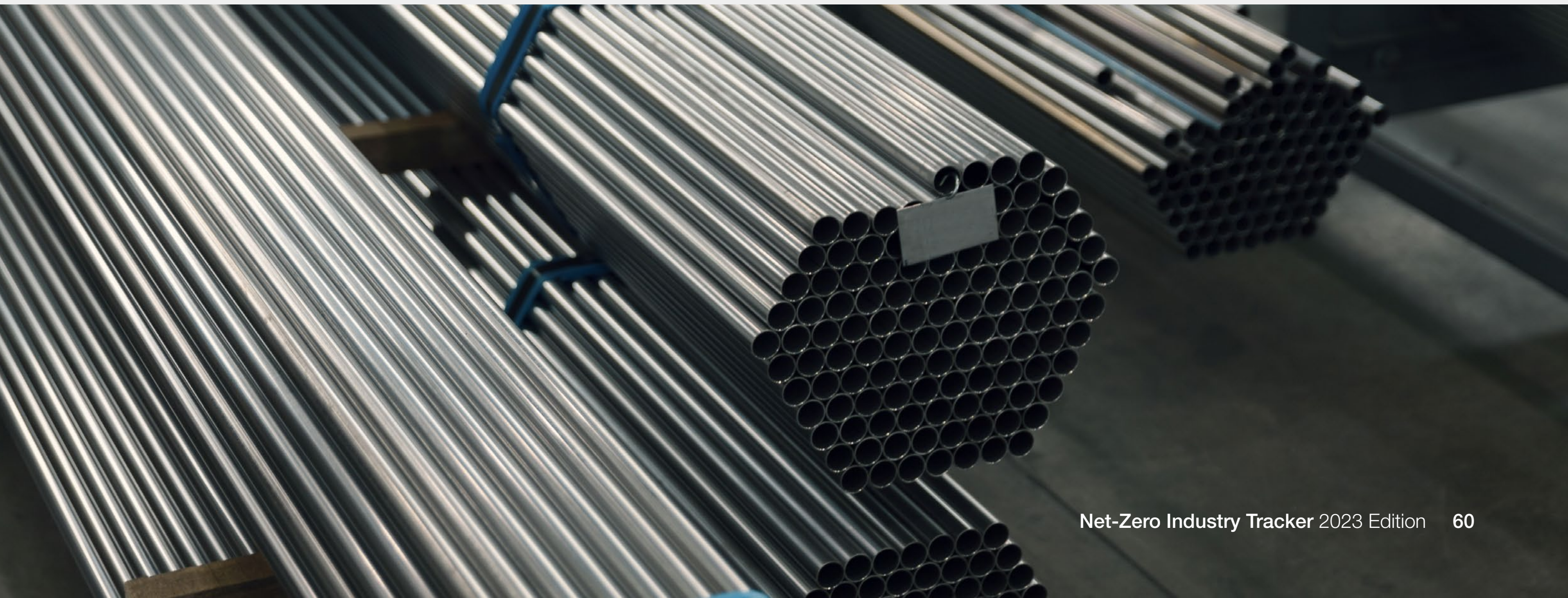
Meeting the steel industry's clean hydrogen demand would require substantial investments ranging from $200-$890 billion[231] for additional capacity. Regions with affordable natural gas and clean power are well-suited for near-term adoption of clean hydrogen. CCUS technologies are advantageous in settings with CO_2 storage availability or proximity to industrial clusters where captured carbon can be used as feedstock. United States Steel Corporation and CarbonFree Chemicals Holdings have signed a non-binding MoU to collaborate on capturing CO_2 emissions from US Steel's Gary Works plant. They will deploy CarbonFree's SkyCycle technology with the goal of capturing and mineralizing approximately 50,000 tonnes of CO_2 annually, equivalent to offsetting the carbon emissions of nearly 11,000 passenger cars each year.[232]

Clean power generation will be a priority in regions where the role of EAF production is expected to increase, such as China and North America.

FIGURE 39 **Investments required for enabling infrastructure**

	Investments required	Percentage of total investments	Capacity required
Clean power generation	Up to $1.6 trillion	61%	830 GW
Clean hydrogen production	Up to $890 billion	34%	70 MTPA
CO_2 transport and storage	Up to $130 billion	5%	750 MTPA

Source: Accenture analysis based on multiple data sources including IEA IRENA BNEF and Global CCS Insititute

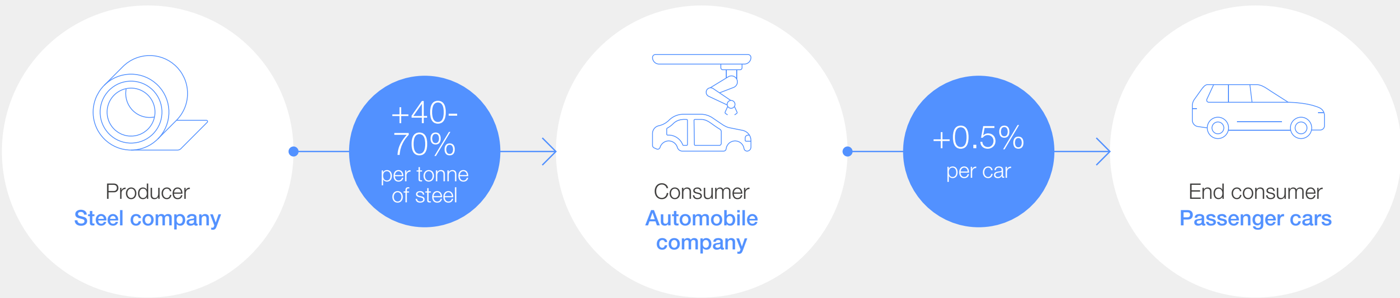


Demand

The ability of customers to absorb a green premium of 40-70% per tonne[233] is untested beyond prototype projects as low-emission steel represents less than 1% of global supply.

A 40-70% increase in the per tonne cost of steel translates into lower green premiums for end consumers. It can range from 0.5% for passenger cars to 2% for buildings.[234]

FIGURE 40 **Estimated B2B and B2C green premium**



Source: MPP

Circular economy models should be promoted where steel producers can recycle and reuse their own steel scrap.

The ability for the industry to pass along this premium, or to monetize near-zero-emission steel as a differentiating attribute depends on the target consumer segment (for example, passenger cars vs buildings), and geography (developed vs developing regions). The largest forecasted increases in steel consumption globally align with the markets with likely the lowest ability to absorb a significant green premium.

Currently, several major global players are taking proactive steps towards decarbonizing steel production. China Baowu Group, the world's largest steel producer, has signed an MoU with Rio Tinto to jointly explore green steel projects.[235] They've also established a Global Low-Carbon Metallurgical Innovation Alliance with partners from 15 countries, aimed at reducing GHG emissions in steelmaking.[236]

In the automotive industry, bilateral offtake agreements with steel producers are impacting the market,[237] offering convenient access to buyers who secure their supply in advance. For instance, Volkswagen Group and Salzgitter AG have signed an MoU to source near-zero-emission steel starting in late 2025.[238]

The Clean Energy Ministerial Industrial Deep Decarbonisation Initiative (IDDI)[239] is developing globally recognized targets for the public procurement of near-zero-emission steel. The IDDI is set to introduce standardized definitions, methodologies and guidelines across the industry. Additionally, Responsible Steel have implemented auditable to near-zero-emission steel production certifications, available to its members.[240] These initiatives signal a potential shift towards boosting demand and encouraging collective efforts towards near-zero-emission products, and ultimately driving a positive trajectory towards net-zero emissions.

Improving supply chain efficiency and promoting circularity is essential to accelerate secondary steel production in regions with limited access to scrap steel. In these areas, optimizing supply chains becomes paramount to ensure a consistent flow of recyclable materials. Implementing connected supply chain networks, supported by AI technology and blockchain, can enhance transparency and traceability, reducing waste and losses.[241] Moreover, promoting a circular economy model by encouraging steel producers to recycle and reuse their own steel scrap can reduce reliance on external sources. By integrating these strategies, regions facing scrap steel shortages can bolster their secondary steel production capabilities.

STEEL

2 Policy

Policy efforts to promote and support the decarbonization of the steel industry are still in their early stages, particularly in the Asia Pacific region, which produces 70% of the world's steel.[242]

Global steel production is highly concentrated, with the top five producing companies accounting for around 75% of production. Public policies should be aimed at:

- Supporting the development of clean power and clean hydrogen infrastructure
- Providing R&D support and market-based incentives to accelerate low-emission steel technologies, especially in their early stages
- Implementing demand-side interventions such as green public procurement and updated product codes to stimulate market demand for near-zero-emission steel.

While policy measures to facilitate decarbonization are beginning to emerge, they will require time to fully mature. Local regulations, such as Environmental Product Declarations (EPDs), often prioritize pollution control, life cycle assessments and performance standards but may not sufficiently address CO_2 emissions reduction. Currently, policy development is mainly driven by Europe and the US. However, it is crucial to strengthen policy initiatives in the Asia Pacific region, given its substantial contribution to global steel production.

As steel is a highly traded commodity, international collaboration on policy measures is essential to prevent the uneven application of policies that could lead to market distortions.

Existing policy landscape

TABLE 8

Policy summary

Enabler	Policy type	Policy instruments	Key examples	Impact
Technology	Incentive-based	Direct R&D funds/grants	– EU Clean Steel Partnership (CSP)[243] – Japan Green Innovation Fund	CSP: Allocated budget of $1.7 billion to achieve TRL 8 levels for identified technology pathways by 2030. Japan: $1.5 billion allocated to fund innovative steelmaking technologies.[244]
	Market-based	Carbon price	– EU-ETS[245] – California ETS[246] – South Korea ETS[247] – China ETS[248] (announced)	Incentivizes steel producers to reduce emissions but impact is limited by free emission allowances and lower carbon prices.
		Border adjustment tariff	– EU CBAM (pending implementation)[249]	Emission-intensive steel exporters to the EU face increased costs of compliance. Currently 30% of steel consumed is imported from non-EU countries. Needs to be complemented by transparent and fair carbon accounting standards.
Infrastructure	Incentive-based	Direct funding support	– IRA tax-credits to clean power[250]	Projected to accelerate clean power generation capacity in US, with clean power forming 80% of the power mix by 2030.[251] Supports faster transition of 70% of US steel production to clean power.
Demand	Incentive-based	GPP	– Federal buy clean initiative in US[252] – Key steel producers as IDDI members – US, India, Japan[253]	Creates a viable market for near-zero-emission steel through green public procurement commitments – 25% of steel demand already comes from public procurement.[254]
	Mandate-based	Product standards	– GSA low embodied-carbon steel standards in US[255]	Specific targets on embodied carbon in steel products provides clear guidelines to green public procurement.
Capital	Incentive-based	Direct funding	– EU public funding to steel plants to decarbonize[256]	More than $2 billion in public funding to install hydrogen-based DRI steel plants in Europe.
		Tax credits and subsidies	– IRA tax-credits to clean power, green hydrogen and CCUS	Potential to reduce cost of near-zero-emission steel by up to 35%.[257] With limited funding available in developing economies, international funding collaboration mechanisms can be an option to raise the required capital.

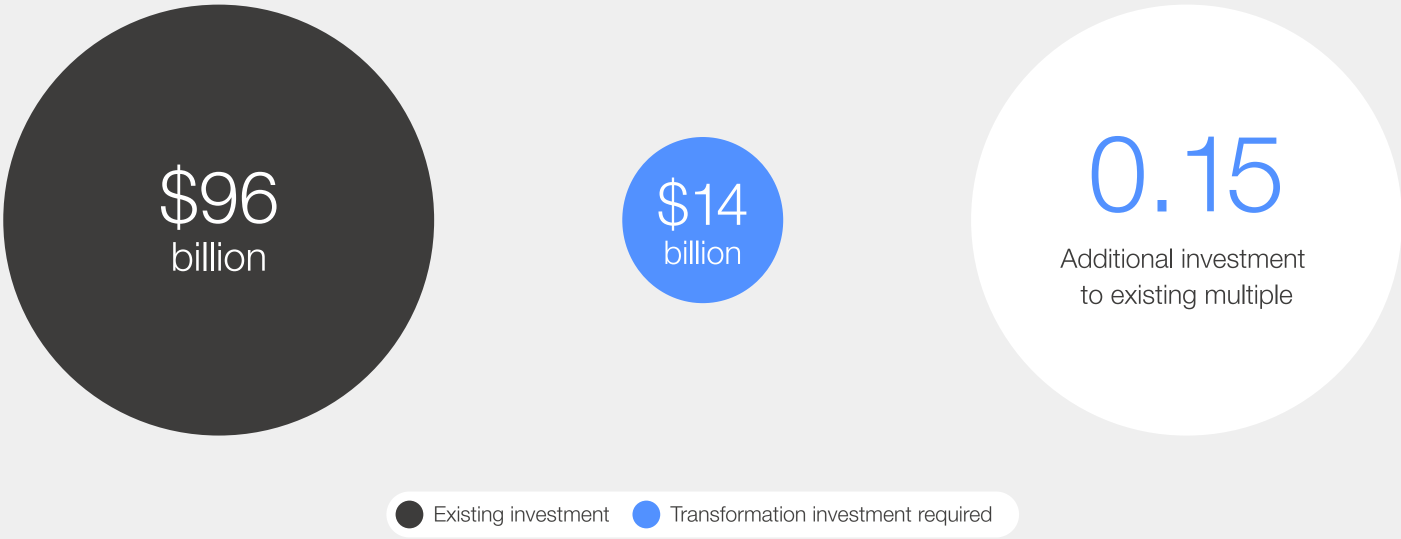
STEEL

1 Capital

In the steel industry, transforming existing assets with near-zero technologies could require cumulative investments of $372 billion by 2050.[258] Such a requirement implies annual investments of $14 billion, in addition to the regular annual CapEx of $96 billion – an additional 15% investment.[259]

Current industry profit margins of 13%[260] and WACC of 10%[261] suggest that the industry is not positioned to absorb these additional costs and generate sufficient returns to fund investment through own generated cash flows.

FIGURE 41 **Additional investment required to existing investment ratio**

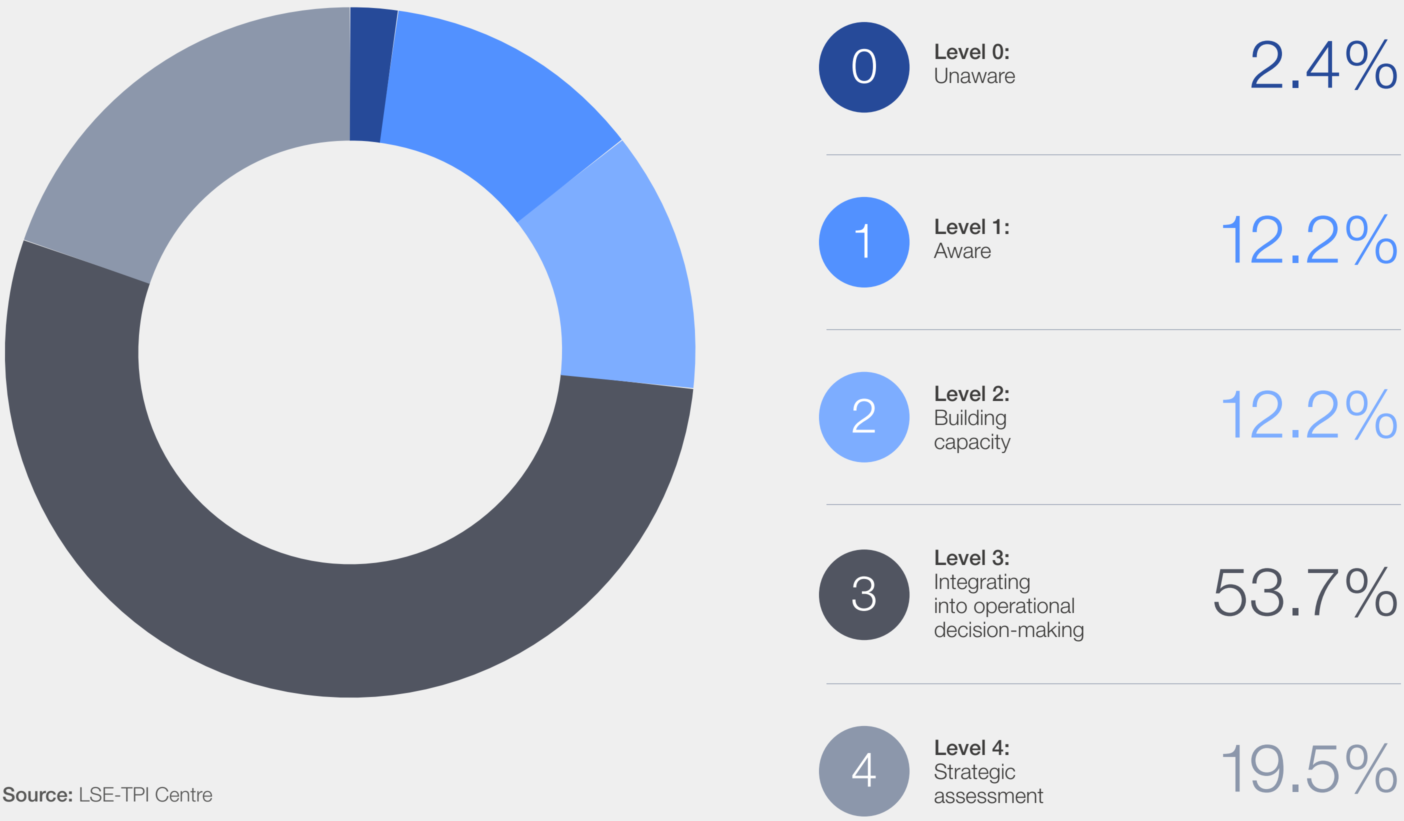


Source: Accenture analysis based on Green Steel and ETC data

To direct the capital towards transforming the industry, policy interventions like carbon pricing, subsidies/incentives for technology development and public procurement commitments will need to be adopted to improve returns. Large institutional investors and multilateral banks (World Bank, Asian Development Bank etc.) can play a crucial role by providing access to low-cost capital linked to stringent emission reduction targets. Additionally, capital flows within this industry are tied to region-specific technology pathways. For the EU and China, the capital should mainly be directed towards expanding their EAF asset base as secondary steelmaking assumes a major role. In India and the US, capital flows will need to address the maintenance of existing EAF asset base as capacity expansion will be limited by scrap availability.

Approximately 70% of large publicly-traded steel companies consider climate change as a key consideration for their strategic assessment and integrate it into their operational decision-making.[262] Meanwhile, 12% of companies are building basic emissions management systems and process capabilities. Finally, 12% of companies acknowledge climate change as a business issue.

FIGURE 42 **Distribution of companies in the steel sector according to the management of their GHG emissions and of risks and opportunities related to the low-carbon transition**



Source: LSE-TPI Centre

6 Cement industry net-zero tracker

While increased use of alternative fuels is a positive signal, CCUS adoption remains critical for net zero and needs to scale from less than 1% to 90% by 2050.

Key emissions data[263, 264, 265, 266, 267]

6%	Contribution to global GHG emissions
2.6 $gtCO_2e$	Scope 1 and 2 emissions
-0.3%	Emissions growth (2019-2022)
0.58 tCO_2	Emissions intensity (per tonne of cement, 2022)
92%	Fossil fuels in the fuel mix (2020)
1.5 times	Expected demand increase by 2050
<1%	Current low-emission production
<1%	Reduced emission production

Readiness key takeaways

Technology

Cement can use CCUS (TRL 6-9), clean hydrogen and clean power (TRL 5-6) for decarbonization – however, production costs are nearly double that of Portland cement.

Infrastructure

Less than 1% of infrastructure is installed today, requiring investments of up to $300 billion by 2050.[268] Rich CO_2 streams from clinker position cement as a primary candidate for CCUS.

Demand

Near-zero-emission cement held less than 1% of the market in 2022. A B2B green premium of 60-100% may be necessary, with about 1-3% affecting consumers.[269] However, this remains untested.

Policy

Early-stage cement decarbonization policies needed especially in Asia-Pacific (with 70% global cement production[270]). Policies should focus on technology incentives, carbon pricing, near-zero-emission cement standards and updated building codes.

Capital

$750-900 billion CapEx required by 2050.[272] The business case remains weak, given 11% industry profit margin and 10% WACC.[273]

Stated energy transition goals

– Industry aims for a 25% emissions intensity reduction by 2030 and net-zero emissions by 2050.[271]

– 61% of large publicly traded cement companies consider climate change in their decision-making processes.

Emission focus areas for tracker

Cement emissions can be divided into two main categories:

1. **Energy-related emissions** arise from fossil fuel used in kiln heating, material grinding and machinery operations. High temperatures transform raw materials into clinker, releasing CO_2 and other GHGs.
2. **Process emissions** stem mainly from chemical reactions during raw material conversion to clinker, emitting CO_2 through limestone calcination.

Sector priorities

Existing assets

Reduce emissions intensity of clinker production by:

– Increasing fuel substitution with biomass and renewable waste[274]

– Reducing thermal energy consumption through efficiency improvements

– Substituting clinker with supplementary cementitious materials (SCMs) and reducing the clinker-cement ratio.[275]

Next generation assets

Accelerate infrastructure development to drive absolute emissions reduction by:

– Investing in CO_2 storage and transport infrastructure

– Retrofitting cement kilns with clean hydrogen capability

– Enabling access to grid-based clean power and deploying electrified kilns.

Ecosystem

De-risk capital investment to scale technology by:

– Implementing a blend of policies, principally carbon pricing

– Incentivizing near-zero-emission production, reducing low-emission production costs through an increased shared CCUS projects at industrial hubs

– Enabling shared infrastructure and supply chain stability through strategic partnerships.

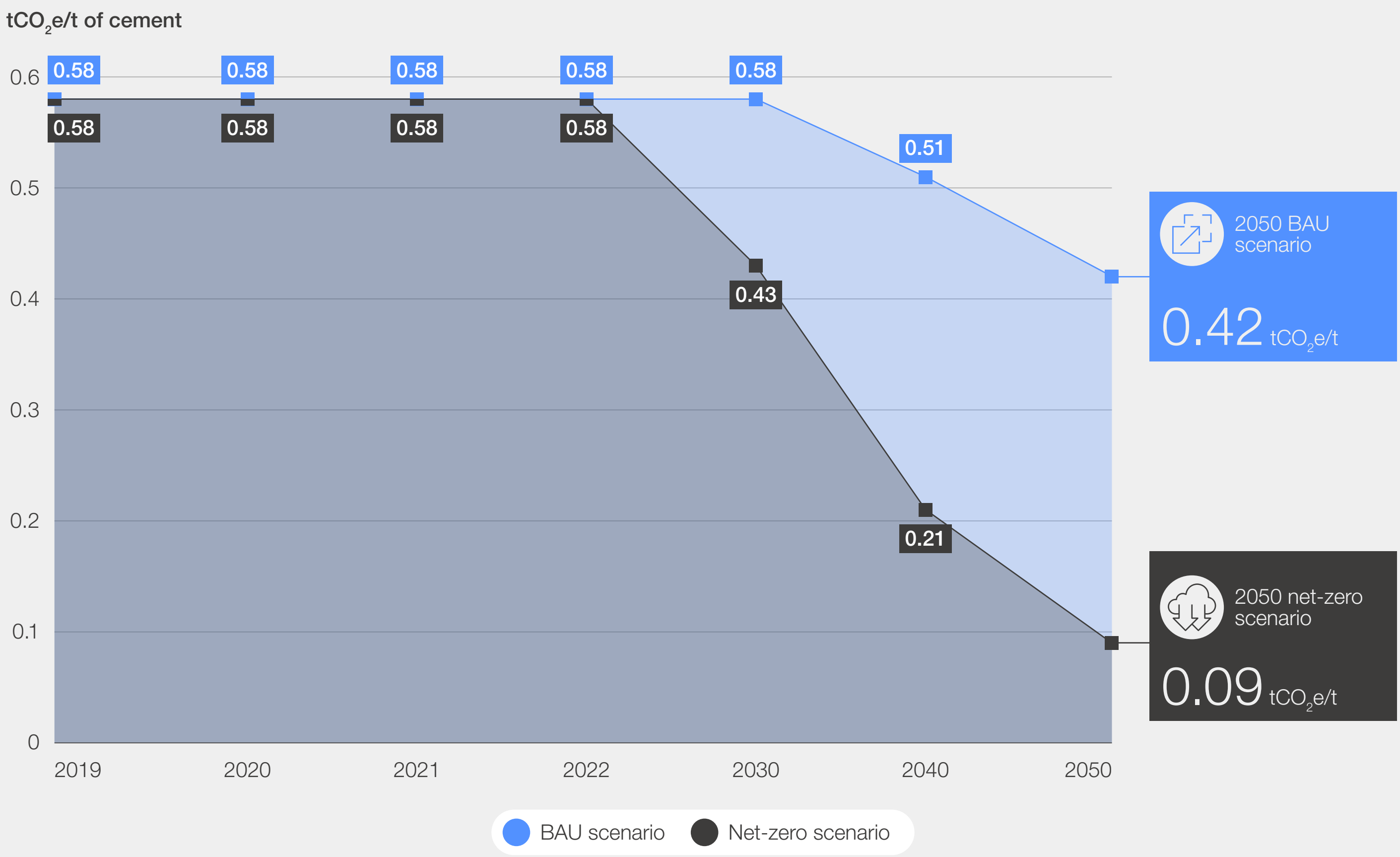
Performance

The clinker production process is the primary contributor to emissions in the cement industry, accounting for roughly 60%. The remaining 40% is generated through the intense heating energy required to heat cement kilns, primarily supplied by the combustion of coal and gas.[276]

Absolute CO_2 emissions declined by less than 1% over the last four years amid increases in global production. Emissions intensity remained static over the same time period despite a 9% rise in the clinker-to-cement ratio.[277] The average ratio is currently 72%,[278] while the proposed GCCA target is 56% by 2040.[279] The twin forces of urbanization and population growth are driving cement consumption in China (51% global demand) and India (9% global demand),[280] which necessitates accelerated action to decarbonize the sector to mitigate the impacts of increased production.

Energy intensity for cement production is a function of kiln type, combustion, fuel quality and heat transfer efficiency and averages 2-3 GJ/t. Over the last five years, global cement energy intensity decreased by 2%,[281] due to increased use of biomass and non-renewable waste in the fuel mix.

FIGURE 43 **Emissions intensity trajectory, net-zero vs BAU scenario**

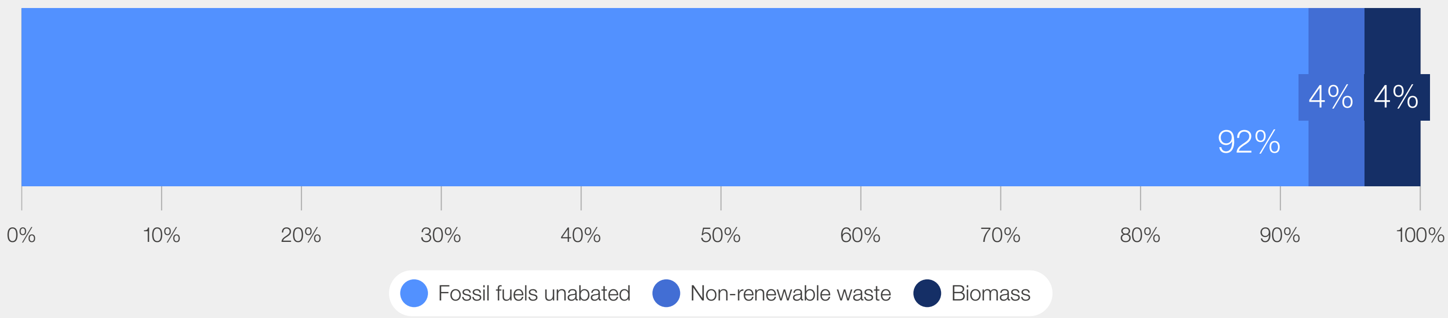


Source: IEA

Path forward

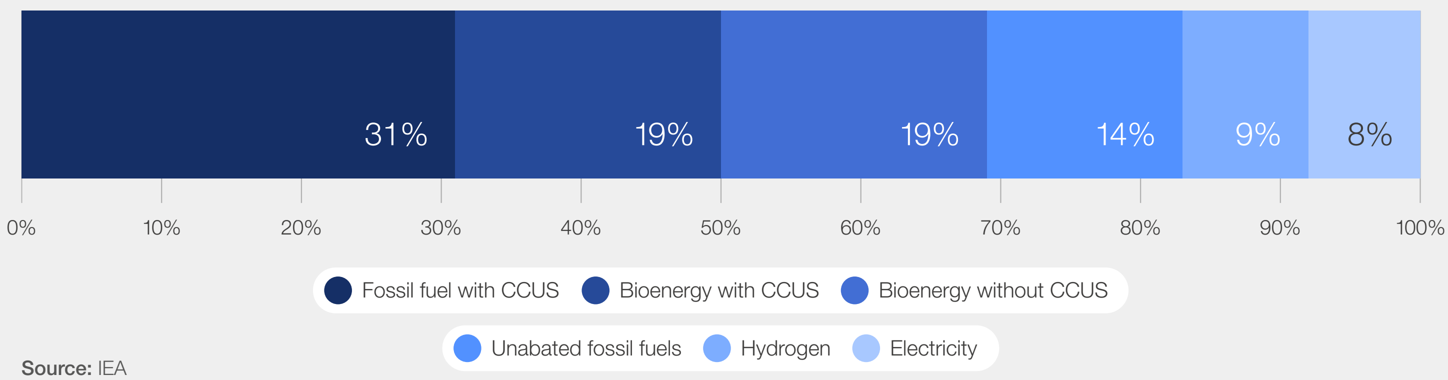
The GCCA is targeting a 20% emissions reduction by 2030 and net zero emissions by 2050 (from 2020 levels).[282] In the near term, efficiency measures, circularity measures, clinker substitution with SCMs and decarbonizing the kiln heating process may contribute to a 25% emissions reduction.[283] However, the additional reduction will require decoupling cement emissions from market demand increases through a reduction in non-abated fossil fuels from 92% of the fuel mix to 10%, requiring a significant step up in CCUS deployment. The scenario considers a 10-fold increase in the proportion of biofuels in the fuel mix and a 25% deployment of renewables, with clean hydrogen projected to represent 5%.[284] Further scaling of CCUS, clean electrification and hydrogen will likely be required in some regions.

FIGURE 44 | **2020 fuel mix**



Source: IEA

FIGURE 45 | **2050 fuel mix – net-zero scenario**



Source: IEA

2

CEMENT

Technology

Three leading decarbonization pathways have emerged, and CCUS technologies are the most developed (TRL 6-9). Clean hydrogen and clean power-based technologies are limited to prototype stage (TRL 5-6). Production costs for these technologies are nearly double the cost of Portland cement.[285]

Process emissions abatement measures

Scaling in-plant CCUS from less than 1% to 90% by the 2040's[286] to capture the CO_2 emitted during the clinker production process is critical to achieve near-zero-emissions. The CO_2 from cement process emissions is a rich stream and can be attractive to the CCUS industry alongside the right blend of policies and incentives. Lehigh Cement, a division of Heidelberg Materials in Alberta, Canada,[287] is set to launch the industry's inaugural full-scale CCUS facility. Designed to capture around 1 MTPA of CO_2 emissions, equivalent to about 95% of the plant's total emissions, the facility aims to be operational by 2026. This marks a positive step towards technology adoption among major industry players.

In the near term, cement should work to cut emissions from clinker production, scaling the deployment of both clinker substitution (SCMs) and alternative cement composition (green cement). Though commerciality and scalability challenges still need to be solved, these innovations complement the near-zero decarbonization strategies.

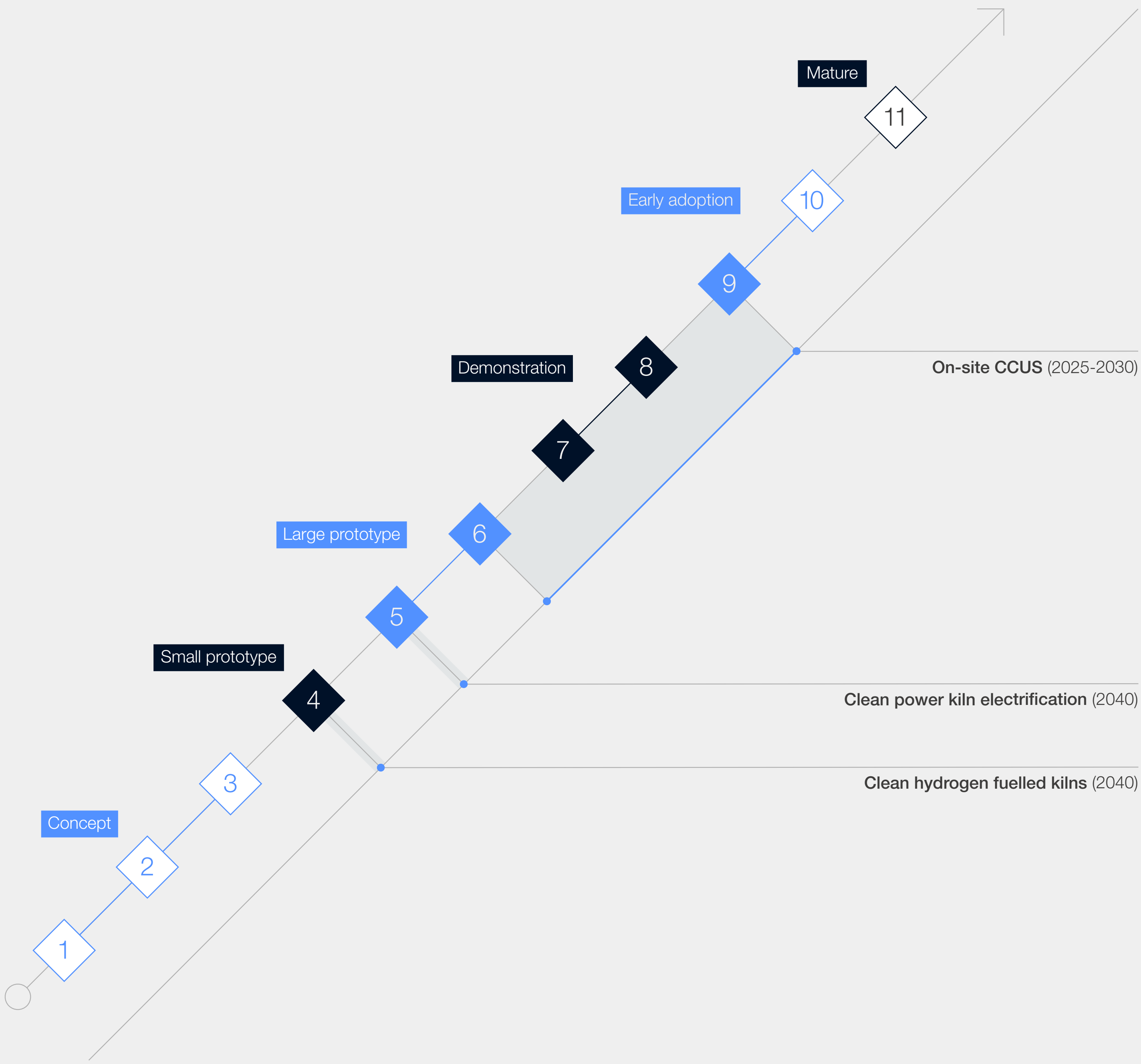
Energy emissions abatement measures

Kiln electrification supplied by clean, renewable electricity alongside clean hydrogen to replace coal and natural gas as fuel sources target the approximately 40% of emissions associated with fuel consumption. The requirements for intense heat energy align with electrification and clean hydrogen as critical net-zero pathways.

However, most projects are currently prototyped at scale, energy storage requirements to overcome intermittency need to be considered, and clean hydrogen is not currently cost-competitive or widely available. In the near term, increasing the volume of biomass in the fuel mix can reduce energy emissions while near-zero technologies advance to commercial scale.

Technology pathways

FIGURE 46 **Estimated TRL and year of availability for key technology pathways**



Source: GCCA and ECRA

CEMENT

2 Infrastructure

Decarbonization of cement is dependent on the availability of CCUS, clean hydrogen and clean power infrastructure. However, less than 1% of the necessary infrastructure for near-zero-emission production has been installed.[288] The total infrastructure required to support the global cement industry is estimated at up to $300 billion through 2050.[289]

The rich CO_2 streams from clinker production position the cement industry as a leading candidate for investment in CCUS. It is likely that cement production can form one of the anchors of emerging CCUS hubs, such as the Northern Lights JV Longship Project,[290] due to become operational in 2024 and capture up to 1.5 MTPA of captured carbon. Longship is Europe's first cross-border CO_2 transport and storage network, in which cement collaborates with infrastructure owners and other co-located industrial players to accelerate the build-out of CCUS infrastructure.

Given the scale of their demand, cement plants may need to consider captive on-site generation, as clean hydrogen grids may not have the capacity to meet their intermittent clean hydrogen demand profile without additional storage investment.

Clean power is a pre-requisite for delivering the CO_2 reduction potential of kiln electrification. The cost of the renewable generation, transport and distribution and likely storage for intermittency is yet to be quantified.

FIGURE 47 **Cement infrastructure investments**

	Investments required	Percentage of total investments	Capacity required
CO_2 transport and storage	Up to $240 billion	80%	1,370 MTPA
Clean hydrogen production	Up to $60 billion	20%	5 MTPA
Clean power generation	Data unavailable	Data unavailable	Data unavailable

Source: Accenture analysis based on multiple data sources, including GCCA, IRENA, IEA and BloombergNEF

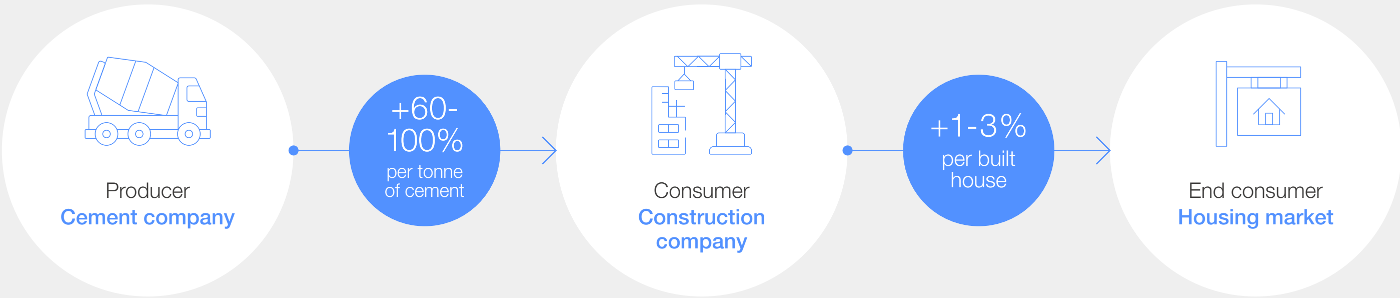
CEMENT

2 Demand

The ability of customers to absorb a green premium of 60-100% per tonne[291] is untested beyond prototype projects, as low-emission cement represents less than 1% of global supply.[292]

A 60% increase in the per tonne cost of cement translates into a 3%[293] increase in the cost of a built house. When considered as a share of the total lifetime emissions of a building, the green premium for near-zero-emission cement is more competitive.

FIGURE 48 **Estimated B2B and B2C green premium**



Source: Accenture analysis based on multiple data sources to include ECRA, Bloomberg and Fortune

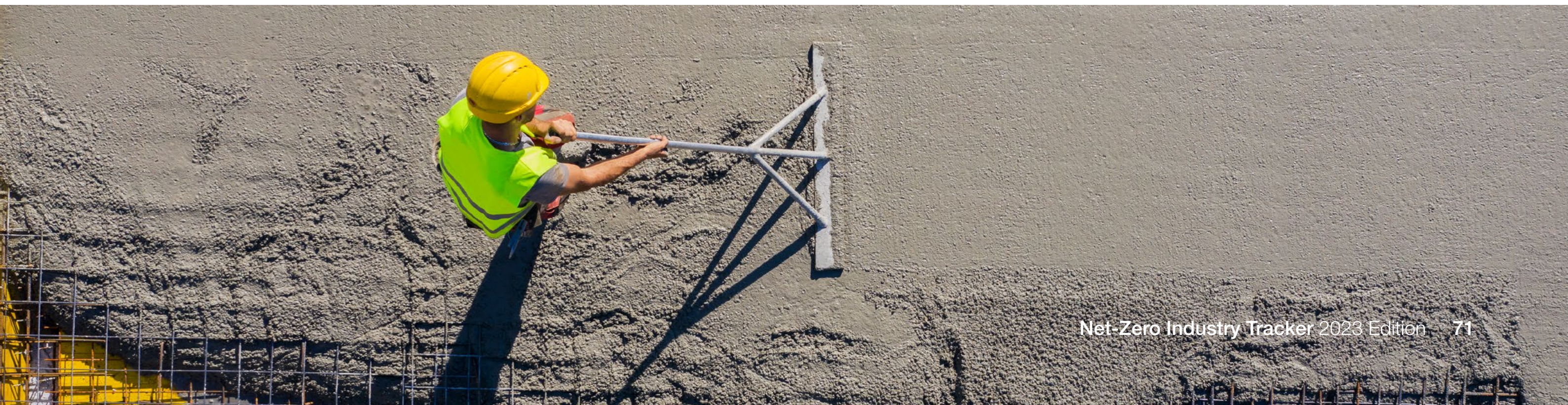
The ability of the industry to pass along this premium or to monetize near-zero-emission cement as a differentiating attribute depends on the target consumer segment (B2B vs consumer) and geography (developed vs developing cost of housing). The largest forecasted increases in cement consumption globally align with the markets with likely the lowest ability to absorb a significant green premium.

While current adoption is low, industry demand for near-zero-emission and "green" cement products is emerging. Industry consortia, such as the FMC, are mobilizing market demand through purchase commitments. In 2023, the FMC[294] pledged to buy 10% of its annual cement supply as near-zero-emission cement by 2030. Comparable initiatives are occurring in the cement and building materials sector. In March 2023, Hoffman Cement[295] contracted with Alkern Group to supply 28% of their current production as decarbonized cement until 2027.

> The absence of standardized definitions, certifications and traceability prevents industry from understanding the market potential.

The absence of standardized definitions, certifications and traceability mechanisms has prevented consumers from having the necessary transparency to fully consider paying the green premium or for the industry to fully define the pathway to understand the market potential at a higher cost of production. The introduction of ISO 19694-3[296] in March 2023 may improve the tracking of CO_2 emissions.

The global construction landscape is showing signs of change as industries move to reduce CO_2 emissions on various fronts. Breakthrough developments such as low-carbon design,[297] nanotechnology,[298] algae-based biogenic cement[299] alternatives and 3D printing, which can reduce the volume of cement used in construction by up to 70%[300] may disrupt business-as-usual requirements. The cement industry may need to diversify traditional portfolios and adapt business models to remain competitive and maintain market share through the evolving landscape, balancing supply with demand for an increasing number of lower-emission products.



CEMENT

3 Policy

Policy measures to support the decarbonization of the cement industry remain at an early stage; in particular, policy frameworks are yet to be established in the Asia Pacific region, where 70% of cement is produced.[301]

Global cement production is dominated by multinational players alongside smaller local players. Local regulations, for example at urban or municipal levels, often focus on pollution control, life cycle assessments and performance standards without addressing CO_2 emissions reduction. A suite of targeted policies on the supply side can subsidize technology adoption while discouraging emissions through carbon pricing and cross-boarded adjustments. To drive demand, a transparent definition of low-emission cement is needed, together with green public procurement and updated building codes with standards for waste material use and co-processing, landfill bans or taxes and regulations on building demolition, and mandated minimum quantities of recycled materials.

Existing policy landscape

TABLE 9 **Policy summary**[46]

Enabler	Policy type	Policy instruments	Key examples	Impact
Technology	Incentive-based	Direct R&D funds/grants	– EU Innovation Fund[302]	$800 million in funding for six cement CCUS projects in the EU.
		Supporting regulations	– EU Net-Zero Industry Act[303]	Strengthens regulations and create an enabling environment to boost CCUS technology development and stimulate investments. Currently in the proposal stage.
	Market-based	Carbon price	– EU-ETS[304] – California ETS[305] – China ETS[306] (inclusion of cement announced, not formalized)	Incentivizes cement producers to reduce emissions.
		Border adjustment tariff	– CBAM[307] (pending implementation) – Prove It Act[308] (under discussion)	Emission-intensive cement exporters to EU face a cost escalation of up to 100%. Needs to be complemented by transparent and carbon accounting standards.
Infrastructure	Incentive-based	Direct funding support to CCUS infrastructure	– Public funding of CCUS hubs in EU[309] – Provision for CCUS hubs under Bipartisan Infrastructure Law[310]	Over $6 billion committed to develop CCUS hubs in the US and the EU.
Demand	Incentive-based	GPP	– Policies in place for green public procurement of concrete products in Germany, the Netherlands, the UK, Sweden[311] – Federal buy clean initiative in the US[312] – Key cement producers as IDDI members – the UK, India[313]	Creates a viable market for low-emission cement through GPP commitments.
	Mandate-based	Building/end-use/product codes and standards	– Embodied carbon limit policies in the Netherlands, Sweden, France and Germany[314] – US General Service Administration (GSA) low embodied-carbon concrete standards in the US[315]	Provides a clear market signal to low-emission cement production.
Capital	Incentive-based	Tax credits/ subsidies	– CCUS tax credits under IRA[316]	20-30% reduction in costs to deploy CCUS in cement plants.

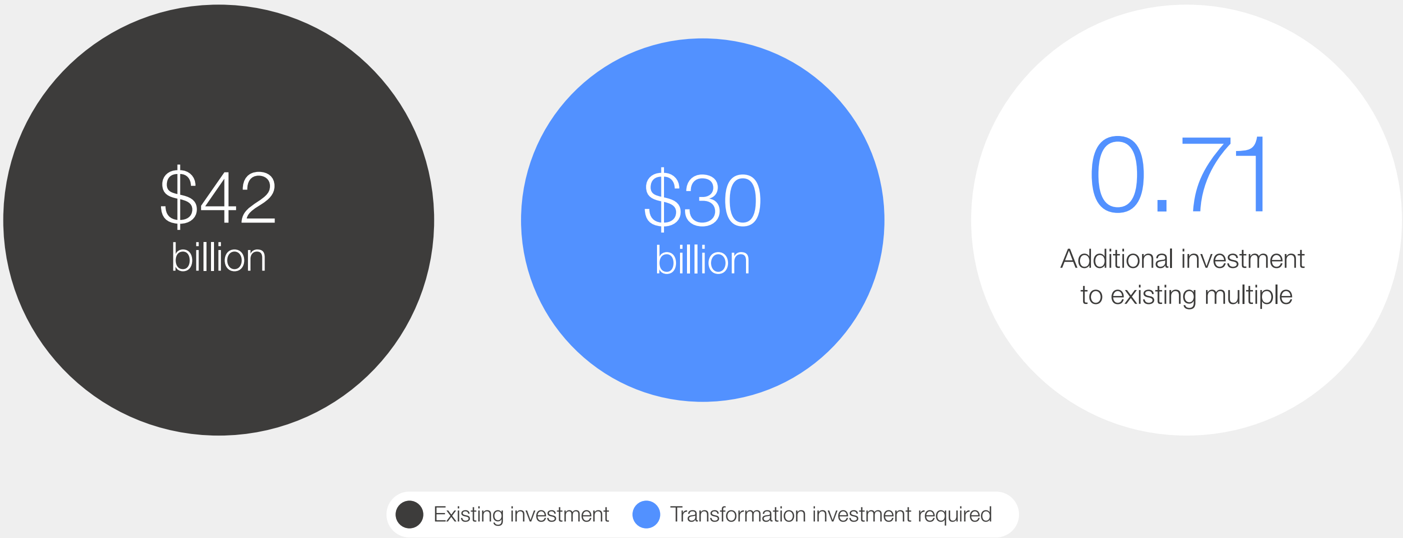
CEMENT

1 Capital

The cement industry is estimated to require $750-900 billion in CapEx for CCUS enabled plants by 2050.[317] This translates into an annual investment of approximately $30 billion, equivalent to 71% of existing CapEx[318] (without adding new capacity or generating additional returns). Further capital will be needed to adopt clean hydrogen and electrified kilns.

The business case for investment in near-zero-emission cement assets remains weak. Current industry profit margins of approximately 16%[319] and WACC is 10%.[320] Despite relatively low end use green premium, considering the heavy amount of CapEx involved, it may be a challenge for the industry to self finance in the absence of carbon pricing in certain regions.[321] Cement companies also need to balance capital allocation towards low-emission assets, with competing objectives of funding dividends and share buybacks to fulfil investor expectations.

FIGURE 49 **Additional investment required to existing investment ratio**

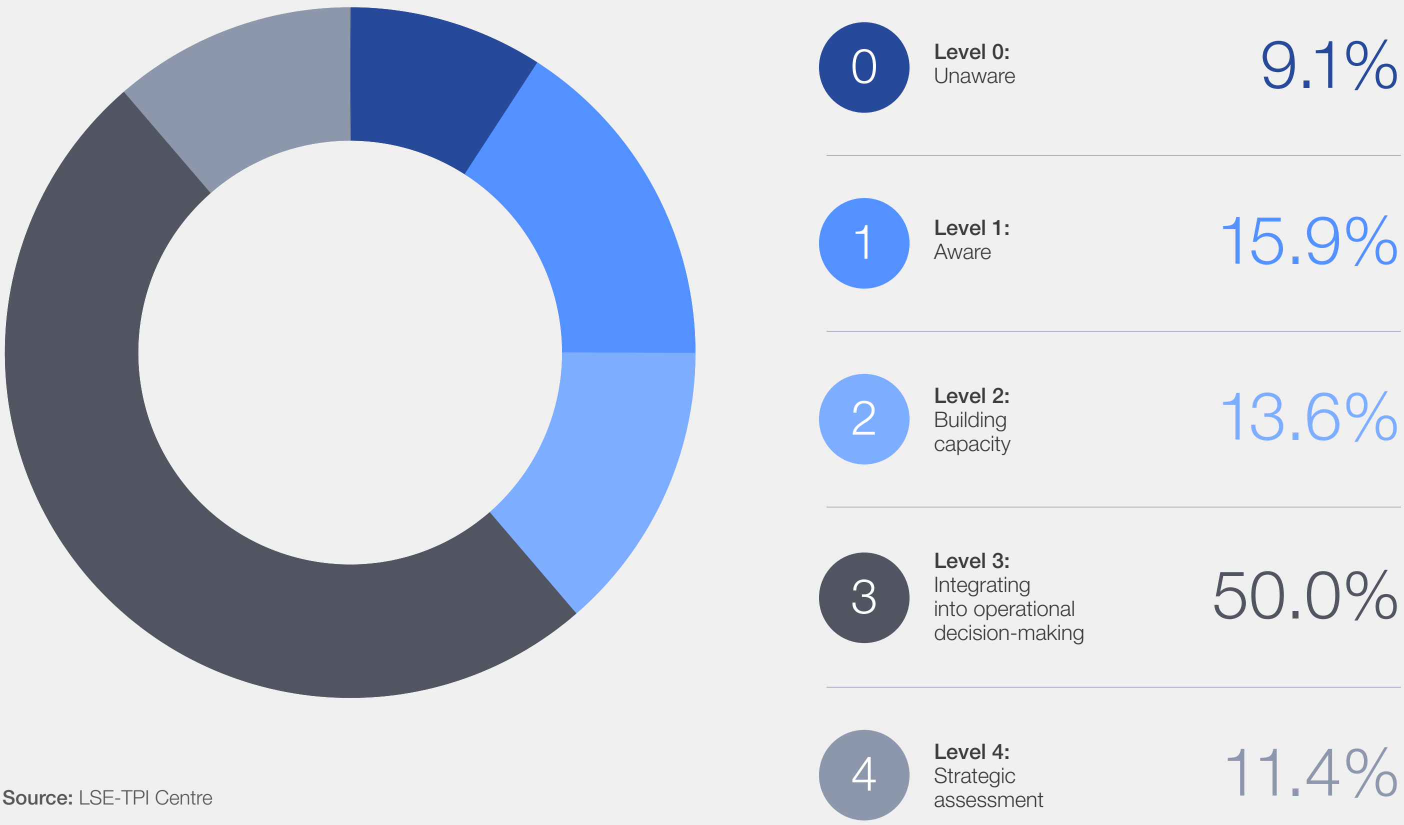


Source: Accenture analysis based on multiple data sources to include ECRA and Global CCS Institute

Funding mechanisms to direct capital to developing market cement production to incentivize institutional investors and multilateral banks could be considered, linking capital to emission reduction. Organizations like the Climate Bonds Initiative,[322] which introduced cement sector certification in 2022, aim to enhance transparency and guidance around clean investments, which may help to accelerate this effort. In Europe, the industry will need to replace 30% of kilns by 2030 and capital needs should prioritize newer assets with CCUS.[323]

Approximately 61% of large, publicly-traded cement companies consider climate change as a key consideration for their strategic assessment and integrate it into their operational decision-making.[324] Meanwhile, 14% of companies are building basic emissions management systems and process capabilities. Finally, 16% of companies acknowledge climate change as a business issue.

FIGURE 50 **Distribution of companies in the cement sector according to the management of their GHG emissions and of risks and opportunities related to the low-carbon transition**



Source: LSE-TPI Centre

7

Aluminium industry net-zero tracker

To reach net zero, the industry will need to increase use of clean power, improve the share of recycled aluminium and progress low-emission smelting and refining technologies.

Key emissions data[325, 326, 327, 328, 329, 330]

3%
Contribution to global GHG emissions

1.2 $gtCO_2e$
Scope 1 and 2 emissions

4%
Emissions growth (2019-2021)

11.2 tCO_2
Emissions intensity (per tonne of aluminium, 2021)

67%
Fossil fuels in the smelting power mix (2021)

1.7 times
Expected demand increase by 2050

<1%
Current low-emission primary production

47%
Reduced emission primary production

Readiness key takeaways

Technology

Aluminium should use clean power and scrap to reduce its emissions. Low-emission refining and smelting methods are proposed to be accessible by 2030. Production costs for low-emission aluminium can be up to 40% higher than traditional methods.[331]

Infrastructure

30% of clean power infrastructure exists while current hydrogen and CO_2 transport infrastructure is below 1% of what is required by 2050.[332] Investments of up to $560 billion[333] are needed to accelerate infrastructure development.

Demand

Low-emission aluminium held less than 1% of the market in 2022. A B2B green premium of around 40%[334] may be necessary, with about 1-2% affecting consumers.[335] However, this remains untested.

Policy

Global aluminium trade requires both domestic and international regulations for decarbonization. Key producing countries, such as China, require more tangible policies especially focused on improving access to clean power infrastructure.

Capital

Over $200 billion in CapEx[338] is required by 2050 to retrofit existing assets with inert anode technology and low-emission smelting technology. However, the business case remains weak, given 8% industry profit margin and 9% WACC.[339]

Stated energy transition goals

- Current industry net-zero scenarios propose a 30% reduction in emissions intensity by 2030 and 97% emissions by 2050.[336]
- 71%[337] of large publicly-traded aluminium companies consider climate change in their decision-making processes.

Emission focus areas for tracker

Aluminium emissions can be divided into two main categories:

1. **Energy-related emissions** primarily due to fossil-based electricity consumption during smelting and thermal energy consumption during refining.
2. **Process emissions** from smelting requiring the presence of carbon-based anodes.

Sector priorities

Exisiting assets

Reduce near-term emissions intensity by:

- Switching to clean power sources for smelting operations where feasible
- Retrofitting existing fossil-fuel-based captive power assets with CCUS, where access to clean power grids is not economical
- Improving end-user scrap collection rate from 70% currently to maximize secondary production.[340]

Next generation assets

Accelerate technology and infrastructure development to drive absolute emissions reduction by:

- Investing in clean power grid capacity supported by energy storage systems to support transition
- Accelerating market readiness for low-emission smelting technologies like inert anodes
- Develop and deploy low-emission refining technologies like electric boilers, mechanical vapour recompression, etc.

Ecosystem

De-risk capital investment to scale infrastructure capacity by:

- Implementing policies that level the playing field for low-emission technologies, enable access to clean power infrastructure and encourage scrap use
- Reducing production cost premiums through an increased number of low-emission projects
- Enabling shared infrastructure and supply chain stability through strategic partnerships.

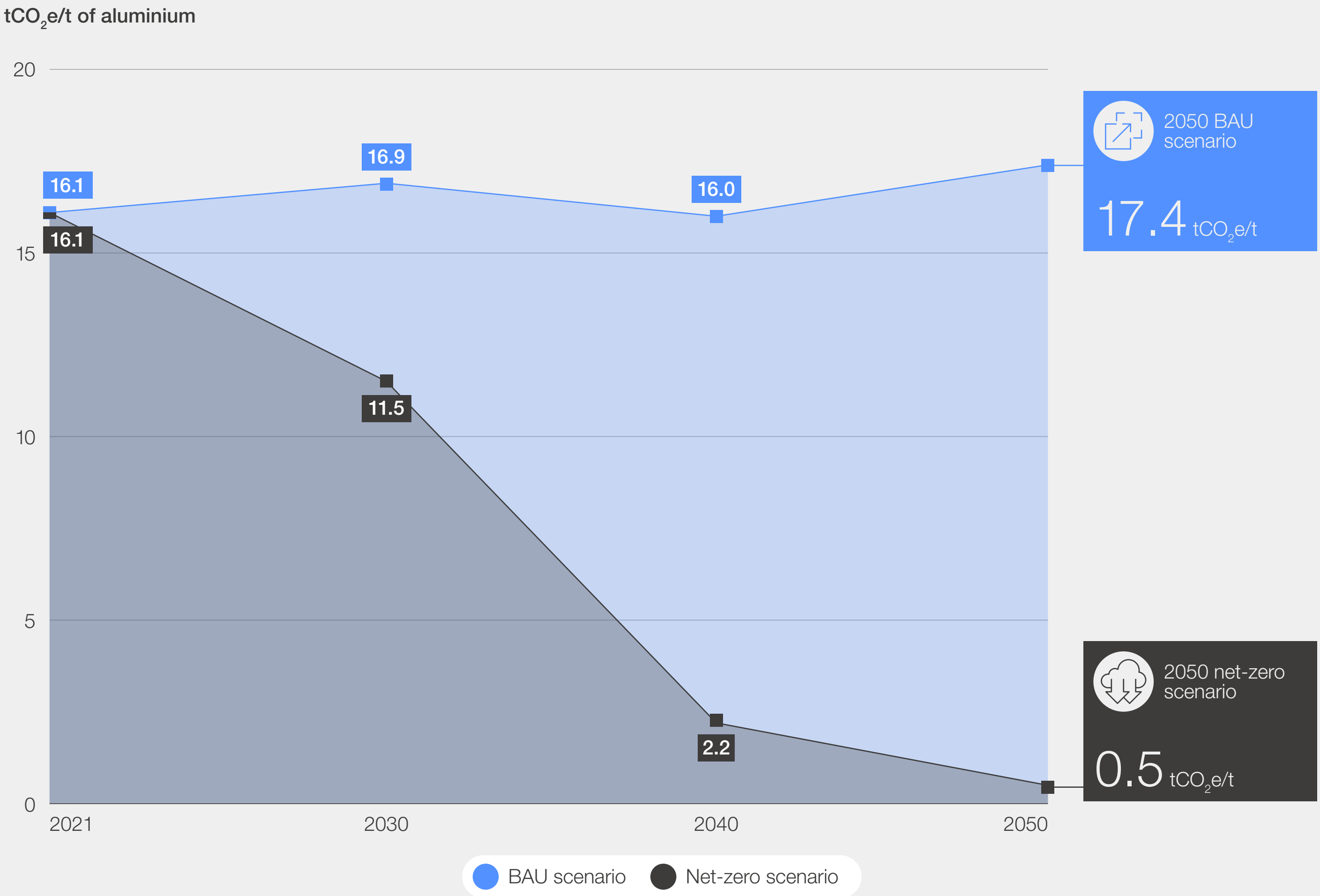
Performance

Nearly 70% of the emissions from the aluminium production process arise due to electricity consumption during smelting.[341] This electricity requirement accounts for around 4% of global power consumption, with up to 70% sourced from fossil fuels (predominantly coal) and the remaining 30% from renewables, primarily hydropower.[342] Among the industrial sectors, it features one of the highest levels of renewable energy use for energy requirements. Process emissions during the smelting process contribute 13% to the emissions, while the use of fossil fuels for providing thermal energy across the value chain results in a further 13% of emissions.[343]

Both absolute emissions and emission intensity have remained stable over the past three years due to the smelting power mix remaining almost constant.

The energy intensity of primary aluminium is around 70 GJ/tonne, making it more energy-intensive than steel and cement on a per-tonne basis. Secondary aluminium production consumes just 5% of the energy required for primary production.[344]

FIGURE 51 **Emissions intensity trajectory, net-zero vs BAU scenario[345]**



Note: Based on primary production only

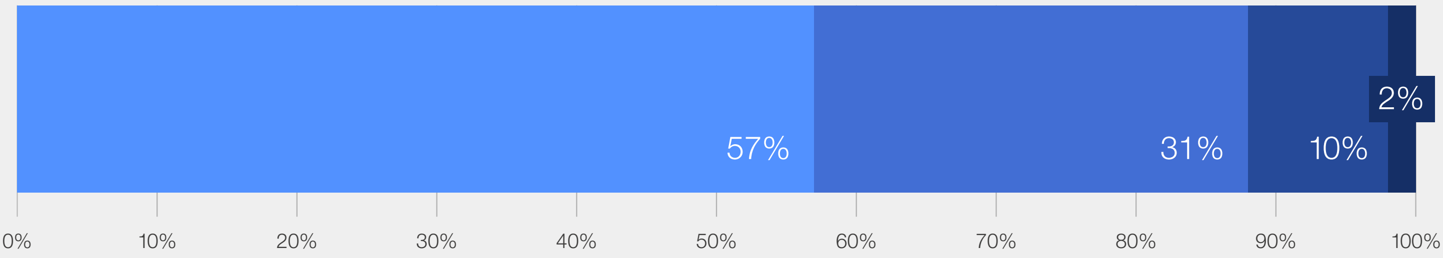
Source: IEA and IAI

Path forward

Aluminium needs to reduce its absolute emissions by 80% to reach net zero by 2050.[346] Achieving this reduction will involve switching to completely clean power sources for smelting – either renewables (solar, wind, hydro, nuclear, etc.) or through captive power plants retrofitted with CCUS.

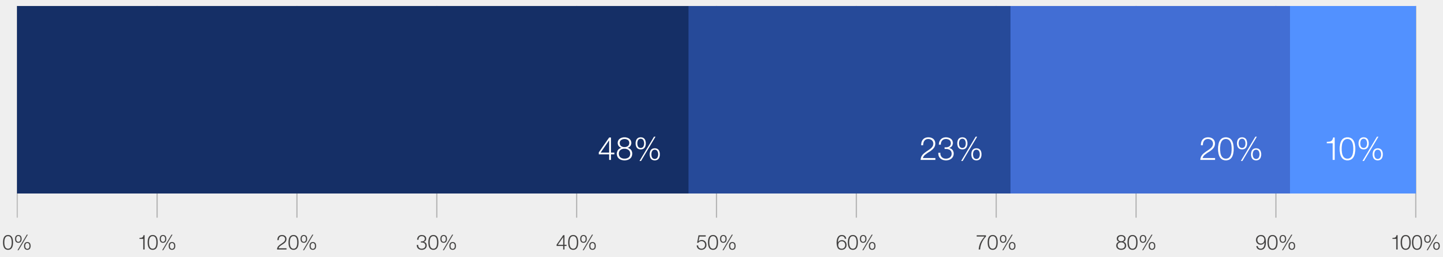
Furthermore, accelerating the adoption of secondary aluminium is key. By 2050, secondary aluminium production is projected to constitute 50% of the production as per industry net-zero projections.[347]

FIGURE 52 | **2021 primary smelting power mix**



Source: International Aluminium Initiative

FIGURE 53 | **2050 primary smelting power mix – net-zero scenario**



Source: MPP

ALUMINIUM

3 Technology

Three leading decarbonization pathways have emerged. Two of these pathways are currently available: shifting to clean power and transitioning to secondary aluminium. The third pathway explores low-emission refining and smelting processes, which are still mostly in early stages and are expected to be commercially available by 2030 or after. Deploying these technology pathways can lead to production cost increase of around 40%.[348]

Clean power for smelting

Clean power solutions for aluminium include; decarbonizing electricity input through renewable grids/purchase power agreements (PPAs) and using CCUS with captive power plants where access to renewables is not feasible. Using nuclear-powered small modular reactors is also an alternative, but the technology is still emerging. Between 30-35% of the current primary production is already through hydro-based electricity production.[349] While renewables are cost-competitive in many areas, fossil fuels with CCUS come with a cost premium of up to 30% in some regions.[350] Smelters need continuous access to electricity. Thus, assets switching to renewables with a lower capacity factor will need supporting technologies like battery storage, which can further add to costs. Innovative technologies like EnPot that, which enables smelters to vary energy consumption based on available power will also be key.[351]

Secondary production

Maximizing secondary aluminium production has great potential for emissions reduction owing to its low-carbon footprint. Transitioning to secondary aluminium could result in up to a 25% reduction in annual emissions by 2050,[352] by avoiding the loss of 15 million tonnes of metal at end-of-life. However, this has a strong dependency on increasing post-consumer scrap collection from current levels of 70% to near 100%.[353] Also, technologies that improve scrap quality, like scrap sorting and purification technologies, will be vital. Secondary production is reliant on fossil fuels (especially gas) for heat. There is an opportunity to make this production process net zero by switching to cleaner energy sources like clean power, hydrogen, biofuels, etc.

Low-emission refining and smelting technologies

> **Low-emission refining technologies are expected to increase production costs by 6-11%.**

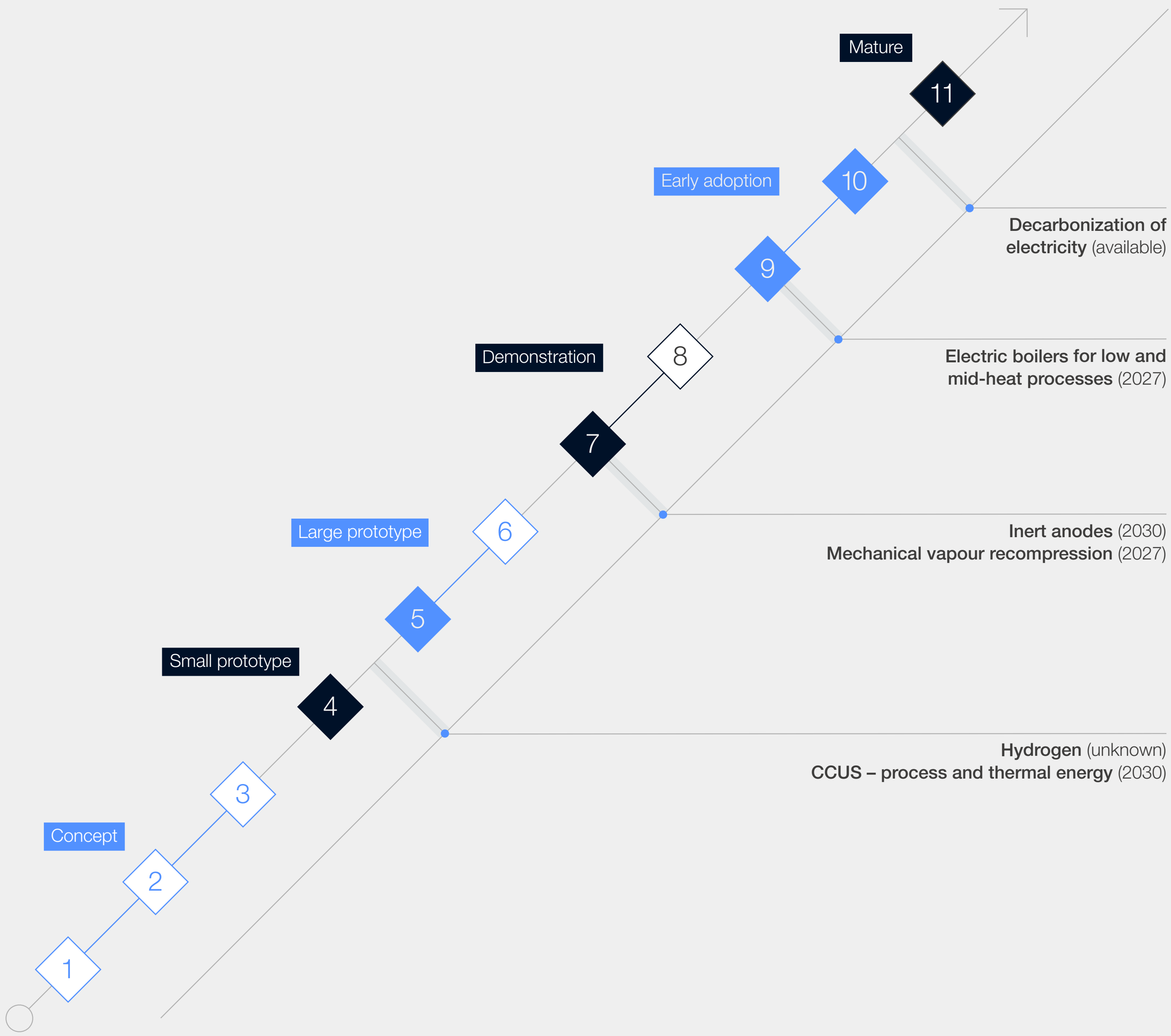
Low-emission refining technologies like use of electric boilers, and mechanical vapour compression (MVR) will be critical to remove thermal energy emissions from the refining process. Electric boilers are already available and have been successfully tested across other industries. MVR technology is expected to be available after 2027. These technologies address the digestion process, which contributes 70% of refining energy consumption.[354] The remaining 30% of energy is consumed by the calcination process, where technologies like hydrogen calciners or electrified calciners can reduce emissions. These technologies are still emerging, with TRL levels of 4-5. Low-emission refining technologies are expected to increase the production costs by 6-11%.[355]

Low-emission smelting technologies include inert anodes and CCUS. Inert anodes are critical to remove the process emissions during smelting and are expected to be commercially available after 2030 with a production cost increase of 9%. ELYSIS, a joint venture between Alcoa and Rio Tinto, is working on commercializing a patented inert anode technology with support from the Canadian government.[356]

CCUS in smelting applications is still in early stages, and with low CO_2 concentrations in smelting flue gas, it is expected come with increased costs of carbon capture.

Technology pathways

FIGURE 54 **Estimated TRL and year of availability for key technology pathways**



Source: IEA

ALUMINIUM

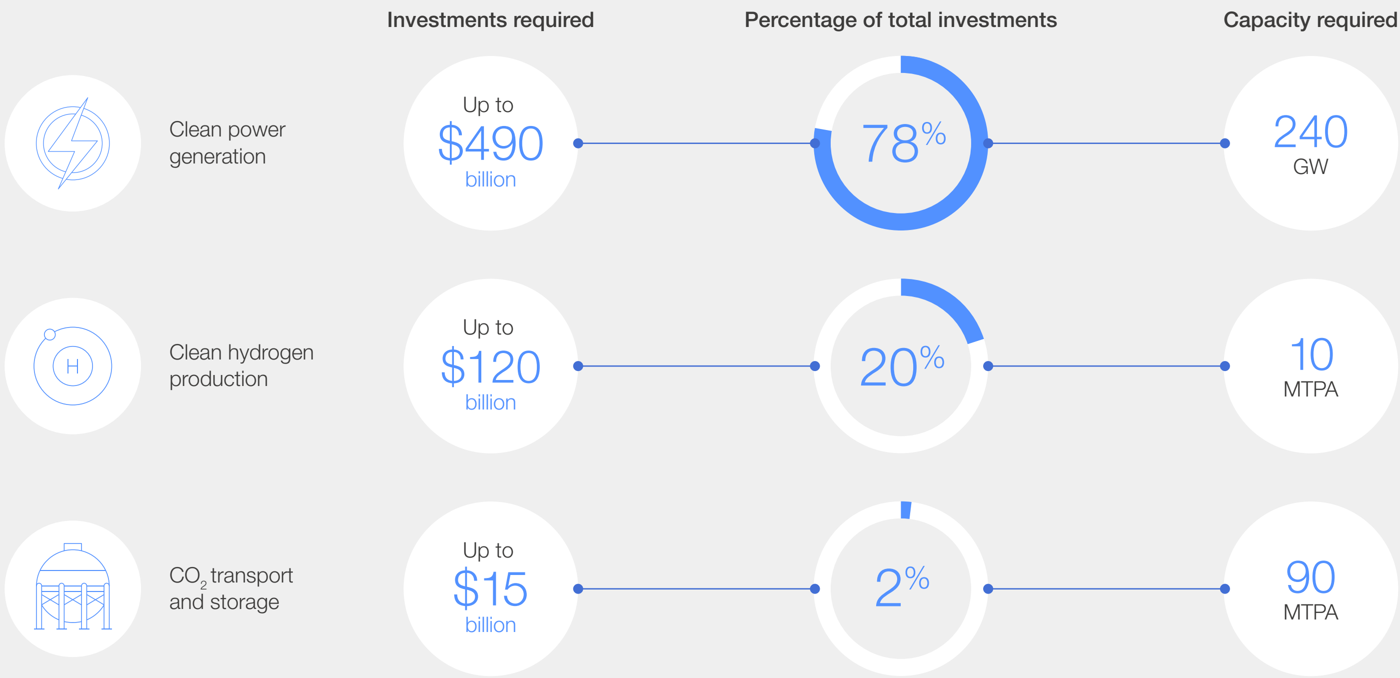
3 Infrastructure

Aluminium decarbonization relies primarily on clean power generation for electricity in smelting, supported by clean hydrogen infrastructure for refining. CO_2 transport and storage infrastructure will be required if CCUS technology is scaled, to address smelting process emissions. A total of 30%[357] of the clean power infrastructure required already exists, while hydrogen and CO_2 transport infrastructure are below 1% of what is required. The total infrastructure investment required to support the global aluminium industry is estimated at up to $630 billion through 2050.[358]

To decarbonize primary aluminium smelting, approximately 240 GW of clean electricity generation capacity is needed, requiring an investment of $490 billion. A significant challenge is proximity to clean power plants, with 30% of global smelting facilities currently at risk of having no access to clean power.[359] These plants will either need to relocate or adopt CCUS technologies. For instance, numerous Chinese aluminium plants are moving to provinces with better access to low-carbon power,[360] with up to 50% of their smelters at risk of no access to clean power.

The required hydrogen capacity for refining is estimated to be at 9.3 MTPA by 2050, necessitating an investment of $40-120 billion.[361] CO_2 transport and storage infrastructure to support CCUS deployment in smelting will need a further investment of up to $15 billion.[362]

FIGURE 55 **Investments required for enabling infrastructure**



Source: Accenture analysis based on multiple data sources, including IAI, IEA and BloombergNEF

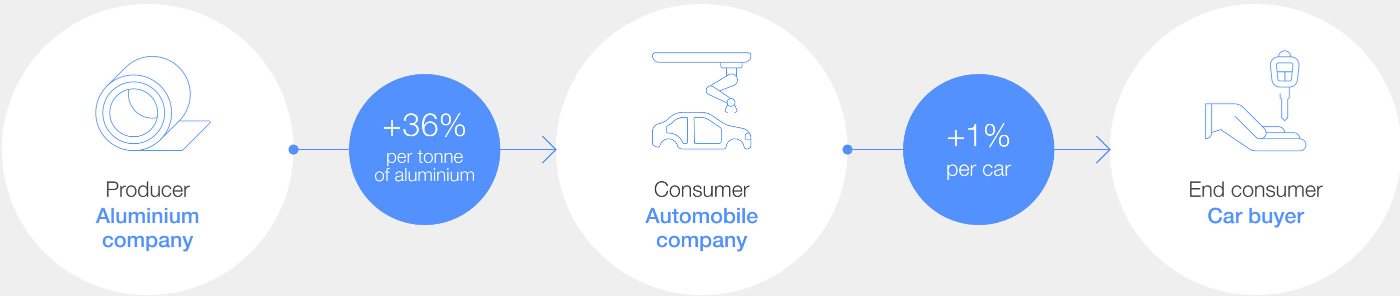
ALUMINIUM

4 Demand

The market's capacity to accommodate a 40% per tonne green premium[363] remains unverified beyond prototype projects. At present, less than 1% of aluminium adheres to industry net-zero thresholds for low-emission aluminium, as implied by current net zero by 2050 scenarios. Still, the demand for green aluminium is growing stronger, evident by its inclusion in the scope of the FMC and several other offtake agreements. Also, consumer goods companies like Apple are increasingly targeting to source low-emission aluminium for their electronic products.[364]

A 40% increase in aluminium production costs translates to a 1-2%[365] increase for end consumer industries such as automobiles or consumer goods.

FIGURE 56 **Estimated B2B and B2C green premium**



Source: Accenture analysis based on multiple data sources, including CRU, INSEE and European Aluminium

Business model shifts have been observed including investing and prioritizing secondary smelting over primary.

To position the industry to fulfil low-emission demand, business model modifications may be necessary. This includes widening the scope of industrial customers beyond traditional applications. Aluminium is a critical metal from a technologies perspective, as the foundation of a net-zero future: electric vehicles (EVs), wind turbines, photovoltaics, and energy storage. Therefore, regions such as China,[366] which are expected to witness a growth in demand for such technologies, will demand more low-emission aluminium as compared to other regions.

A business model shift that has been observed in the industry, which includes investing and prioritizing secondary smelting assets over primary.[367] Companies are also introducing "low-carbon" products as part of their portfolio. For instance, Alcoa is expanding its EcoSource™ low-carbon alumina brand to include non-metallurgical grade alumina.[368] In 2021, Rusal launched ALLOW, 98% of which is claimed to be produced using renewable energy supplied by hydropower plants in Siberia.[369]

To incorporate transparency for end users, Rio Tinto has launched START, aimed at empowering end users to make informed choices about the products they buy.[370] In a similar move, The London Metal Exchange (LME) announced the launch of LME passports. This digital register stores electronic certificates of analysis and sustainability credentials for LME-listed metals.[371] Price assessments of "low-carbon" aluminium by commodity research firms such as Standard & Poor's (S&P) also provide transparency and enable consumer demand.[372] The industry, however, needs to adhere towards globally recognized, standardized definitions of low-emission aluminium, to comply with net-zero thresholds and boost demand signals.

ALUMINIUM

Policy

Global aluminium production is highly concentrated, with China contributing 60%[373] of the total output. However, it is also extensively traded, which means that both domestic and global regulations significantly influence aluminium production. The policy landscape for creating a low-emission aluminium industry is still developing. Key producing regions require more robust and tangible policies, especially with regard to improving access to clean power infrastructure.

Public policies should be directed towards supporting the following aspects in the aluminium sector: facilitating clean power adoption and access to clean power infrastructure, promoting R&D alongside market-based approaches to accelerate early-stage low-emission smelting and refining technologies, and encouraging higher recycling rates through infrastructure buildout that improves sorting and purification of aluminium scrap.

Currently, policy measures to support decarbonization across the four readiness enablers are still in the early stages. While a few initiatives have been explored in Canada, the EU and China, the need for more concrete policy actions, especially in key producing regions, remains paramount.

Existing policy landscape

TABLE 10 **Policy summary**

Enabler	Policy type	Policy instruments	Key examples	Impact
Technology	Incentive-based	Direct R&D funds/grants	– Canada's investment in ELYSIS' inert anode technology	$60 million in direct funding positions ELYSIS to support further R&D and achieve commercial scale.[374] R&D funding support to accelerate innovative technologies need to be supported by policies that enable technology access and transfer to developing countries.
	Market-based	Carbon price	– EU-ETS[375]	Incentivizes aluminium producers to reduce emissions.
		Border adjustment tariff	– CBAM[376]	Emission-intensive aluminium exporters to the EU face increased costs of compliance. Currently, 50% of aluminium consumed is imported from non-EU countries. Needs to be complemented by transparent and fair carbon accounting standards.
	Mandate-based	Direct regulations	– Inclusion of aluminium in the EU's Critical Raw Material Act[377]	Improves the circularity and sustainability of critical raw materials like aluminium. Still in the proposal stage.
Infrastructure	Mandate-based	Government targets	– China's renewable energy use targets for aluminium	Doubles the share of renewables in the aluminium energy mix by 2045.[378]
Demand	Market-based	Product standard	– Aluminium Stewardship Initiative's Performance Standard 3, recognized by Green Building Council of Australia	Provides transparency and standardization to the environmental performance of aluminium products.[379]
Capital	Incentive-based	Subsidies	– China: provincial level subsidy	Public support to smelters to move to incentivize energy-efficiency technologies.[380]

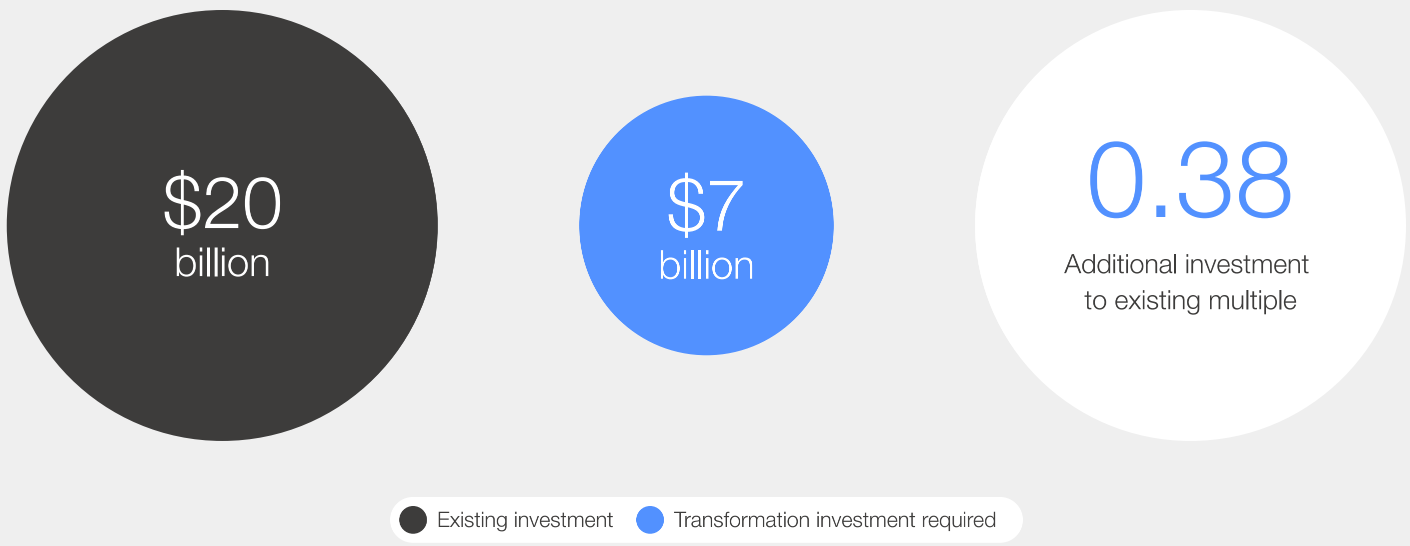
1 Capital

The aluminium industry will require significant capital investment in low-emission smelting and refining technologies beyond power decarbonization. The capital requirements can be estimated with some degree of certainty for the predominant low-emission smelting technology, inert anodes. Retrofitting existing assets with inert anodes could require cumulative investments of $200 billion by 2050.[381] This implies annual investments of $7 billion, in addition to the regular annual CapEx of $20 billion – an additional 38% investment.[382] Additional capital will be needed to improve refining, recycling and sorting processes.

To direct the capital towards transforming the industry, policy interventions like carbon pricing, subsidies/incentives and R&D funding for technology development will need to be adopted to guarantee returns. Large institutional investors and multilateral banks (World Bank, Asian Development Bank, etc.) can play a crucial role by providing access to low-cost capital linked to stringent emission reduction targets.

The business case for investment remains weak with additional costs of 38%[383] and uncertainties around returns from low-emission aluminium. Current industry profit margins of 13%[384] and WACC of 9%[385] suggest that the industry is not positioned to absorb these additional costs and generate sufficient returns to fund through its own generated cash flows.

FIGURE 57 **Additional investment required to existing investment ratio**

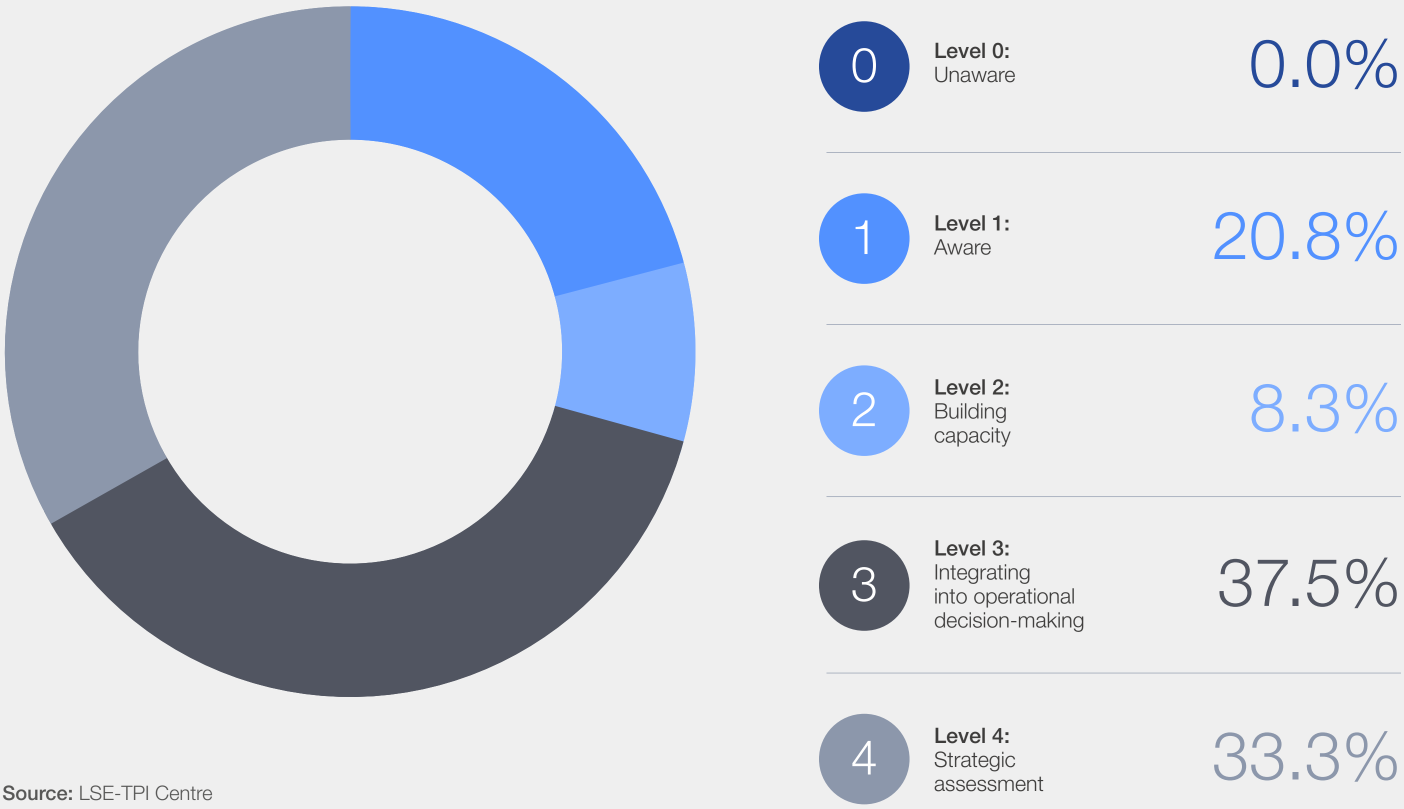


Source: Accenture analysis based on MPP data

There is a need for workable and increased support for funding for clean technology value chains across enterprises. A key development includes Canada's innovation funding for inert anode technology through ELYSIS. Another notable development includes collaboration between top lenders to the aluminium industry – Citi, ING and Societe Generale – and the Rocky Mountain Institute to develop a climate-aligned financing framework, currently in progress.[386]

Approximately 70% of large, publicly-traded aluminium companies consider climate change as a key consideration for their strategic assessment and integrate it into their operational decision-making.[387] Meanwhile, 8% of companies are building basic emissions management systems and process capabilities. Finally, 21% of companies acknowledge climate change as a business issue.

FIGURE 58 **Distribution of companies in the aluminium sector according to the management of their GHG emissions and of risks and opportunities related to the low-carbon transition.**



Source: LSE-TPI Centre

8

Ammonia industry net-zero tracker

While increased production costs of blue and green ammonia remain a challenge, demand from newer sectors like shipping and power can be key for ammonia decarbonization.

Key emissions data[388, 389, 390]

NH$_3$

1%	Contribution to global GHG emissions
0.46 $gtCO_2e$	Scope 1 and 2 emissions
2%	Emissions growth (2019-2022)
2.6 tCO_2	Emissions intensity (per tonne of ammonia, 2020)
97%	Fossil fuels in the fuel mix (2021)
3 times	Expected demand increase by 2050
<1%	Current low-emission production
2.2%	Reduced emission production

Readiness key takeaways

Technology

Clean hydrogen production is critical for ammonia decarbonization. The green premium for low-emission ammonia can vary from 40% to over 100%[391] depending on production route and region. Globally, steam methane reforming (SMR)/auto thermal reforming (ATR) with CCUS is cheaper.

Infrastructure

To meet the increase in demand, infrastructure investments of around $2.3 trillion are required.[392] The majority directed to increasing clean power capacities to 1,260 GW by 2050.[393]

Demand

Green premiums of 10-100%[394] will be difficult to absorb for fertilizer companies without policy support. Demand will be boosted by shipping, power and hydrogen carrier applications.

Policy

Policies for ammonia are emerging, particularly within the broader hydrogen landscape. Policies should focus on electrolyser manufacturing, CCUS implementation and regulatory frameworks.

Capital

1.5 times current investments required for decarbonization efforts. However, the business case remains weak, given 13% industry profit margin and 9% WACC.[397]

Stated energy transition goals

– The ammonia industry aims for a 27% emissions intensity reduction by 2030 and a 96% reduction by 2050. [395]
– 91%[396] of large publicly traded ammonia companies consider climate change in their decisions-making processes.

Emission focus areas for tracker

Ammonia emissions can be divided into two main categories:

1. **Energy-related emissions** primarily due to fossil fuel use to produce the required process heat and pressure for production of hydrogen.
2. **Process emissions** stem mainly from using fossil fuels as feedstock in the hydrogen production process.

Sector priorities

Exisiting assets

Reduce near-term emissions intensity by:

– Retrofitting existing fossil-fuel-based production with CCUS where access to CO_2 handling infrastructure is feasible
– Investing in CO_2 storage and transport to enable CCUS-based hydrogen production
– Adopting energy efficiency measures across existing plants.

Next generation assets

Accelerate technology and infrastructure development to drive absolute emissions reduction by:

– Investing in electrolyser plants to generate electrolysis-based green hydrogen
– Investing in sufficient clean power capacity, accelerating the maturity of methane pyrolysis and biomass gasification through pilots across lowest cost regions.

Ecosystem

De-risk capital investment to scale infrastructure capacity by:

– Investing in R&D to reduce costs, scale up the electrolyser capacity and the deployment of CCUS
– Supporting policies that stimulate demand from new applications
– Enabling infrastructure access through strategic partnerships.

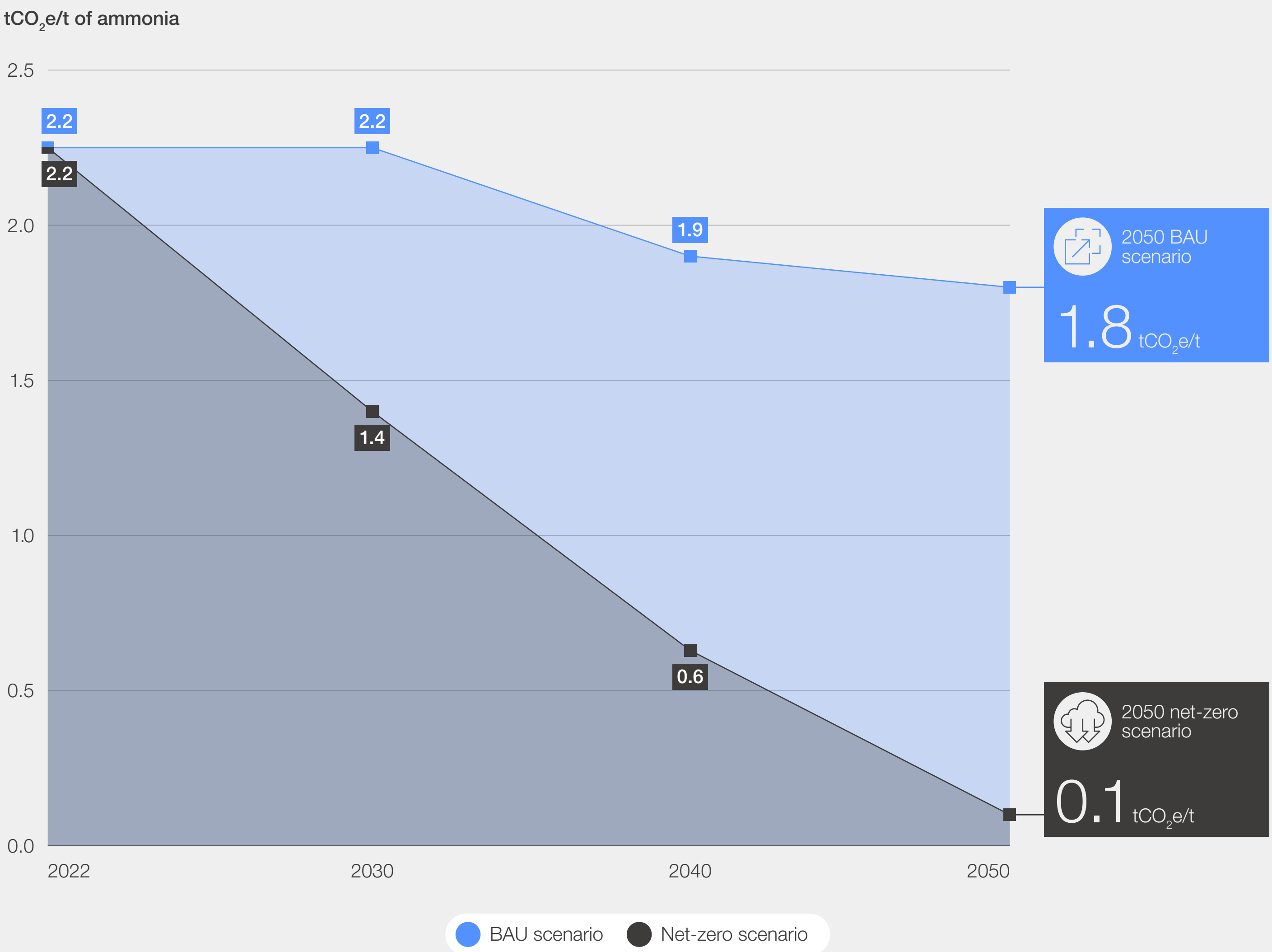
Performance

Approximately 98% of ammonia value chain emissions stem from the hydrogen production stage, which is heavily reliant on fossil fuels, particularly natural gas, for both feedstock and energy needs.[398]

Over the past five years, ammonia scope 1 and 2 emissions have plateaued at approximately 0.42 $gtCO_2$.[399] Current production processes like SMR and ATR, rely heavily on natural gas, rely heavily on natural gas and contribute to 73% of ammonia production, resulting in a high emission intensity of 2.4 tCO_2e per tonne.[400] Coal gasification, accounting for 26% of ammonia production, carries an even higher emission intensity of around 3.9 tCO_2e per tonne. To meet the industry net-zero trajectory by 2030, emissions must be reduced by 37%.[401]

The overall energy intensity of ammonia, averaging at 34 GJ/t,[402] is a function of various factors including: hydrogen production, fossil fuel use and the reaction kinetics involving high pressures and temperatures necessary to facilitate the formation of ammonia.

FIGURE 59 **Ammonia emissions intensity**

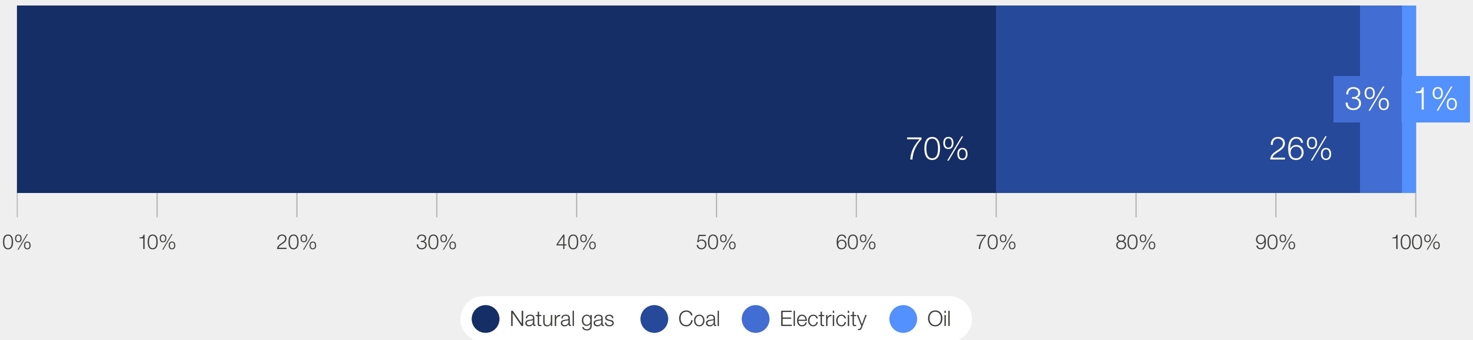


Source: IEA Ammonia Technology Roadmap

Path forward

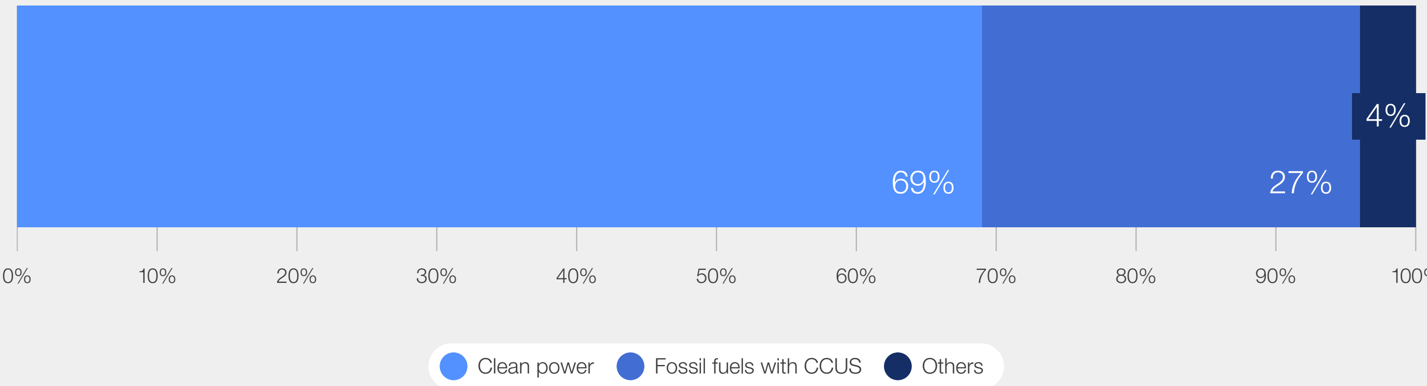
The 2050 net-zero fuel mix necessitates reducing the fossil fuel share from 99% to around 30%.[403] This transition can be primarily achieved by decarbonizing the hydrogen input, either through electrolysis-based hydrogen or CCUS-based blue hydrogen, resulting in a potential 93% reduction in cumulative emissions by 2050.[404] To achieve net zero, these pathways should be complemented by biomass-based ammonia production or methane pyrolysis.

FIGURE 60 | **2021 fuel mix**



Source: IEA Stated Policies Scenario

FIGURE 61 | **2050 fuel mix – net-zero scenario**



Source: MPP

3

AMMONIA

Technology

To decarbonize the ammonia sector, the primary pathway involves clean hydrogen production. This can be achieved through green ammonia, using electrolysis powered by clean power, or blue ammonia, which combines CCUS with existing SMR/ATR processes. The production cost increase for low-emission production can vary from 40% to over 120% depending on the production route and region.[405] Globally, SMR/ATR with CCUS is cheaper than electrolysis, though regional variations exist.

Green ammonia

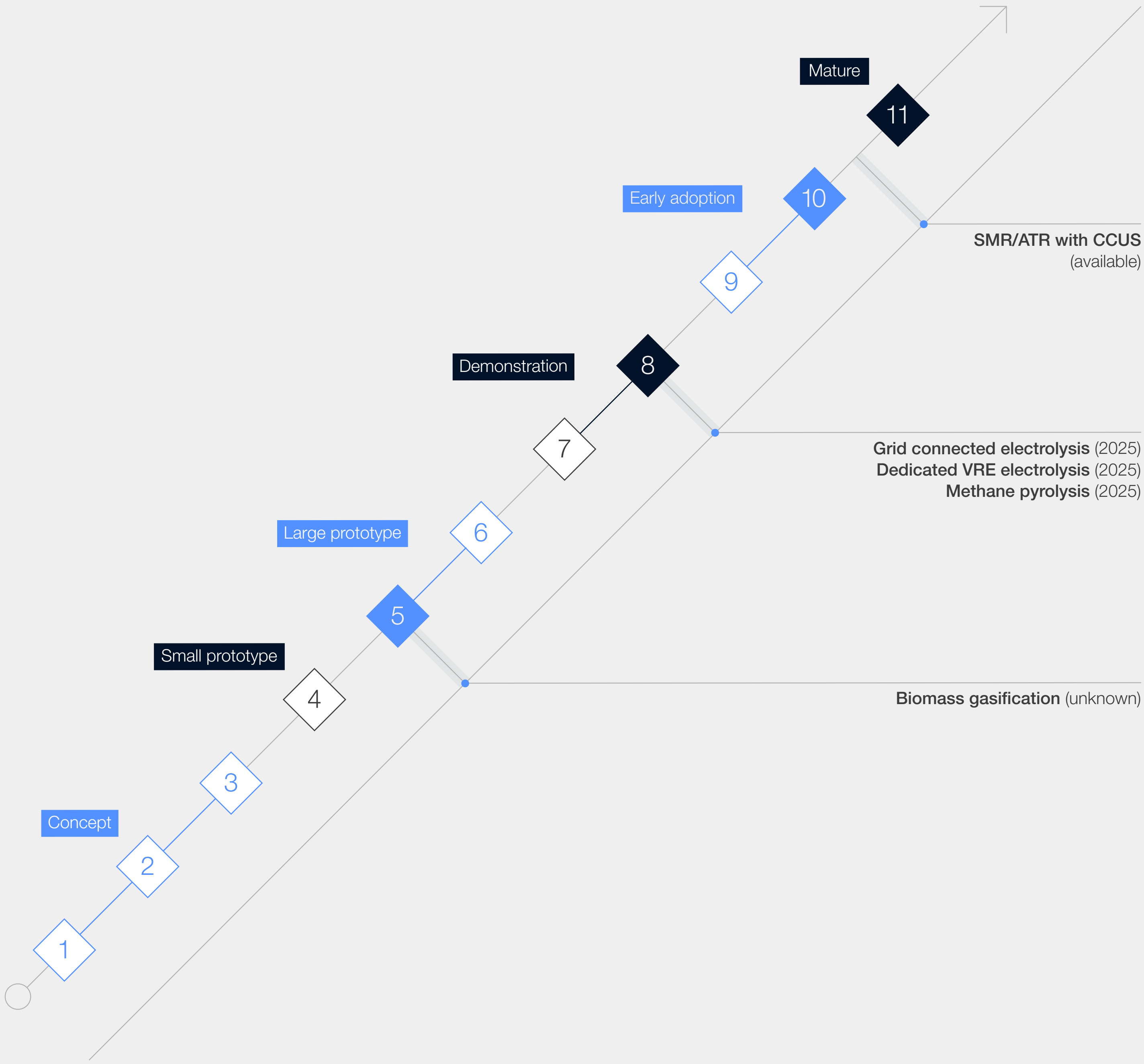
Electrolysis for hydrogen production offers a means to eliminate CO_2 emissions entirely from ammonia production and break away from fossil feedstocks. However, it is expected to be available only after 2025 and might come at a production cost increase of a minimum of 120%. The current planned electrolysis project pipeline capacity is around 180 MT, with 50% of that expected to be online by 2030.[406] Green ammonia production technologies are gaining momentum. For instance, ThyssenKrupp Industrial Solutions has developed a technology that can produce green ammonia from water, air and electricity generated from renewables using alkaline water electrolysis technology.[407]

Blue ammonia

To decarbonize fossil fuel-based ammonia production via SMR or ATR, capturing emissions through CCUS is crucial. Capture technologies like amine-based scrubbing are already established to capture rich CO_2 process streams, but technologies for capturing dilute streams need to be further advanced. Producing blue ammonia incurs a production cost increase of a minimum of 40%. Currently, around 1% of the production is blue ammonia, with a planned capacity of approximately 40 MT.[408]

The future role of supporting technologies like methane pyrolysis and biomass gasification in low-emission ammonia production remains uncertain due to technical challenges such as low hydrogen purity and biomass availability. Methane pyrolysis is expected to be commercially available by 2025, but the readiness of biomass gasification is uncertain.

FIGURE 62 **Estimated TRL and year of availability for key technology pathways**



Source: IEA

AMMONIA

Infrastructure

Meeting a three-fold increase in demand for low-emission ammonia by 2050[409] requires significant investments in clean power capacity and CO_2 handling infrastructure, estimated at $2.6 trillion.[410]

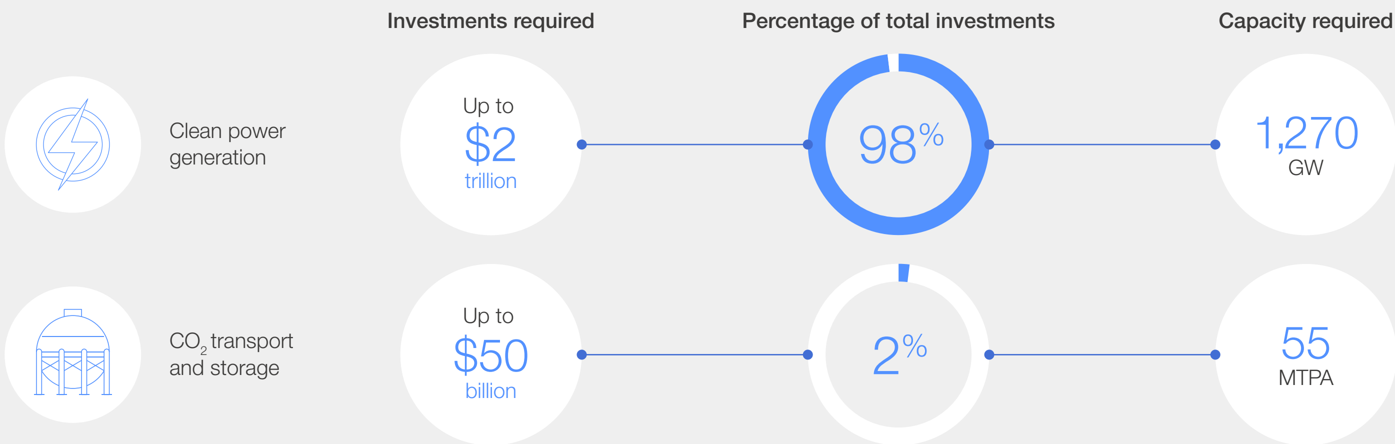
Most of these investments will be needed for clean power capacity to generate electrolysis-based green hydrogen, which will account for around 70% of ammonia in 2050.[411] To achieve this, the industry will need up to 1,320 GW of clean power capacity by 2050, equivalent to the entire generation capacity of the US.[412]

The remaining funds will be allocated for CO_2 storage and transport to enable CCUS-based hydrogen production. As technology advances and the learning curve progresses, CapEx for these infrastructure needs is expected to decrease, potentially accelerating their adoption.

Currently, technologies like methane pyrolysis and biomass gasification are projected to play a very small part in ammonia manufacturing by 2050,[413] and their infrastructure requirements remain uncertain.

The choice of technology adoption will depend on regional infrastructure availability. In regions where CO_2 transport and storage infrastructure will be affordable, technologies like SMR and ATR with CCUS will continue to scale up. Such geographies showing early promise include North America and the North Sea. Similarly, clean hydrogen may be adopted in locations where low-cost clean power sources are already accessible. For instance, ENGIE and Mitsui are collaborating on one of the world's first industrial-scale clean power-based hydrogen projects to supply feedstock to Yara's existing ammonia operations in Western Australia.[414]

FIGURE 63 **Investments required for enabling infrastructure**



Source: Accenture analysis based on multiple sources to include MPP, IEA and IRENA

AMMONIA

2 Demand

The ability of customers to absorb a green premium of 40-120% per tonne remains untested beyond prototype projects as low-emission ammonia represents less than 1% of global supply.[415]

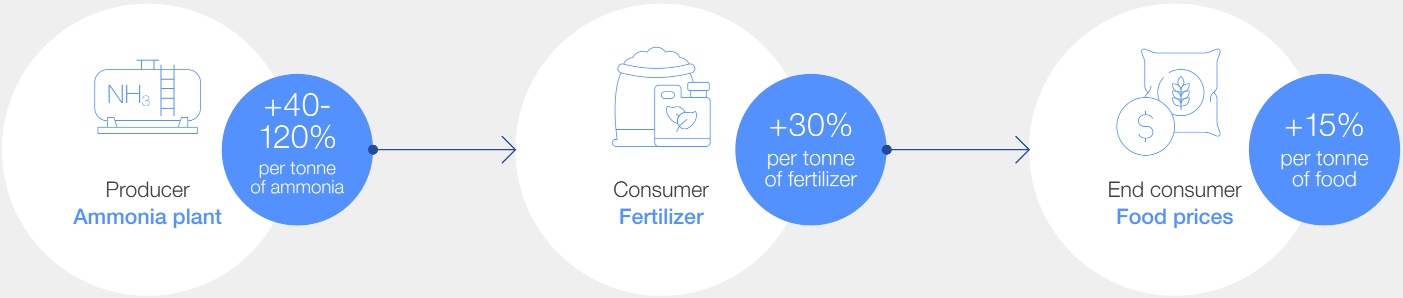
Higher fertilizer prices resulting from the added production of low-emission ammonia could lead to an increase in food prices by up to 15%, posing a risk to food security.[416] Therefore, demand for low-emission ammonia from conventional applications is likely to remain limited until policy measures, such as cross-industry subsidies, come into effect.

Embracing low-emission ammonia will have a disproportionate impact on low-income and developing countries, where fertilizer prices are more closely linked to food security.[417]

Ammonia players will need to strategically adapt to effectively address increased demand from new applications like shipping, power and hydrogen transport. This will include scaling the required low-emission production capacity and proactively securing early offtake agreements to ensure market foothold. However, several factors can impact the eventual demand for low-emission ammonia like weak regulations or availability of substitutes like availability of methanol as a shipping fuel or long-distance pipeline network to transport hydrogen.

Recent evidence indicates emerging demand signals. The first shipment of independently-certified blue ammonia has already arrived in Japan for use as fuel in power generation.[418] The ammonia was produced by SABIC Agri-Nutrients with feedstock from Aramco and sold by Aramco Trading Company to the Fuji Oil Company. Also, the launch of the new Platts ammonia forward curve is an indication of the growing interest in green and blue ammonia,[419] underscoring the increasing importance of price transparency in this sector. The absence of standardized definitions, certifications and traceability may hinder consumers from making informed decisions on paying a premium for green ammonia and limited the industry's understanding of market potential.

FIGURE 64 **Estimated B2B and B2C green premium**



Source: BloombergNEF

AMMONIA

2 Policy

Many producing regions are adopting policy measures across technology, infrastructure, demand and capital.

Public policies supporting clean ammonia production are emerging, particularly within the broader hydrogen policy landscape. However, additional policy frameworks are essential to facilitate the necessary technology and infrastructure deployment. Policies should also drive decarbonization while safeguarding food security.

These policies should promote the expansion of electrolyser manufacturing capacities and the implementation of CCUS technologies to facilitate clean ammonia production. Regulatory frameworks should encourage the growth of clean power generation and CO_2 transport and storage infrastructure.

Furthermore, policies should aim to stimulate demand for ammonia in new applications, such as a fuel in shipping or as a hydrogen carrier.

Many producing regions are beginning to adopt policy measures across the four readiness enablers, especially those with clean hydrogen consumption targets. For instance, the US and the EU have implemented encouraging policy frameworks that include innovation funds, infrastructure support and production tax credits.

Existing policy landscape

TABLE 11 **Policy summary**

Enabler	Policy type	Policy instruments	Key examples	Impact
Technology	Incentive-based	Direct R&D funds/grants	– EU Innovation Fund[420]	R&D grants of around $2 billion to green hydrogen projects, including green ammonia production projects.[421]
	Market-based	Carbon price	– EU-ETS[422]	Incentivizes ammonia producers to reduce emissions.
		Border adjustment tariff	– EU CBAM (pending implementation)[423]	Emission-intensive ammonia exporters to the EU face increased costs of compliance. Pre-Ukraine, ammonia imports to the EU amounted to 20% of total consumption.[424] Needs to be complemented by transparent and fair carbon accounting standards.
Infrastructure	Incentive-based	Direct funding support	– US funding of clean hydrogen hubs	$8 billion allocated towards the creation of hydrogen hubs across the US.[425]
Demand	Mandate-based	Industrial consumption targets	– India's green hydrogen consumption obligation policy	10% green hydrogen consumption targets for fertilizer and refining industries by 2030 – equivalent to a demand of 1.3 MTPA.[426]
		Direct targets	– RePowerEU's import targets of ammonia as a hydrogen carrier	Targets to import 4 MTPA of clean hydrogen in the form of ammonia – equivalent to a demand of 20 MTPA of ammonia.[427]
Capital	Incentive-based	Tax credits and subsidies	– IRA tax-credits for clean hydrogen production	50% reduction in clean hydrogen production costs that can boost scaling of clean hydrogen-derived ammonia.[428]

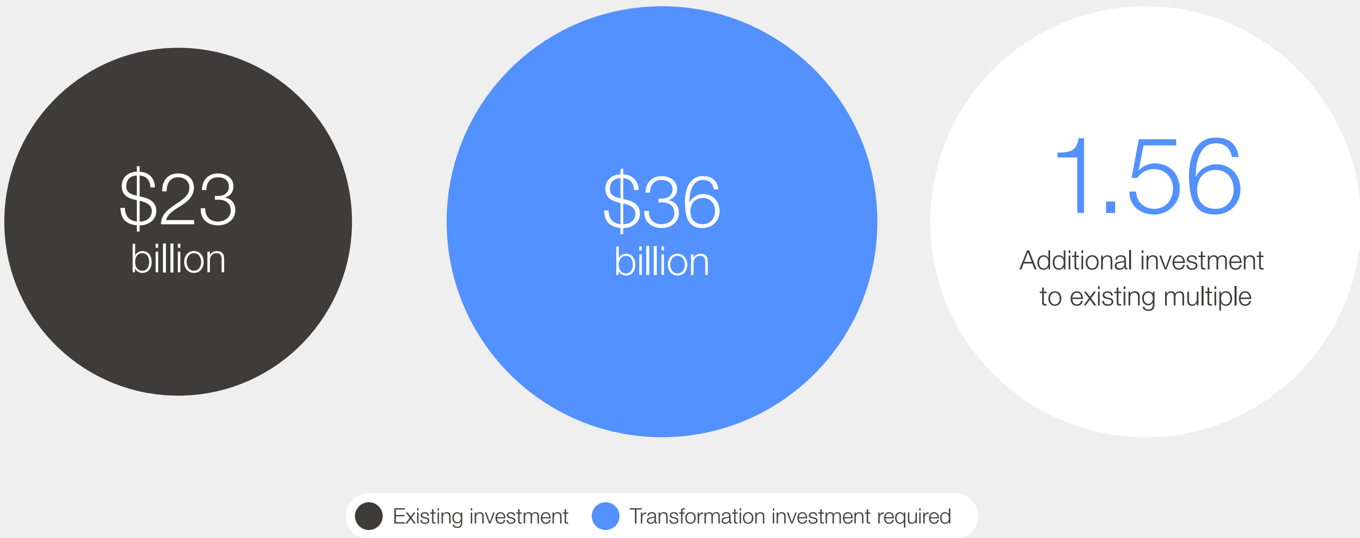
AMMONIA

1 Capital

The ammonia industry will need almost 1.5 times the amount of current investments annually to transition to low-emission assets with capital directed towards deploying electrolysers and CCUS.[429] These technologies could require cumulative investments of $970 billion by 2050. This implies annual investments of $36 billion, in addition to the regular annual CapEx of $23 billion.[430] Ammonia plants have long lifespans (up to 50 years). The current average age is around 25 years, but this varies regionally. Plants in Europe (9% of production) are around 40 years old on average and expected to witness an investment cycle in the next 10 years, so the investment should focus on low-emission assets to avoid emissions lock-in.[431]

Current industry profit margins of 21%[432] and WACC of 9%[433] suggest that the industry is not positioned to absorb these additional costs and generate sufficient returns to fund through its own generated cash flows. Some region-specific investment momentum exists. For example, Neom Green Hydrogen Company has achieved financial close on the world's largest green hydrogen production facility at a total investment value of $8.4 billion.[434]

FIGURE 65 **Additional investment required to existing investment ratio**



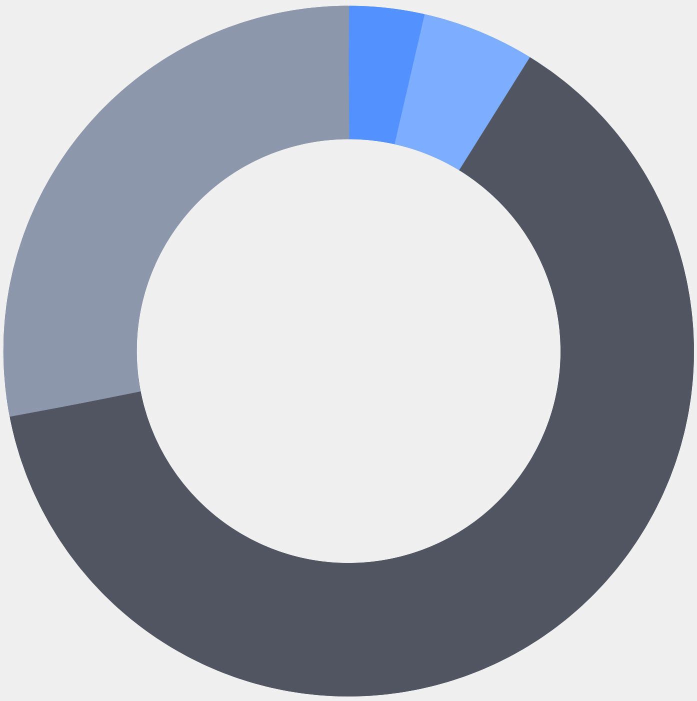
Source: Accenture analysis based on MPP and IEA data

Various financing models can be considered based on sectoral and regional context. The early investment of public funds, which could be done efficiently through development banks, could lead to faster deployment of the technologies and hence a faster decline in their cost. This could create competitive advantages to countries and regions that act fast and position themselves ahead of the curve. Regional variation in capital requirements will depend on the technology route and access to capital. Regions with low-cost CO_2 transport and storage and existing investment momentum like North America could direct capital towards deploying ammonia assets with CCUS as compared to regions with lower cost renewables, to earmark capital for electrolyser deployment.

Approximately 91% of large publicly traded companies consider climate change as a key consideration for their strategic assessment and integrate it into their operational decision-making.[435] Meanwhile, 5% of companies are building basic emissions management systems and process capabilities. Finally, 4% of companies acknowledge climate change as a business issue.

FIGURE 66

Distribution of companies in the ammonia sector according to the management of their GHG emissions and of risks and opportunities related to the low-carbon transition



0 **Level 0:** Unaware 0.0%

1 **Level 1:** Aware 3.5%

2 **Level 2:** Building capacity 5.3%

3 **Level 3:** Integrating into operational decision-making 63.2%

4 **Level 4:** Strategic assessment 28.1%

Note: Scope of data for this assessment covers chemicals companies, including ammonia.

Source: LSE-TPI Centre

9

Oil and gas industry net-zero tracker

Addressing methane and flaring emissions remain the key priority for the industry, but achieving net zero needs increased use of electrification and CCUS across the value chain.

Key emissions data[436,437, 438, 439]

15%

Contribution to global GHG emissions

5.1 $gtCO_2e$

Scope 1 and 2 emissions

-4%

Emissions growth (2018-2022)

90 $kgCO_2e$

Emissions intensity (emitted per barrel, 2022)

100%

Fossil fuels in the fuel mix (2019)

0.6 times

Expected demand increase by 2050

<1%

Current low-emission production

9-11%

Reduced emission production

Readiness key takeaways

Technology

Mature technologies like methane monitoring and mitigation, zero flaring, electrification and CCUS for gas processing face deployment limitations. Due in part to upfront costs, policy incentives, standards and infrastructure access. Low-emission refinery technologies are in early stages of development.

Infrastructure

Decarbonization of the oil and gas sector will need clean power generation capacity for electrification, CO_2 handling capacity for CCUS deployment at processing plants and refineries, and clean hydrogen generation capacity for refineries. Required investments are estimated to be up to c.$300 billion.[440]

Demand

Current green premiums remain below 10%,[441] but the market may switch to cost-competitive low-emission alternatives, particularly in developed economies.

Policy

Effective policies are vital, including incentives for low-emission tech, standards, taxation, flaring bans and R&D funding. Although major production areas have outlined emission targets, action plans and measurement, reporting and verification (MRV) guidelines, more effort is needed to turn these policies into practical, widely embraced initiatives.

Capital

The sector can invest in decarbonization by directing capital to low-emission technology, including methane reduction, electrification, CCUS and refinery transformation. Investments needed by 2050 could be up to $870 billion, about 4-6% of annual industry CapEx.[444] High levels of free cash flows could fund these investments.

Stated energy transition goals

– To align with net-zero ambitions, the industry aims for a 50% emissions intensity reduction by 2030 and 80% reduction by 2050.[442]
– 93% of large publicly traded oil and gas companies consider climate change in their decision-making processes.[443]

Emission focus areas for tracker

Oil and gas emissions can be divided into two main categories:

1. **Energy-related emissions** primarily due to energy consumption across the value chain.
2. **Process emissions** stem mainly from vented and fugitive methane emissions, gas flaring, transportation of crude oil, oil products and natural gas over long distances, and process emissions from refining.

Sector priorities

Exisiting assets

Reduce near-term emissions intensity from upstream and midstream operations by:

– Deploying available methane abatement and zero flaring technologies, supported by robust MRV standards
– Electrifying upstream and liquid natural gas (LNG) operations where feasible and enhance carbon capture gas processing
– Optimizing asset portfolios by directing capital allocation towards low-emission intensive assets.

Next generation assets

Accelerate downstream technology and infrastructure to drive absolute emissions reduction by:

– Deploying CCUS to capture carbon from rich CO_2 streams in refining
– Enabling access to clean hydrogen for heating and process application where refineries are co-located with clean hydrogen infrastructure
– Diversifying products – from traditional refining products to biofuels and synthetic fuels.

Ecosystem

De-risk investments to scale infrastructure capacity by:

– Using policy incentives for advanced technologies, while expanding access to existing infrastructure
– Progressing the technical maturity of low-emission refinery applications through R&D and pilot projects
– Deploying strategic partnerships to collaborate on technology advancement, infrastructure buildout and offtake agreements for low-emission products.

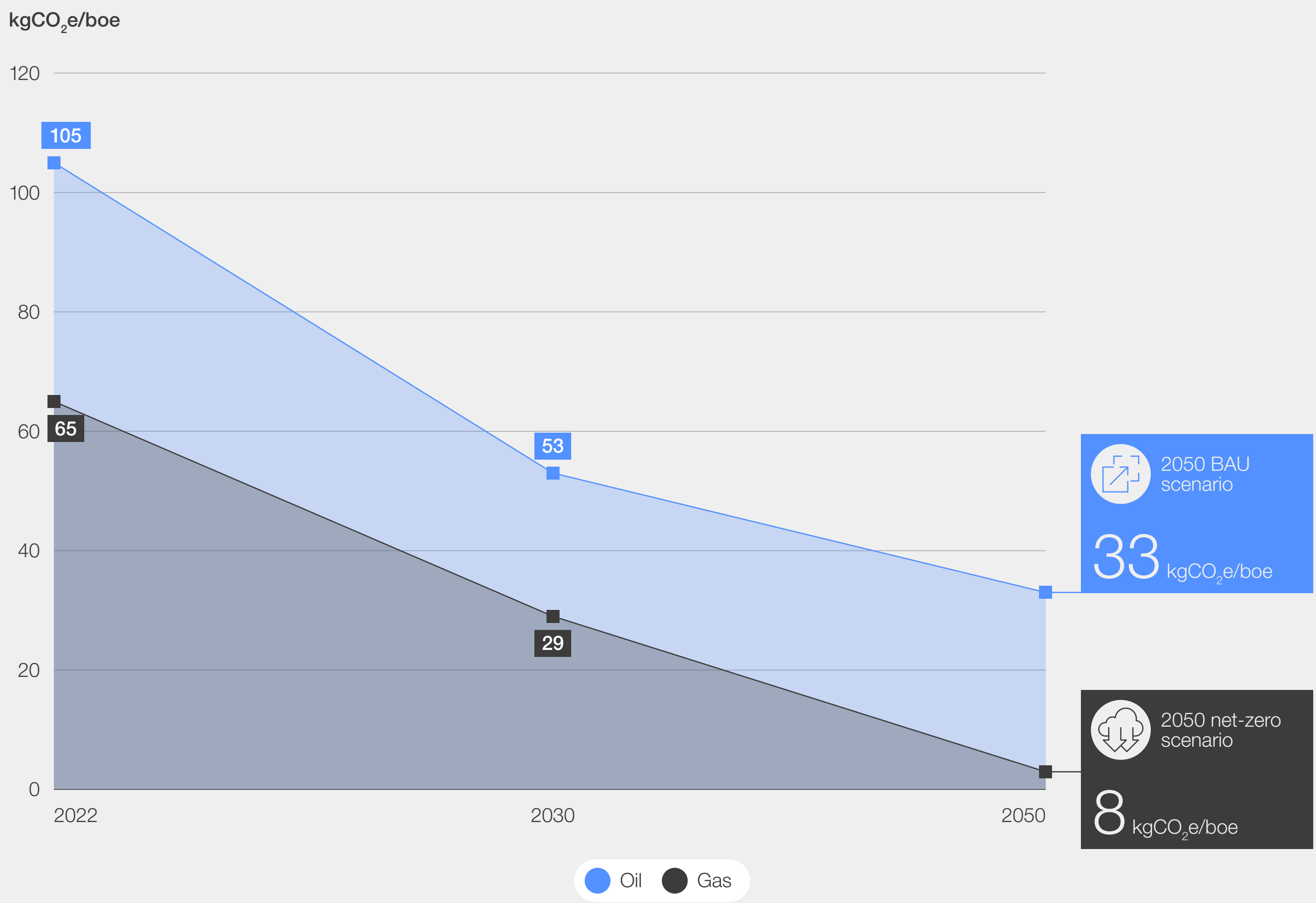
Performance

Over half of scope 1 and 2 emissions result from methane venting, fugitive emissions and gas flaring. Energy consumption across the value chain constitutes approximately 15% of the emissions, with the remaining from process emissions (refining, natural gas processing and midstream operations). Globally, the emissions intensity of operations average 90 $kgCO_2e/boe$, but this varies by operator and asset type.[445] For instance, Middle Eastern assets are, on average, 26% less emission-intensive than their North American counterparts.[446]

Methane emissions increased by 4% from 2020 to 2022 due to recovering oil and gas demand,[447] but 150 countries have pledged to reduce them by 30% below 2020 levels by 2030 under the Global Methane Pledge.[448]

Flaring emissions have dropped by 3% between 2020 and 2022, with a 12% reduction in flaring intensity (flared volume per barrel of oil produced).[449] The Zero Routine Flaring by 2030 initiative is endorsed by 35 countries and 54 oil and gas companies.[450]

FIGURE 67 **Oil and gas emissions intensity trajectory**



Source: IEA

Note: BAU projections for scope 1 and 2 emissions intensity are not available.

Path forward

To align with net-zero ambitions, the industry aims to achieve the following by 2030: a more than 50% reduction in scope 1 and 2 emissions intensity, a 75% reduction in methane emissions[451] and a 95% reduction in flaring emissions.[452] Achieving these objectives requires deploying methane abatement technologies, eliminating non-emergency flaring, electrifying oil and gas facilities, adopting CCUS in gas processing and decarbonizing refinery operations through CCUS and clean hydrogen, where possible. Energy efficiency will also be vital.

OIL AND GAS

4 Technology

Five leading decarbonization pathways have emerged to address energy and process-related emissions: methane abatement, zero gas flaring, electrification, CCUS and clean hydrogen. Methane and flaring reduction technologies, along with upstream electrification technologies, are already available with little to no cost increase. CCUS technology for gas processing operations is available with a cost increase of 7%.[453] However, refining decarbonization measures, including CCUS and clean hydrogen, are still in their early stages and are expected to raise refining costs by 7-9%.[454]

Upstream and midstream emissions abatement measures

Barriers to technology deployment include limited access to gas markets, higher upfront costs for smaller operators and the absence of technology standards.

Many methane abatement technologies, like vapour recovery units and leak detection and repair (LDAR), enable methane capture and reduction without added costs when considering the value of recovered gas. However, barriers to technology deployment include limited access to gas markets, higher upfront equipment costs for smaller operators and the absence of technology standards. These technologies also require support from effective methane detection tools and reporting guidelines. To enhance methane detection and mitigation, the UN introduced the Methane Alert and Response System (MARS) at COP27, a satellite-based system that notifies governments, companies and operators of methane leaks for faster response times.[455]

Zero-flaring techniques involve on-site gas use, treatment, storage or distribution to existing gas markets, aided by appropriate infrastructure like gas pipelines, on-site gas compression and gas reinjection. Most of this technology is available with minimal cost increase. Many major players are committed to eliminating routine flaring, as seen with Exxon's cessation of all routine flaring in their Permian operations.[456]

The electrification of oil and gas facilities reduces dependence on diesel or natural gas for energy requirements. Technologies for electrifying upstream operations and LNG processes are readily available and can be deployed with incremental production costs. For instance, bp's US shale subsidiary, bpx, has already electrified 80% of its Permian operations with the aim to increase coverage up to 95% by the end of 2023.[457] To address energy consumption and associated emissions, energy efficiency initiatives are also being explored, including energy demand optimization using digital and AI-based technologies. Some examples include the use of digital twins to optimize the power consumption of electric submersible pumps, reducing the energy consumption of turbines using analytics and data-driven asset maintenance programs to improve efficiency.[458,459]

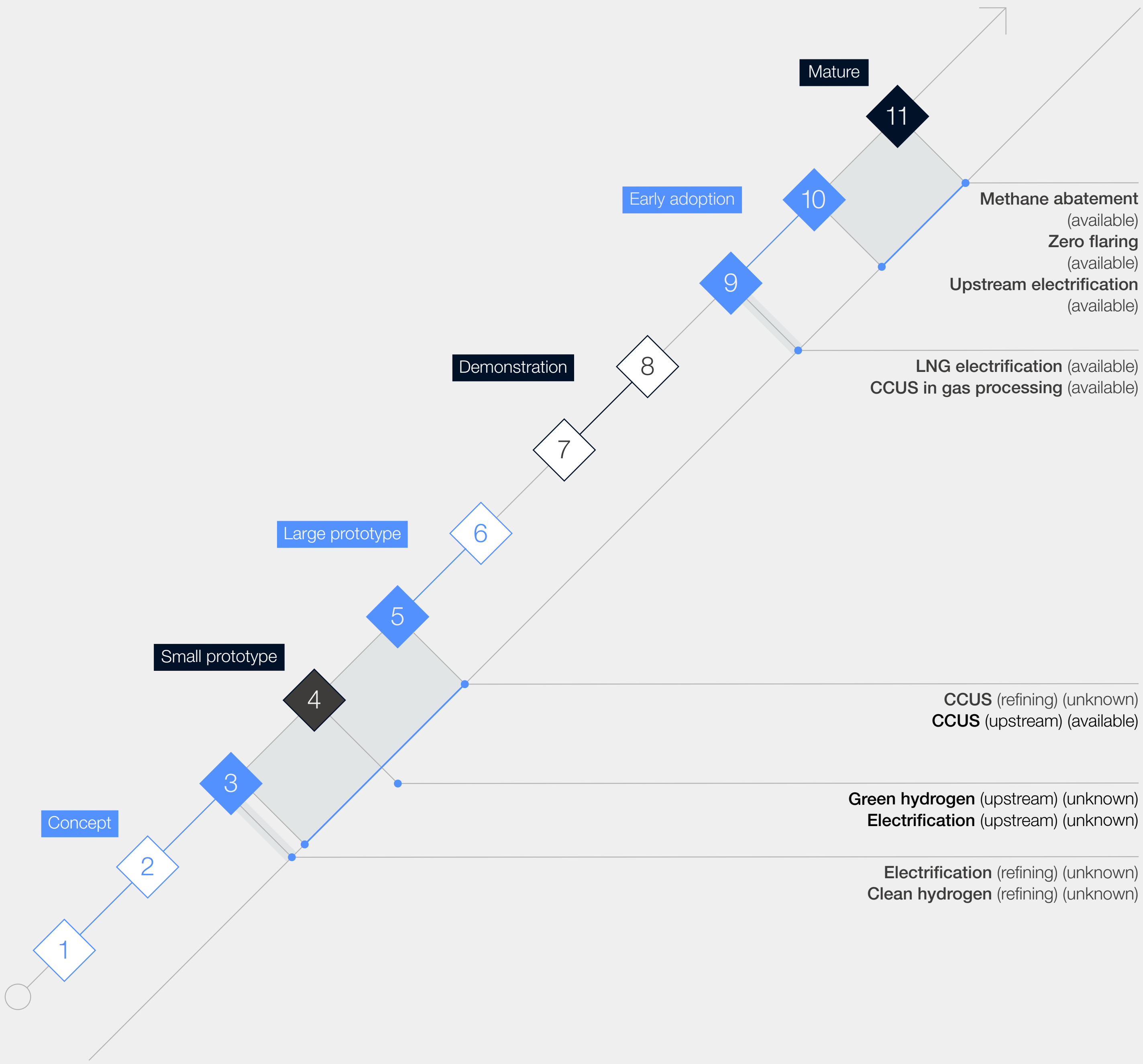
Decarbonization technologies for gas processing, such as CCUS, are commercially available, albeit with a modest 7% increase in production costs.[460]

Refining decarbonization measures

CCUS is the primary decarbonization pathway for refineries, particularly for reducing emissions from burning waste fuel gases and pet coke. Refinery hydrogen production units generate a sufficiently pure stream of CO_2, making carbon capture suitable. Additionally, emerging technologies like clean hydrogen and electrification of heat and power sources offer potential decarbonization alternatives, albeit at early stages of development.

Technology pathways

FIGURE 68 **Estimated TRL and year of availability for key technology pathways**



Source: IEA; MPP

OIL AND GAS

2

Infrastructure

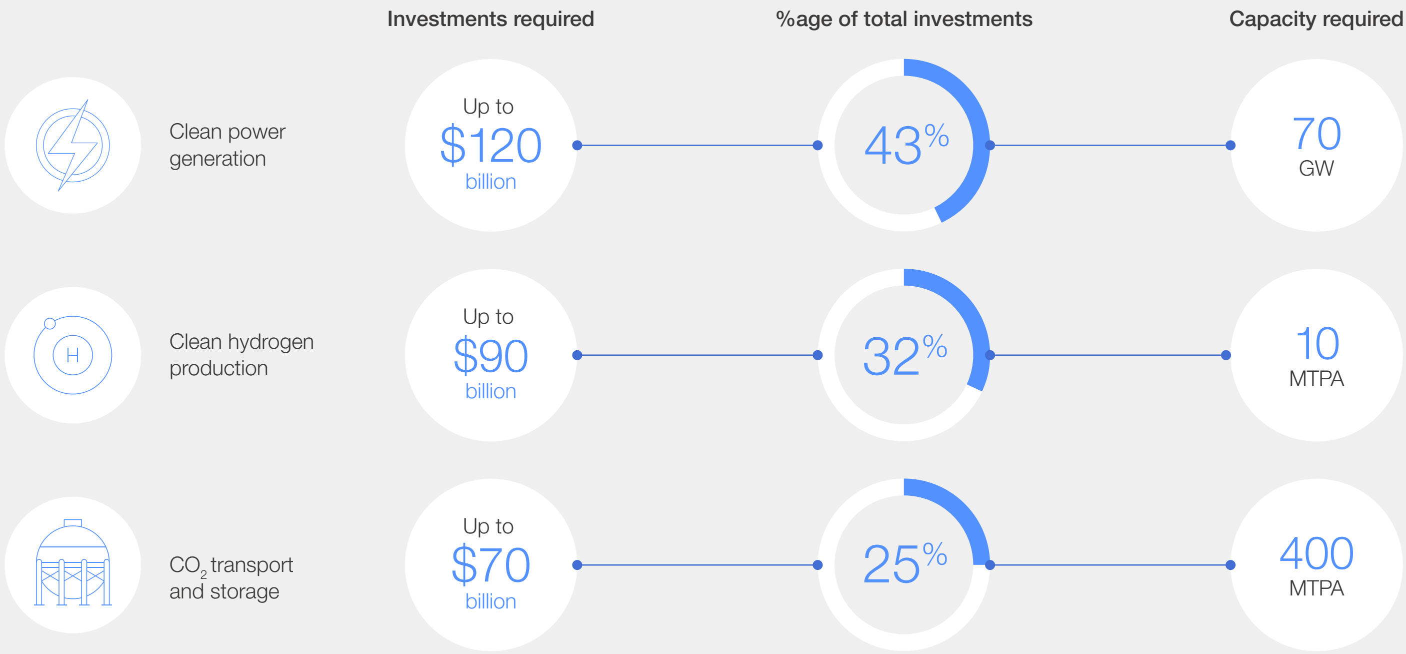
Decarbonization of the oil and gas sector relies on three key factors: the capacity of clean power generation available for facility electrification, robust CO_2 handling and storage capacity for CCUS deployment at processing plants and refineries, and clean hydrogen generation capacity for refineries. The required infrastructure investments are estimated to be up to $300 billion,[461] a figure that falls below the industry's annual CapEx. Considering the industry's experience in CCUS, natural gas and hydrogen infrastructure, and renewables position the industry as a potential leader in developing infrastructure hubs.

Electrifying production sites can be achieved through grid-sourced renewable electricity or captive power generation systems, necessitating an investment of approximately $120 billion to enable 70 GW of clean power capacity by 2050.[462]

To meet the demand for clean hydrogen in refineries, an additional 8 MTPA of clean hydrogen generation capacity is needed, requiring investments of $30-90 billion.[463]

The construction of up to 380 MTPA of CO_2 handling infrastructure is necessary, with over 50% of its capacity dedicated to managing carbon captured during gas processing, and the rest to support refineries.[464] Approximately 28 MTPA of CO_2 handling infrastructure is already in place for existing gas processing operations.[465] Building this infrastructure will require an investment of $30-70 billion.[466] Exxon's acquisition of Denbury, a provider of carbon transport and storage solutions, is a significant development that positions the company to expands its CO_2 handling infrastructure, not only for its operations but for adjacent industries like clean ammonia, clean hydrogen and synthetic transportation fuels.[467]

FIGURE 69 **Investments required for enabling infrastructure**



Source: Accenture analysis based on multiple data sources, including IEA, IRENA, BloombergNEF and Global CCS Institute

3 OIL AND GAS

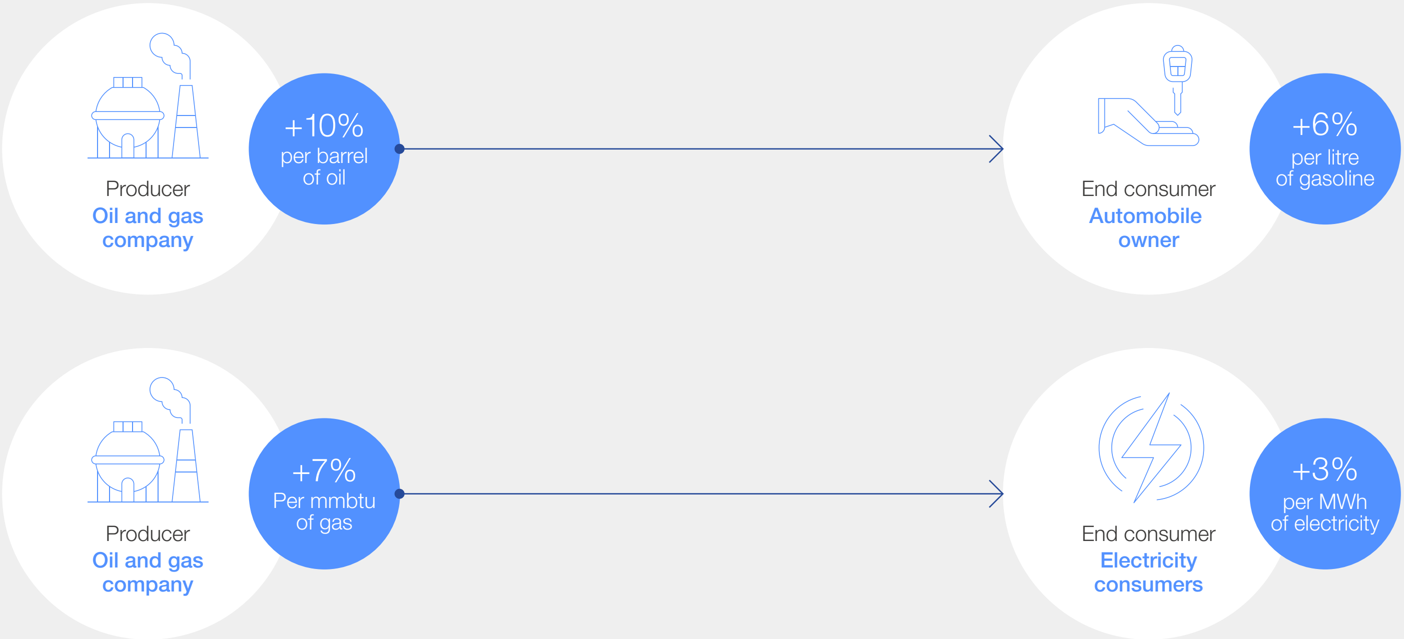
Demand

The ability of oil and wholesale gas buyers to absorb a green premium of 7-10% remains untested at scale as low-emission oil and gas represents less than 1% of global supply.[468] A 10% increase in production costs leads to 3-10% green premium for end users.[469] Historically, the market has shown limited price elasticity of demand, indicating that it can absorb the required green premiums.

Government intervention will be needed to safeguard lower-ncome households affected by rising fuel prices.

However, green premiums to end consumers will disproportionately affect developing countries and emerging economies, which are importers of oil and gas, especially without sufficient policy support.[470]

FIGURE 70 **Estimated B2B and B2C green premium**



Source: Accenture analysis based on IEA and EIA data

To achieve early breakeven and sustained demand for low-emission products, the oil and gas industry will need to identify the right market -sector clusters. Examples include petrochemical feedstock in Asian markets, heavy transport, fuel and gas as a transition fuel for power in South-East Asia. In the long term, especially in developed countries, markets will shift towards low-emission substitutes like biofuels, clean hydrogen-based fuels for transport and renewable energy for power as they become cost-competitive. There is an opportunity for oil and gas companies to also diversify as the market for these substitutes grow. For example, Shell plans to offer biofuel-based SAF for aviation customers from its Rotterdam plant by 2025.[471] Strategic collaborations with downstream consumers will also be vital as the companies diversify. A key development includes bp and car rental service provider Hertz planning to work together on installing a network of EV charging solutions in North America to service the car rental customers.[472]

Increased transparency on emissions can improve demand signals for low-emission oil and gas. Some standards, guidelines and frameworks exist currently to standardize the MRV of emissions across the oil and gas value chain. The Oil & Gas Methane Partnership 2.0 (OGMP 2.0) provides a robust, measurement-based reporting framework for industry's methane emissions.[473] The Global Reporting Initiative (GRI) Sector Standard for Oil and Gas, effective from 2023, provides a reporting framework and disclosure guidelines for sustainability topics including GHG emissions.[474] The International Group of Liquefied Natural Gas Importers' (GIIGNL) MRV and GHG Neutral Framework provides consistent definitions and emissions measurement approach for LNG cargoes. The first LNG cargo aligned to this framework was supplied by Shell to Taiwan's state refiner CPC in January 2023.[475]

Markets will shift towards low-emission substitutes like biofuels, clean hydrogen and renewable energy as they become cost competitive.

Policy

The oil and gas industry is strategically vital for regions and nations due to its role in ensuring energy security. Therefore, effective policies and regulations are crucial for decarbonizing the sector. To reach net-zero targets, a comprehensive blend of policies is essential. These policies should incentivize the adoption of zero-methane and zero-flaring technologies while promoting CCUS implementation across the oil and gas value chain. Policy tools to support this effort may include incentives for low-emission technologies, technology standards, methane MRV guidelines, methane taxation, flaring bans and R&D funding.

While key producing regions have announced emissions targets, action plans and MRV guidelines, more action is required to translate these policies into tangible implementation and widespread adoption. Countries like Norway, the US and Canada are leading the way by demonstrating ambitious policy commitments to address oil and gas emissions.

Existing policy landscape

TABLE 12 **Policy summary**

Enabler	Policy type	Policy instruments	Key examples	Impact
Technology	Mandate-based	Direct taxes/ fees	– Methane fee under the IRA[476]	Oil and gas facilities to be charged $900/tonne of methane, rising to $1,500/tonne from 2026, incentivizing legacy assets to deploy methane abatement technologies.[477]
		Targets	– Canada's target to reduce methane emissions from oil and gas[478] – Nigeria's targets to eliminate routine flaring and fugitive methane emissions[479]	Canada: reduce methane emissions oil and gas by 75% by 2030 vs 2012 level. Nigeria: elimination of routine gas flaring by 2030 and a 60% reduction in fugitive methane emissions by 2031.[480]
		National roadmaps	– National Methane Action Plan – the EU, the US, Norway and Canada[481]	Multiple policy measures including reduction targets, methane tax, MRV guidelines etc. covering methane emissions from all sectors including oil and gas. Out of over 100 countries who have signed the Global Methane Pledge, only around 30 countries have a methane action plan in place.
		MRV guidelines	– Colombia's national MRV standards[482]	Technical standards and guidelines for fugitive and flaring emissions MRV for upstream oil and gas operations.[483]
	Market-based	Carbon price	– EU-ETS[484]	Incentivizes oil refiners to reduce emissions.
	Incentive-based	International collaboration	– US and United Arab Emirates' Partnership to Accelerate Transition to Clean Energy[485]	Joint efforts to reduce methane and CO_2 across oil and gas value chain by increased investments in low-emission technologies.
Infrastructure	Incentive-based	Infrastructure capacity expansion plans	– Norway government electricity capacity upgrade targets to support electrification of LNG assets[486]	Targets grid expansion and renewables capacity by 2030 to support electrification of Norway's only LNG plant.[487]
Demand	Mandate-based	Standards and frameworks	– GIIGNL framework for GHG neutral LNG MRV[488]	Standardized MRV framework followed at international level followed by all players across the LNG value chain.
Capital	Incentive-based	Direct technology funding	– IRA methane emissions reduction programme[489]	Approximately $1.6 billion provided to US Environmental Protection Agency (EPA) to provide financial assistance to oil and gas facilities for methane reduction technology deployment.[490]

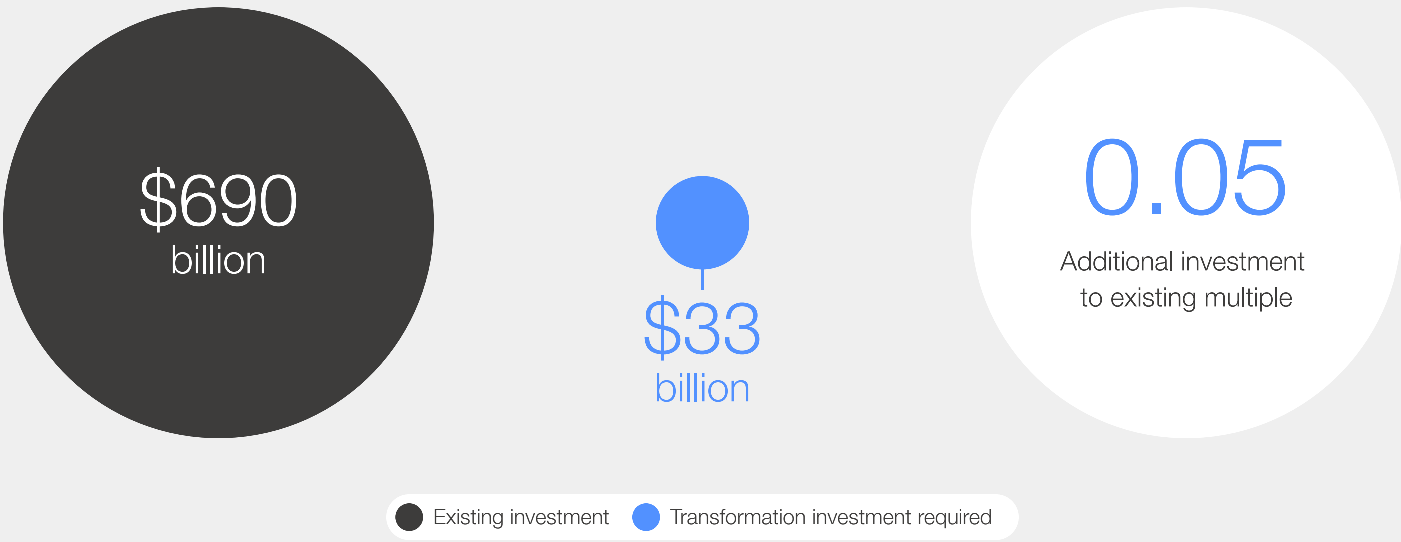
Capital

The oil and gas sector is well-positioned to invest in sectoral decarbonization. Oil and gas will need to re-direct capital towards deploying low-emission technologies across the value chain, including methane and flaring reduction technologies, upstream electrification, CCUS for gas processing and transforming refineries.[491] Investments required by 2050 can reach up to $880 billion or $32 billion in annual investments.[492] This represents only 4-6% of the total annual CapEx of the industry, and with industry average profitability of 20%[493] and WACC of 9%,[494] the industry is in a good position to fund its additional CapEx by self-generated cash flows.

For example, Petrobras plans to invest $4.4 billion in low-carbon initiatives in the upcoming five years, which represents 6% of total CapEx. Of that $4.4 billion, $2.1 billion will be invested in low-carbon solutions for new upstream projects.[495]

The business case for investment is attractive in upstream, where the sale of captured methane generates sufficient returns for investors. The business case for investing in refining needs to be strengthened, as technologies remain in the early stage and returns remain uncertain.

FIGURE 71 **Additional investment required to existing investment ratio**



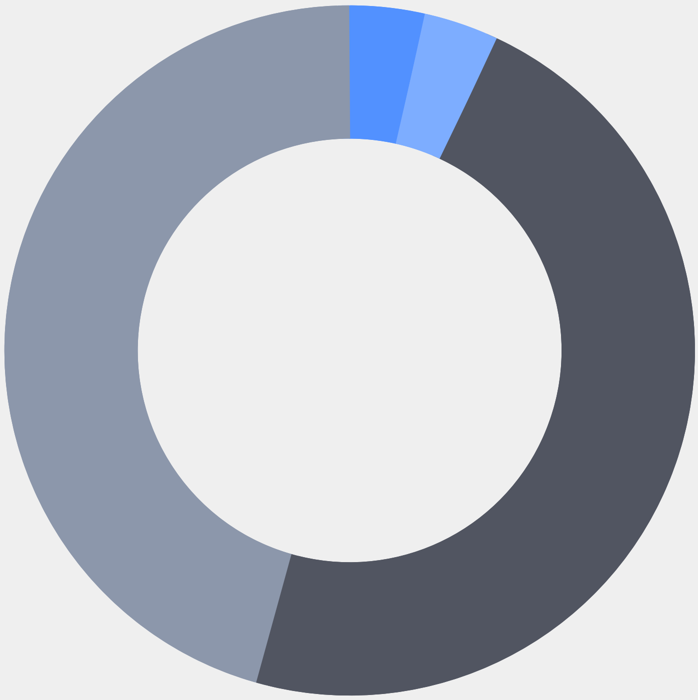
Source: Accenture analysis based on IEA, DNV, Global CCS Institute

Oil and gas supermajors, large independents and most national oil companies are well capitalized to fund their decarbonization efforts. Smaller players will rely on industrial collaboration and government support in some regions for raising the required capital. Investors and policy-makers will also play a crucial role for creating the right enabling conditions for investment. The geographic distribution of oil and gas producing nations and existing infrastructure aids the transition as CapEx need not be concentrated in a particular geography.

Approximately 92% of large publicly-traded oil and gas companies consider climate change as a key consideration for their strategic assessment and integrate it into their operational decision-making.[496] Meanwhile, 4% of companies are building basic emissions management systems and process capabilities. Finally, 4% of companies acknowledge climate change as a business issue.

FIGURE 72

Distribution of companies in the oil and gas sector according to the management of their GHG emissions and of risks and opportunities related to the low-carbon transition



0	**Level 0:** Unaware	0.0%
1	**Level 1:** Aware	3.8%
2	**Level 2:** Building capacity	3.8%
3	**Level 3:** Integrating into operational decision-making	45.3%
4	**Level 4:** Strategic assessment	47.2%

Source: LSE-TPI Centre

Conclusion

In this decade characterized by economic expansion and soaring demand for goods and transport, the paradoxical challenge of simultaneously addressing climate change and creating economic growth and resilience remains ever-present. While there is a notable increase in awareness and action within industries striving for net-zero emissions, it is apparent that none of the emissions intensive industry sectors, across production, energy and transport, is currently on course for achieving net-zero emissions by 2050, signifying that substantial challenges lie ahead.

To steer towards the path of progress, individual companies and industries must forge ahead on multiple fronts. However, it is crucial to recognize that they cannot embark on this journey in isolation. An entire ecosystem of stakeholders and factors must contribute and unite towards the common goal of making new technologies commercially viable and rapidly scaling existing ones. This requires active participation from companies throughout the value chains of supply and demand, as well as policy-makers. Aligning the essential components of demand for sustainable products, policy incentives, capital for technology investments and infrastructure expansion is the key to accelerating progress in these industries.

Industrial decarbonization stands as one of the most daunting challenges in the ongoing energy transition. Every country and industry faces the intricate task of striking a delicate balance, one that involves the need to promote domestic benefits and create quality jobs while upholding the principles of free trade and open markets. In this multifaceted endeavour, cooperation and coordinated efforts among all stakeholders, both domestic and international, will be critical to surmount the challenges and realize a sustainable, resilient and decarbonized future. While challenging, the time for action is now.

Appendices

A1 Abbreviations and acronyms

AtJ	Alcohol-to-jet	**DAC**	Direct air capture
AFIR	Alternative fuel infrastructure regulation	**DPD**	Geopost (formerly Dynamic Parcel Distribution Group)
AREC	Agence Régionale Énergie Climat	**DNV**	Det Norske Veritas
ASTM	American Society for Testing and Materials	**DRI-EAF**	Direct reduced iron-electric arc furnace
ATR	Autothermal reforming	**EAF**	Electric arc furnace
BaaS	Battery as a service	**EEXI**	Energy Efficiency Design Index
BAU	Business as usual	**EIA**	US Energy Information Administration
BECCS	Bio energy with carbon capture and storage	**EJ**	Exajoules
B2B	Business to business	**EPA**	US Environmental Protection Agency
B2C	Business to consumer	**EPD**	Environmental product declaration
BETs	Battery electric trucks	**ESG**	Environment, sustainability and governance
BF-BOF	Blast furnace-basic oxygen furnace	**ETS**	Emissions Trading Scheme
bpx	British Petroleum Exploration	**EU**	European Union
BTC	Blender's tax credit	**EU-ETS**	European Union-Emissions Trading Scheme
CALCFS	California Low-Carbon Fuel Standard	**EV**	Electric vehicle
CAJU	Clean Aviation Joint Undertaking	**FAME**	Fatty acid methyl ester
CapEx	Capital expenditure	**FMC**	First Movers Coalition
CBAM	Carbon Border Adjustment Mechanism	**FT**	Fischer-Tropsch
CCfD	Carbon Contracts for Difference	**GCCA**	Global Cement and Concrete Association
CCS	Carbon capture and storage	**GHG**	Greenhouse gas
CCUS	Carbon capture, utilization and storage	**GIIGNL**	International Group of Liquefied Natural Gas Impmorters
CII	Carbon intensity indicator	**GJ**	Gigajoule
CO_2	Carbon dioxide	**GCL**	Golden Concord Group
CO_2e	Carbon dioxide equivalent	**gCO_2**	Grams of CO_2
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation	**$g/CO_2/MJ$**	Grams of CO_2 per megajoule
CPC	Taiwan Chinese Petroleum	**gCO_2e/RPK**	Grams of CO_2 equivalent per revenue passenger kilometre
CSP	Clean Steel Partnership	**$gCO_2e/t\text{-}nm$**	Grams of CO_2 equivalent per tonne nautical mile

gCO_2e/tnm	Grams of CO_2 equivalent per tonne mile	**MPP**	Mission Possible Partnership
GPP	Green public procurement	**MRV**	Measurement, reporting and verification
GRI	Global Reporting Initiative	**MT**	Million tonnes
GSA	Global Arrangement on Sustainable Steel and Aluminium	**MTPA**	Million tonnes per annum
GT	Gigatonnes or billion tonnes	**MVR**	Mechanical vapour recompression
$gtCO_2e$	Gigatonnes of CO_2 equivalent	**OEMs**	Original equipment manufacturers
GW	Gigawatt	**PPA**	Purchase power agreements
HDT	Heavy duty trucks	**PtL**	Power-to-liquids
HEFA	Hydro processed esters and fatty acids	**R&D**	Research and development
HETs	Hydrogen electric trucks	**SAF**	Sustainable aviation fuels
IAI	International Aluminium Institute	**SCM**	Supplementary cementitious materials
IATA	International Air Transport Association	**S&P**	Standard & Poor’s
ICAO	International Civil Aviation Organization	**SMR**	Steam methane reforming
ICE	Internal Combustion Engine	**SPIC**	Chinese State Power Investment Company
ICS	International Chamber of Shipping	**SSAB**	Swedish Steel (Svenskt Stål AB)
ICCT	International Council on Clean Transportation	**TCO**	Total cost of ownership
IDDI	Industrial Deep Decarbonisation Initiative	**t**	Tonnes
IEA	International Energy Agency	**tCO_2**	Tonnes of carbon dioxide
IMO	International Maritime Organization	**tCO_2e**	Equivalent tonnes of carbon dioxide
IRA	Infrastructure Investment and Jobs Act	**tCO_2e/t**	Tonnes of CO_2 equivalent per tonne of output
JV	Joint venture	**TEN-T**	Trans-European Transport Network
kg	Kilograms	**TRL**	Technology readiness level
$kgCO_2e$/boe	Kilograms of CO_2 equivalent per barrel of oil equivalent	**UN**	United Nations
LCAF	Low-carbon aviation fuel	**US**	United States
LDAR	Leak detection and repair	**VRE**	Variable renewable energy
LME	London Metal Exchange	**WACC**	Weighted average cost of capital
LNG	Liquified natural gas	**WRI**	World Resources Institute
LSE-TPI	London School of Economics Transition Pathway Initiative	**ZEF**	Zero emission fuels
MARS	Methane alert and response system	**ZET**	Zero-emission trucks
MoU	Memorandum of understanding	**ZEV**	Zero emission vehicles

A2 Mission and methodology

An adapted version of the performance framework has been developed to account for variance in reporting requirements for the transport sector. The transport sector framework will account for greenhouse gas (GHG) emissions in the operational and fuel supply value chains against 2050 targets.

The 2023 iteration of the framework for production sectors remains the same.

FIGURE 73 **The Net-Zero Industry performance framework**

Track progress of the **four drivers** of **industry net GHG emissions:**

Track progress of the **four drivers** of **industry net GHG emissions:**

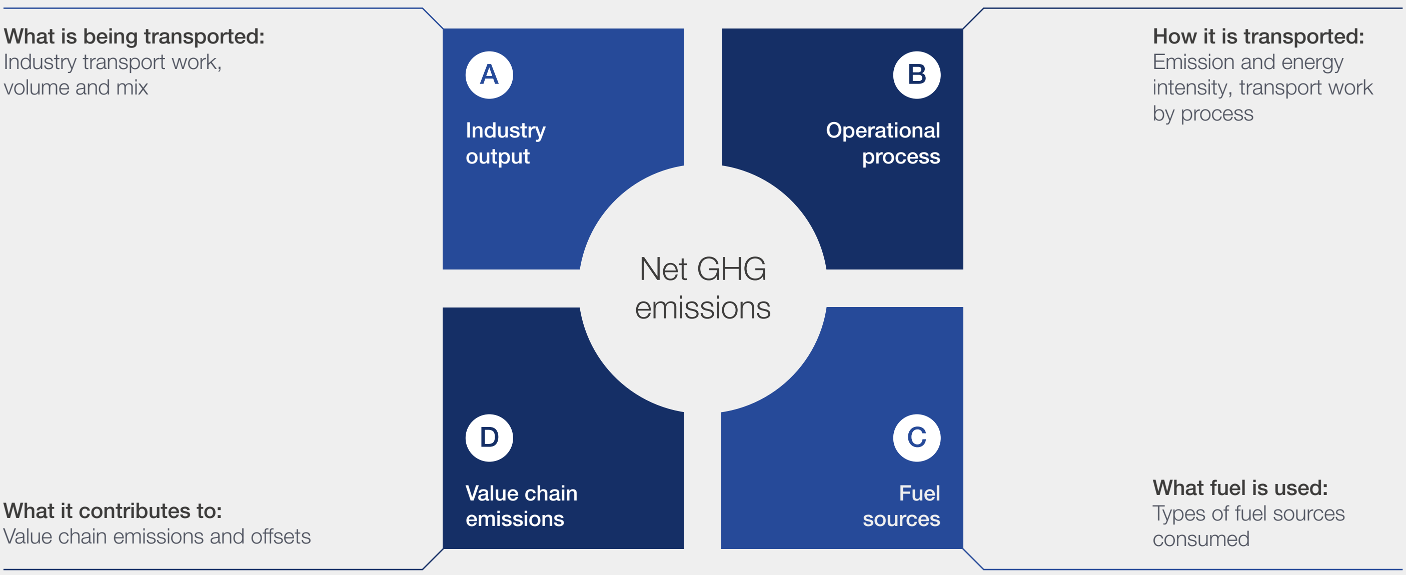


TABLE 13 | **Criteria for assessing readiness stages of transformation enablers**

Technology	Infrastructure	Demand	Policies	Capital
Availability of technology – Technology options for low-emission production – Technology emission abatement potential – Technology readiness level (TRL) – Technology maturity timeline – Competitiveness of technology – Technology impact on production cost – Technology deployment – Technology adoption/ deployment	**Infrastructure requirements** – Infrastructure capacity required by 2050 – Infrastructure investments required by 2050 – Infrastructure deployment – Infrastructure deployment level	**Market dynamics** – Size of market – Historical price volatility – Price elasticity of demand – Availability and scalability of substitutes – Green premium for direct customers/ wholesale customers – Green premium for end consumers – Business model readiness – Standards and traceability of low-emission products – Availability of low-carbon substitute in the market – Effective green demand – Market share of low-emission products – Volume and strength of demand signals (e.g. regulation, public procurement)	**Industry-/product-specific policies** – Product specification standards – Product use standards – Public procurement standards – Product emission regulation/penalties – Impact of existing policies – Coverage of existing policies – Policy gaps – Competitiveness of technology – Carbon pricing – Carbon border adjustment mechanisms – Emission regulation – Public regulation – Public action/projects – Tax breaks – Subsidies	**Ability to attract capital** – Availability of adequate taxonomy – Profitability/level of returns – Cash availability – Credit rating – Cost of capital – Environment, sustainability and governance (ESG) rating – Expected returns as a differentiated product – Capital deployment – Scale of investments needed – Number of projects invested – Amount of green capital expenditure (CapEx) – Amount of green bonds – Amount of R&D investments – Amount of venture capital investments – Amount of government funding – Risk to early investors – Geographic distribution of assets

A3 Data sources

Methodology sources

Aluminium Stewardship Initiative (ASI)

BloombergNEF (BNEF)

Commodities Research Unit (CRU)

First Movers Coalition

Global CCS Institute

Global Cement and Concrete Association (GCCA)

Global Maritime Forum

International Air Transport Association (IATA)

International Aluminium Institute (IAI)

International Council on Clean Transportation (ICCT)

International Energy Agency (IEA)

Transition Pathway Initiative Centre, London School of Economics and Political Science (LSE-TPI Centre)

Mission Possible Partnership

Standard & Poor's Global (S&P Global)

World Steel Association

Other data sources

Accenture

Air Transport Action Group (ATAG)

ABB

Biogasworld

Breakthrough Energy

Det Norske Veritas (DNV)

Drive to Zero

Ember

Energy Information Administration (EIA)

Energy Transitions Commission (ETC)

European Cement Research Academy (ECRA)

European Maritime Safety Agency (EMSA)

Financial Times

Food and Agriculture Association of the United Nations (FAO)

Fortune Business Insights

Georgia Institute of Technology

Green Steel

Holcim

Industry Tracker

International Civil Aviation Organisation (ICAO)

International Gas Union (IGU)

International Maritime Organization (IMO)

International Renewable Energy Association (IRENA)

Maersk McKinney Moller Center for Zero Carbon Shipping (MMM)

National Institute of Statistics and Economic Studies (INSEE)

NYU Stern

Refinitiv

Rocky Mountain Institute (RMI)

Royal Dutch Shell (Shell)

Rystad

Sea-LNG

Sustainable Gas Institute (Imperial College London)

Swedish Steel (SSAB)

The Geography of Transport Systems

Organisation for Economic Cooperation and Development (OECD)

United Nations Conference on Trade and Development (UNCTAD)

United States Geological Survey (USGS)

University of Wyoming

US Department of Energy

Valero Energy

Verifavia

WoodMackenzie

World Bank

Contributors

Project team

Accenture

Muqsit Ashraf
Global Strategy Lead

Sagnik Dey
Consultant, Strategy and Consulting, Energy

Sagar Kalra
Consultant, Strategy and Consulting, Energy

Jade Oakley
Consultant, Strategy and Consulting, Energy

David Rabley
Managing Director and Global Energy Transition Lead, Energy

Samiksha Srivastava
Consultant, Strategy and Consulting, Energy

Francesca Tate
Manager, Strategy and Consulting, Energy

World Economic Forum

Mohammed Algeer
Project Fellow, Centre for Energy and Materials

Laia Barbarà
Acting Head, Climate Strategy

Roberto Bocca
Head, Centre for Energy and Materials; Member of the Executive Committee

Vladimir Borodin
Specialist, Airports of Tomorrow

Espen Mehlum
Head, Energy Transition Intelligence and Regional Acceleration, Centre for Energy and Materials

Sarah Moin
Programme Analyst, Centre for Energy and Materials

Renée Van Heusden
Head, Oil and Gas Industry

Harsh Vijay Singh
Manager, Energy and Industry Transition Intelligence, Centre for Energy and Materials

Thibault Villien De Gabiole
Lead, Industry Decarbonization, Trucking

Production

Laurence Denmark
Creative Director, Studio Miko

Sophie Ebbage
Designer, Studio Miko

Martha Howlett
Editor, Studio Miko

George Messer
Designer, Studio Miko

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Advisory Board Members

Morgan Bazilian
Professor of Public Policy and Director, Payne Institute, Colorado School of Mines

Lin Boqiang
Dean, China Institute for Studies in Energy Policy, Xiamen University

Michaela Campanelli
Head, Climate Strategy, Risk Mitigation and Disclosure, Eni

Lucy Craig
Director, Innovation and Digitalization, DNV

Rabia Ferroukhi
Director, Knowledge, Policy and Finance Centre, International Renewable Energy Agency (IRENA)

Bertrand Magne
Senior Economist, European Investment Bank (EIB)

Davide Puglielli
Head, Scenario Planning and Group Strategic Positioning, Enel

John Scott
Head, Sustainability Risk, Zurich Insurance

Fridtjof Unander
Chief Economist, Aker Horizons

David Victor
Professor of Innovation and Public Policy, University of California, San Diego (UCSD)

Rigoberto Ariel Yepez-Garcia
Manager, Infrastructure and Energy Sector, Inter-American Development Bank (IDB)

Experts

Katrina Abhold
Senior Project Manager, Decarbonisation, Global Maritime Forum

Domagoj Baresic
Research Fellow, University College London (UCL)

Hussein Basma
Researcher, Heavy Duty Vehicles, International Council on Clean Transportation (ICCT)

Chris Bayliss
Director, Standards, Aluminium Stewardship Initiative

Robert Boyd
Global Sustainability Policy and Partnerships, Boeing

Clare Broadbent
Head, Communications, World Steel Association

Antonio Carillo Dobaldo
Head, Climate and Energy, Holcim

Albert Cheung
Deputy Chief Executive Officer and Head, Global Transition Analysis, BloombergNEF

Claire Curry
Global Head of Technology, Industry and Innovation, BloombergNEF

Kelly Driscoll
Research Manager, CRU

Asa Ekhdahl
Head, Environment and Climate Change, World Steel Association

Cederic de Meeus
Vice-President, Group Public Affairs and Government Relations, Holcim Group

Elisabeth Fauvelle Munck af Rosenschold
Global Sustainability Manager, IKEA Supply AG

Araceli Fernandez
Head, Technology Innovation Unit, International Energy Agency (IEA)

Samuel Flückiger
Head, EU Climate Policy, ThyssenKrupp

Andrew Gadd
Principal Marketing Sustainability Projects, BHP

Al-Karim Govindji
Global Head, Public Affairs, Energy Systems, DNV

Thomas Guillot
Chief Executive Officer, Global Cement and Concrete Association (GCCA)

Natalie Gupta
Director, Bunkering, Value Chain Partnerships, Yara Clean Ammonia, Yara

Max Held
Manager, Systemiq

Jaakko Kooroshy
Global Head of Sustainable Investment Research, FTSE Russell

Atul Kulkarni
Senior Analyst, CRU

Shivakumar Kuppuswamy
Development and Innovation Director, Responsible Steel

Claude Lorea
Innovation and ESG Director, GCCA

Matthew Loughrey
Principal Technology Consultant, Global CCS Institute

Owen MacDonnell
Technical Project Manager, Calstart

Oskar Meijerink
Head, Future Fuels, SkyNRG

Alex Menotti
Vice-President, Government Affairs, Policy and Sustainability, Lanzajet

Andrew Minson
Director, Concrete and Sustainable Construction, GCCA

Frederic Nyssen
Director, Net Zero Priorities and Opportunities, BASF

Ludimilla Ospova
Researcher, ICCT

Katherine Palmer
Shipping Lead, Climate Champions

Andrew Purvis
Director, Sustainable Manufacturing, World Steel Association

Xavier Sara
Senior Manager, Scouting, BASF

Andrew Spencer
Vice-President Corporate Affairs, Sustainability and Enterprise Risk, Cemex

Luke Stafford
Manager, Government Relations and Regulatory Strategy, London Stock Exchange Group (LSEG)

Meg Whitty
Vice-President, Marketing and Corporate Relations, Lanzajet

Andrew Wood
Director, Sustainable Investment and Legal, Aluminium Stewardship Initiative

Alex Zapantis
General Manager, External Affairs, Global CCS Institute

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World Economic Forum
91–93 route de la Capite
CH-1223 Cologny/Geneva
Switzerland

Tel.: +41 (0) 22 869 1212
Fax: +41 (0) 22 786 2744
contact@weforum.org
www.weforum.org