Decarbonization Lever Library

Mapped Sectoral Transition Pathways

November 2025

BSR®

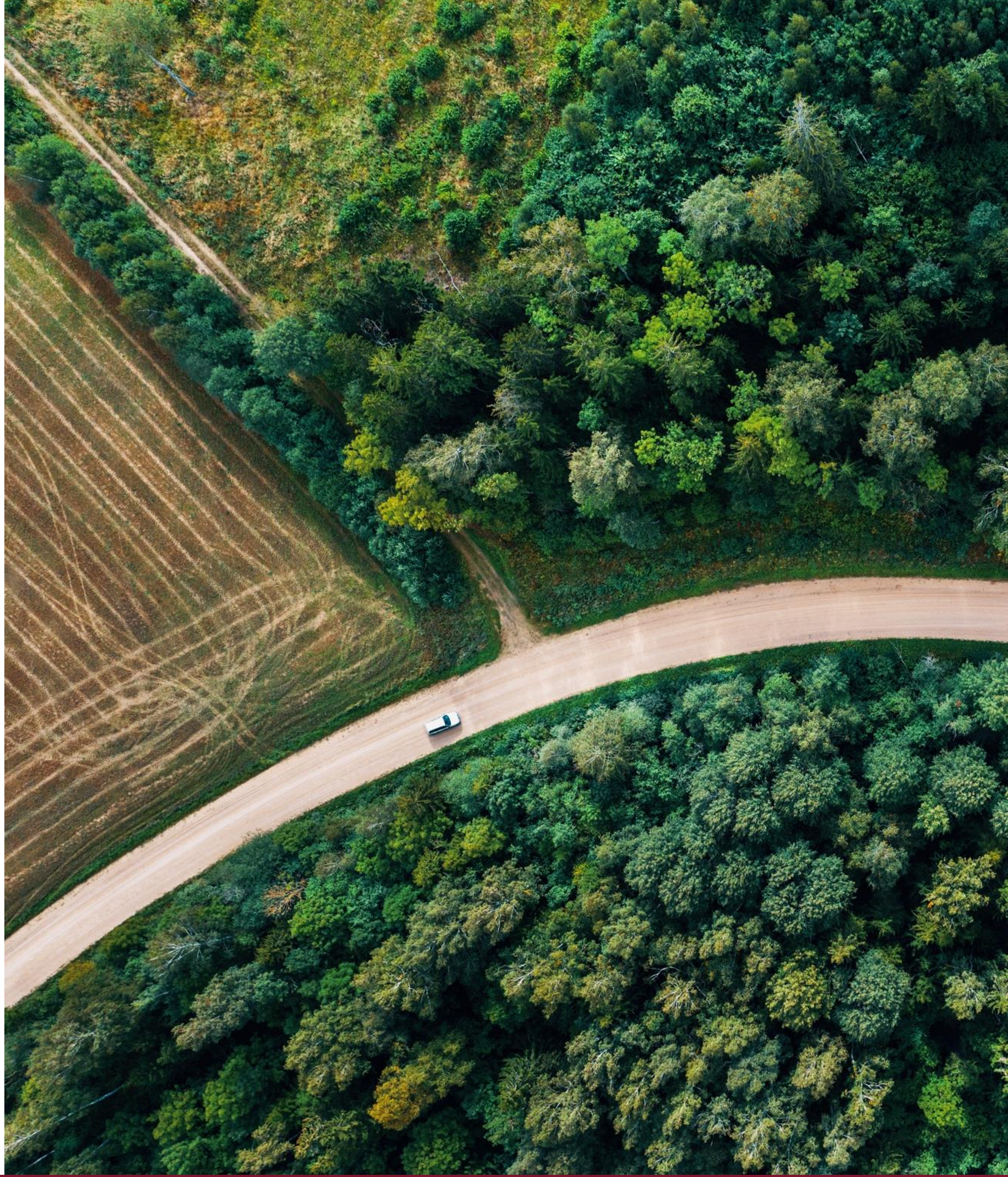
Contents

Acknowledgements

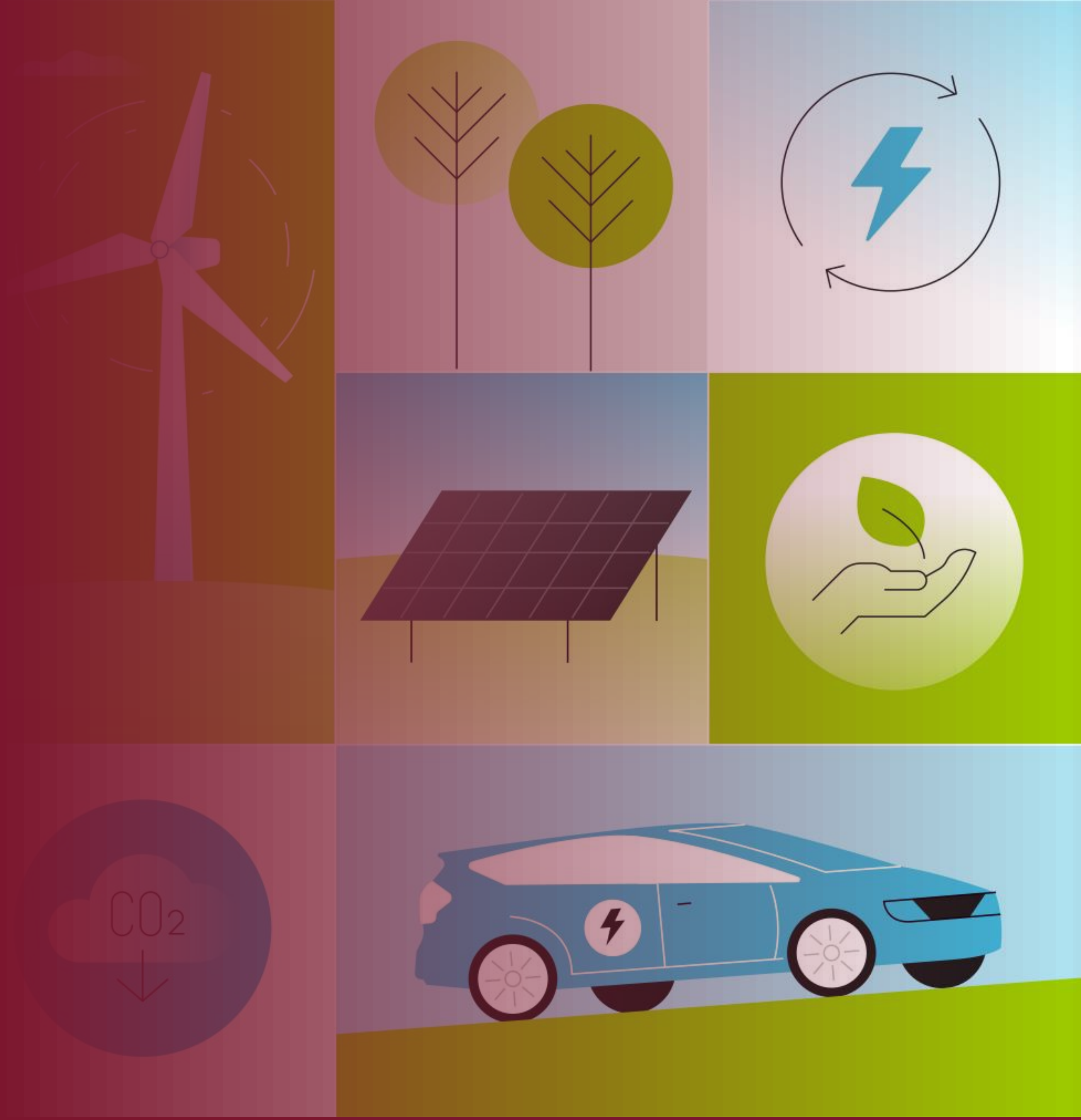
The following toolkit was developed by BSR, a sustainable business network and consultancy focused on creating a world in which all people can thrive on a healthy planet. The perspectives expressed solely reflect the views of BSR and the authors and have been informed by desktop research, insights, and discussions.

This document was authored by Saad Khan, Nina Hatch, and Ameer Azim. Additionally, the authors thank colleagues at BSR for their support in the creation of this guidance. Any errors that remain are those of the authors. Please direct comments or questions to BSR.

This guidance contains research, findings, and insights to support companies in their climate transition. The content may be revised as the context and topic, company action on climate transition, and stakeholder expectations evolve and advance.



01
Introduction



Business Benefits of Net Zero

Successful transition strategies have embedded strategic enterprise benefits beyond the goal of corporate responsibility. Businesses can mitigate transitionary climate risks related to their emissions and energy use, develop new products and technologies that take advantage of the broader transition, comply with global regulations, and meet expectations from key stakeholders, fostering brand and organizational loyalty.

Mitigate Climate Risk

Unless the world acts today to dramatically curb emissions, we will face severe impacts from climate change with severe risks to business.

Reduction in emissions is critical for continued business and economic success.

Comply with Regulation

Global leaders are taking decisive action to curb emissions that put substantial compliance burden and cost on companies. Those businesses making credible commitments and taking proactive action to design solutions will have the opportunity to get ahead of regulation and their competitors.

Meet Stakeholder Expectations

There will continue to be growing interest from investors, customers, employees, and other critical stakeholders to reach net zero. Those who do not take credible and legitimate action will increasingly be left behind.

Business Transformation

There is an immediate opportunity for business to be a key player in the transition economy, including being a first-mover in a world that is facing stagnating economic growth, meeting new market needs and capturing new customers, and building resilience in face of competition for transition technology.

Companies that focus on business transformation and enabling systemic change, including through the promotion of Just Transition principles, will have the chance to capture these opportunities and gain market share, setting them up for long-term resilience.

How to Use this Resource

- This guidance presents decarbonization levers critical to the energy transition, mapped to sectors where they are most applicable.
- The decarbonization levers and technologies presented here apply first to the underlying activities that generate emissions, rather than to sectors themselves.
- To use this resource effectively, begin by examining your own inventories to identify the key sources of emissions and the activities that drive them.
- Once those activities are clear, map them to the relevant technologies and decarbonization levers.
- From there, navigate to the sector pages where the application of those levers is most typical and prevalent for business-model context.
- Finally, explore and discuss how the technology can be deployed in the specific context of your company, considering operational realities, financial planning, and external dependencies, to inform a credible, actionable transition plan.

Principles	Ambition	Action		Accountability	
Disclosure elements	1. Foundations	2. Implementation Strategy	3. Engagement Strategy	4. Metrics & Targets	5. Governance
	1.1 Strategic Ambition 1.2 Business model and value chain 1.3 Key assumptions and external factors	2.1 Business operations 2.2 Products and services 2.3 Policies and conditions 2.4 Financial planning	3.1 Engagement with value chain 3.2 Engagement with industry 3.3 Engagement with government, public sector, communities, and civil society	4.1 Governance, engagement, business and operational metrics and targets 4.2 Financial metrics and targets 4.3 GHG metrics and targets 4.4 Carbon credits	5.1 Board oversight and reporting 5.2 Management roles, responsibilty and accountability 5.3 Culture 5.4 Incentives and remuneration 5.5 Skills, competencies and training

- The **Transition Plan Taskforce** **provides** the above framework, consisting of three guiding principles (Ambition, Action, and Accountability), and five elements (Foundations, Implementation Strategy, Engagement Strategy, Metrics & Targets, and Governance), which make up a high-quality public transition plan.
- This **tool offers support with the 'Action' element**, by providing a mapping of decarbonization levers to business operations, highlighting how they may be integrated into financial planning, and providing guidance on outward dependencies and impacts that should be actively managed to achieve a successful transition.

The Industry Sectors

The sectors were identified by considering the standard list of S&P 500 sectors alongside those that are highly relevant to the climate transition, as identified by the International Energy Agency (IEA).

Each industry slide includes key decarbonization levers that may be relevant to the industry as a whole.

Companies can explore potential decarbonization levers by navigating to their industry. This is not exhaustive but can serve as directional guidance for most companies within the sector.

Additionally, a company should consider their broader GHG inventory. If your company is reliant on another industry for business success (e.g., you ship your goods via maritime shipping) or operates in the intersection of multiple sectors, you may also navigate to additional industry slides to explore what decarbonizing your supply chain could entail when evaluating the diversified segments of the business.

The Levers

The decarbonization levers were identified considering credible net-zero scenarios, taxonomies, and BSR research and expertise.

Information	Details
Range of costs to implement the technology	Each lever highlights a range of potential costs for implementation, looking at sub-technologies. Utilize this information to help explore potential financial implications of transition technologies.
Mitigation potential of the technology	Each technology is evaluated for the scale of decarbonization possible, expressed in intensity-linked emissions savings
Key dependencies and external factors for lever success	The success of each technology may hinge on external factors and key dependencies. This information will help companies with climate transition plan disclosure, while providing an understanding of what likely needs to be true for success.
Key impacts on nature and people related to lever implementation	Lever implementation may come with negative impacts on nature and people. This information will help companies better understand actual and potential impacts to people and nature, mitigate harm, and develop proactive strategies for providing remedy if needed.
Net Zero 2050 Pathway	A description of the pathway to a successful net-zero state in 2050, considering individual industry dynamics and key dependencies and hurdles.

Electricity and Energy

- Bioenergy
- Energy and Electricity Storage
- Geothermal
- Low Emission Hydrogen
- Grid Technologies and Modernization
- Hydropower
- Nuclear
- Solar
- Wind

Transport

- Light-Duty and Micromobility
- Maritime Decarbonization
- Aviation Decarbonization
- Freight Decarbonization
- Public Transport

Industry

- Low Carbon Cement
- Low Carbon Steel
- Low Carbon Aluminum
- Chemicals
- CCUS

Buildings

- Efficient Fixtures
- Building Envelopes
- Data Center Cooling
- Refrigerants
- Efficient Heating and Cooling

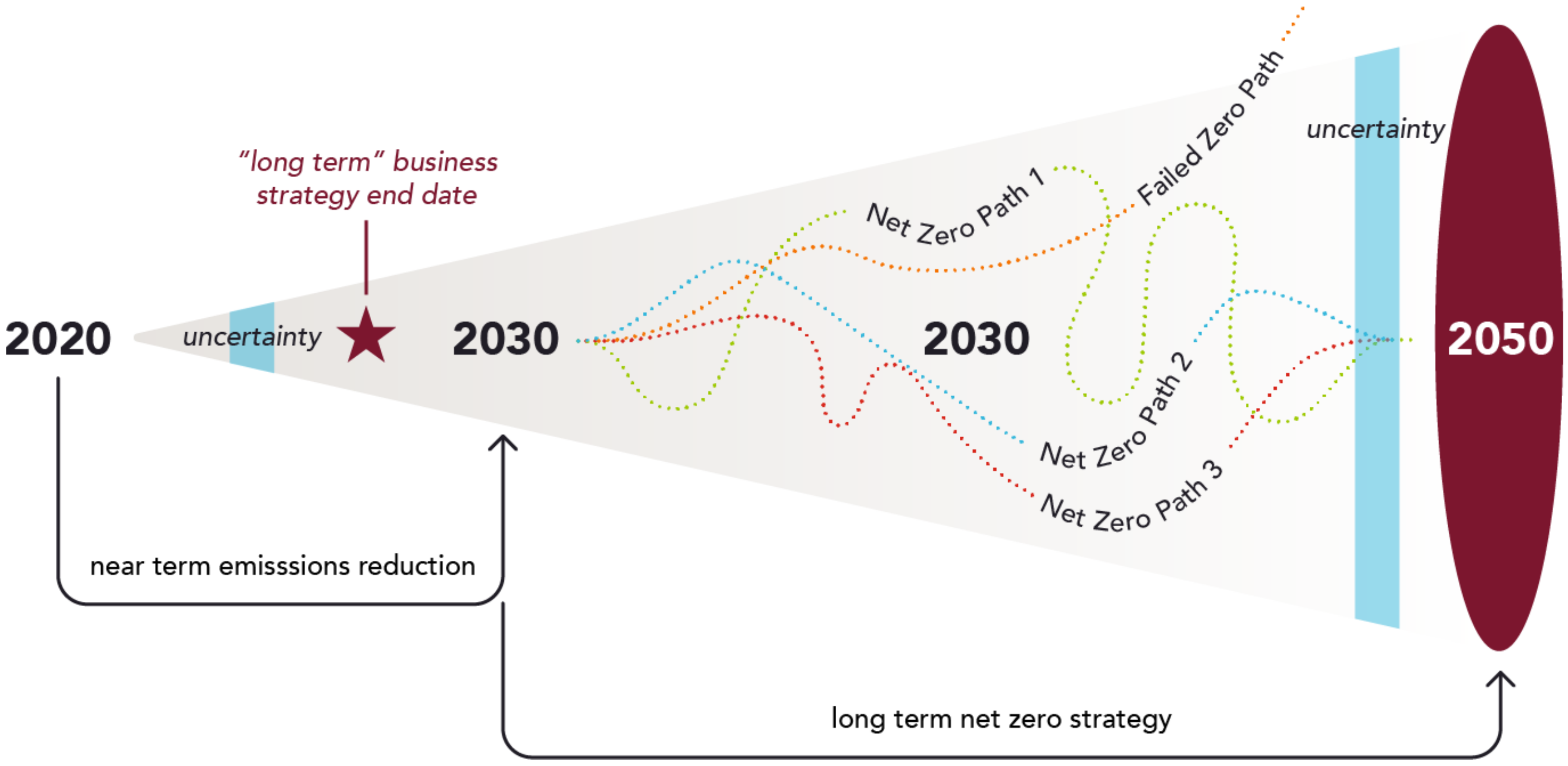
Flag and Water

- Afforestation, Reforestation, and Restoration
- Ecosystem Protection and Conservation
- Agricultural Methane Solutions
- Regenerative Farming & Nitrogen Management

Planning With a 10-, 20-, and 30-Year Time Horizon Is Challenging

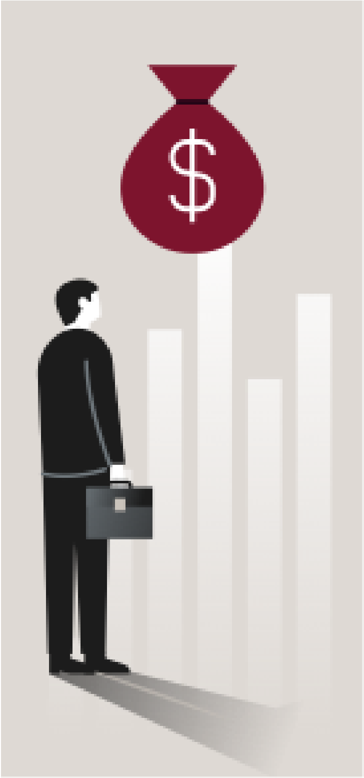
Many companies are not yet taking decisive and focused action due to the long-term uncertainty facing businesses in the path to 1.5°C. Companies seek and desire a clear transition plan to get to 1.5°C, but long-term uncertainty limits the development of clear roadmaps.

- Typical 'long-term' business strategy planning looks out only 5 years where there is limited uncertainty.
- Companies tend to focus on efforts for near-term emissions reduction. Long-term net-zero planning requires not only near-term technological action but strategically thinking about the company vision and business model.
- To achieve Net Zero, companies must act on long-term time horizons, where uncertainty is high, and potential pathways of action are many. Companies must accompany technological implementation with broader systemic changes and business transformation for success and resilience over the long term.



Long-Term Success Requires Business Transformation and Systemic Change

No one company or single technology can achieve net zero. Doing so requires shifting the focus from individual company action to systemic change and broadening the conversation beyond specific technologies. Net zero involves a transformation that requires better business models, supporting policies, and behavior changes. In addition to the technological levers in this library, businesses should consider transformation levers including:



Non-Technological Lever	Purpose	Examples
Operational and Purchasing Changes	Shift the demand-side paradigm to build markets for low-carbon offerings and shrink demand for higher-emitting products.	• Rental of products and utilization of secondhand markets • Employee carpooling incentives
Public Policy and Advocacy	Engage governments with industry insight on key obstacles to decarbonization, unlocking public finance, supportive legislation, and permissive permitting processes.	• Advocacy to enable innovation incentives, such as subsidies or tax programs • Collaboration with government for systemic change support
Supplier Engagement	Assist suppliers with shifting their operations to lower-carbon alternatives, particularly for small, resource-constrained businesses.	• Training suppliers and developing formal engagement mechanisms • Support for suppliers to change procurement or manufacturing practices
Customer Engagement	Guide customers on how to approach changes to lifestyle and consumption, to minimize friction and maintain brand support.	• Customer engagement to increase lifestyle and consumption changes, and changes to purchasing processes for corporate clients
Industry Collaboration	Utilize shared resources and capacity to achieve economies of scale through demand-side levers and accelerate research efforts.	• Working across industry to tackle systemic industry-wide challenges (e.g., green ammonia availability, storage and transport infrastructure buildouts)
Business Model Transformation	Adapt business models to structurally reduce emissions intensity of operations and proactively prepare for macroeconomic effects of the transition.	• Circularity-first business models • Product as a service models • Review of business lines that are incompatible with net zero and development of new business lines that enable the transition

Cross-Lever Insights

Assembling this research surfaced the overarching importance of the following to enable success and evolution of transition technologies.

- **International Cooperation and Globalization**
- **Hydrogen**
- **Green Financing**
- **Workforce Evolution**
- **Decarbonization as Industrial Policy**
- **Integrated Energy Systems**
- **Systematic and Institutional Adaptability**

Key Takeaways

Key Takeaway:

International Cooperation

Achieving net zero by 2050 is dependent on the compliance of every nation in remaking their energy and economic systems. There is an inherent interdependence in doing so: countries with competitive advantages in renewable energy- and infrastructure-related manufacturing (most commonly China) and resource availability (spread across the world) are poised to use excess production capacity to drive an affordable transition for the rest of the world. The coordination required demands a high level of standardization to incentivize actors toward positive and productive outcomes, from biomass feedstock deforestation policies to the redevelopment of the global port system to accommodate low-emission vessels.

In the current environment of de-globalization, tariffs, and supply-chain shocks, such an environment would require significant reconfiguration of the global political and economic order. Most pertinently, the battle lines of the great-power struggle between China and the United States have extended to the future of energy. The U.S. has become the world's largest producer and exporter of oil and gas (O&G), while China has surged to become the seemingly insurmountable dominant manufacturer and exporter of renewable energy infrastructure. While the costs of climate change are increasingly well recognized and felt in the U.S., they are being weighed against the economic impacts of shuttering O&G facilities and the geopolitical risks of offloading energy generation infrastructure to what is portrayed as a potential adversary.

There exists a middle ground and potential forward paths. While a détente in relations and increasing cooperation presents the simplest and most affordable way to transition, domestic investments in renewable energy generation production, potentially made competitive through implementation of advanced robotics, automation, and subsidies, can reshore production to the U.S. While a shift away from the petrodollar system may appear threatening to the greenback, its deep structural qualities for trade still remain: most renewable energy assets exported from China are denominated in dollars, as are the raw materials across the value chain. A shift to renewable energy and Chinese dominance of energy generation infrastructure need not imperil the US economy, and a more prosperous outcome for all may be found through cooperation. American sophistication and resources in software, financing, insurance, and general R&D can each underline the scale and efficiencies needed to advance global transition-related production and capability.

Key Takeaways

Key Takeaway:

Hydrogen

Renewable-driven electrification can solve for much of the transition, but it has limitations due to the need for battery storage and its inability to be used as a substitute for fossil fuels in chemical reactions. This is where hydrogen holds key: it is a storable, flexible chemical carrier that can be used in combustion, catalysis, and synthesis, just like fossil fuels.

Namely, hydrogen can be used in high-temperature industrial processes that are not reasonable to electrify, as clean molecular feedstock in the production of ammonia, methanol, and steel, and in long-distance transport where batteries are not feasible. Hydrogen itself can be transported easily across oceans, allowing the modular global mobilization of clean energy across resource-scarce contexts. It also facilitates dynamic energy systems: excess electricity can be used to produce hydrogen, which effectively stores the energy like a battery would. This can be stored in tanks, caverns, or pipelines, and then used for electricity or industrial fuel as needed.

However, global electrolyzer capacity, which is effectively translated to manufacturing capacity, is still under 1 percent of the projected 2050 net-zero requirement. This means that a successful transition of the hardest-to-abate sectors is reliant on the scaling of supportive infrastructure. This includes compression, storage, transport, terminal facilities, in addition to workforce and social implications of growing a heavy industry by a hundredfold within 25 years.

Investment has been muted largely due to uncertain demand-side signals. Facilities usually launch alongside offtake and purchase guarantees from industrial partners launching green pilots. Expanding these programs, with public support and industry cooperation, is the only way sufficient capacity and infrastructure can be built. National production and purchase targets must be developed, and taxes levied on high-emissions industry and transport to incentivize switching to lower-carbon alternatives. Ultimately, electrolyzer operating costs, and thus the cost of hydrogen production, is dependent on the price of localized renewable electricity. Large, dedicated, integrated production hubs, where the raw implements of water and renewable energy are abundant, may support global consumption, facilitated by hydrogen's transportability.

Key Takeaways

Key Takeaway:

Green Financing

Transition economics are front-loaded: most costs are capital expenditures, while most benefits (energy savings, resilience, avoided emissions) are back-loaded and distributed. Financing mechanisms must therefore do two things at once: mobilize capital at scale and reduce perceived and real risks. This requires a layered mix of instruments, institutions, and incentives spanning the public and private sectors.

Public finance plays a catalytic role. Subsidies and tax credits, such as those in the U.S. Inflation Reduction Act, directly lower capital costs, shift investment curves, and reduce the payback period for early movers. Beyond direct support, governments increasingly act as market makers: using purchase guarantees, contracts-for-difference (CfDs), or floor-price mechanisms to underwrite demand in uncertain or emerging markets like green hydrogen, sustainable aviation fuel (SAF), or carbon capture. Advance market commitments (AMCs), originally used in vaccine deployment, are now being applied to breakthrough decarbonization tech to guarantee volume and price once performance criteria are met. These tools reduce offtake risk, making projects bankable.

Innovation financing must target the full tech stack. Grant funding, prize-based incentives, and mission-driven R&D agencies play a key role in maturing technologies toward commercial readiness.

Carbon markets and credits provide a second pillar. Where properly implemented, they price externalities and create revenue streams for emissions reduction. Voluntary carbon markets are increasingly structured around high-integrity, additionality-certified credits (e.g., engineered removals, nature-based solutions). Regulated markets, such as the EU Emissions Trading System (ETS) or China's national system, are tightening caps and expanding sectoral coverage, creating clearer forward price signals.

Green bonds, sustainability-linked loans, and blended-finance vehicles are scaling, but many projects, especially in emerging markets, face high sovereign or counterparty risk. Development finance institutions (DFIs), export credit agencies, and multilateral banks play a bridging role offering first-loss capital, credit enhancements, and guarantees to crowd in private investment. Public-private platforms can de-risk early deployment, co-invest in strategic infrastructure (e.g., hydrogen corridors, EV charging networks), and provide technical assistance to build project pipelines.

Key Takeaways

Key Takeaway:

Workforce Evolution

Planning, installing, operating, and maintaining the energy and techno-economic systems of the future will require wide upskilling and reskilling of labor. Unlike earlier industrial shifts, which unfolded over a generation and allowed time for workers to retrain, today's transition is occurring at a much faster clip, driven by disruptive technologies, digitization, and AI. This speed demands a far more deliberate and well-financed approach to workforce development, built on sustained capital commitments for reskilling programs worldwide. At the same time, the transition must be guided by Just Transition principles: workforce evolution should be people-centered, gender-responsive, age- and disability-inclusive, and anchored in meaningful participation of stakeholders, especially unions and worker representatives, through structured social dialogue.

The shift to renewable energy has already revealed the social risks and opportunities at stake. Fossil phase-downs pose the potential for large, geographically concentrated job losses, particularly in the oil and gas sector, but the massive new investment required to decarbonize energy systems could generate several times more jobs if the workforce is prepared to take them. Skills will be needed across the value chain: highly competent scientists and engineers to fuel R&D and innovation; digital specialists who can manage the AI-driven data ecosystems underlying energy infrastructure; and millions of operational, construction, and maintenance professionals as the physical build-out scales across geographies. This underscores the need for dedicated STEM and technical pathways, expanded vocational programs, and cross-disciplinary training that transfers digital competencies to physical industrial and energy system applications

Treating 'decarbonization as industrial strategy' demands prioritization of labor policy. Industries and governments should co-invest in retraining initiatives, develop systems that can flexibly match mobile labor with local project needs, and ensure inclusive education pipelines that prepare underrepresented groups for participation. Financial flows must be directed not only to technologies and infrastructure but also to the human capital that enables their deployment. Policy frameworks should support just transition commitments, protecting land rights, embedding social safeguards, and tying subsidies or carbon-removal credits to demonstrable workforce outcomes. This approach turns the rapid pace of disruption into an engine for opportunity, ensuring that the renewable and low-carbon economy is both technically viable and socially legitimate.

Key Takeaways

Key Takeaway:

Decarbonization as Industrial Policy

Crucial to managing the social, democratic support for the transition is to ensure that it remains good economic policy. Asking populations to vote against their ready economic gain, to reduce future risks that may not be locally acute, has proven challenging. These challenges will only deepen as global competitiveness continues to rise alongside heightening local inequalities, sharpening debates around prosperity tradeoffs.

Positioning an economy for success in the transition may take many forms and will vary according to each economy's relative strengths. For example, the Netherlands has unique expertise in geoengineering and wind energy due to centuries of practice, while China has the industrial and labor capacity to dominate manufacturing. Further upstream, the African continent has plentiful supplies of mineral wealth needed for the transition.

As renewable energy assets are most often capital expenditures, where a fixed asset, such as a solar panel or windmill, only needs to be paid for once (debt payments notwithstanding), they have different profiles than fossil fuels, which are constantly consumed, requiring an outflow of dollars at floor prices set by producer countries to maintain profits. The renewable energy promise of effectively zero marginal cost of electricity, (maintenance cost notwithstanding) holds the key to enabling affordable industrialization of all forms across the world. Even for countries that are not economically competitive in manufacturing equipment, or designing complex systems or software, renewable energy adoption can create energy abundance and security in a way that fossil fuels have not been able to.

A complete shift cannot occur overnight; significant investment and planning is needed in grid systems, replacing high-emissions industry, and transport. This can only be done through intentional government policy, which coordinates the economic and physical realities of the realm, prioritizing the highest-return enablers, clearing regulatory obstructions (most often through land-use restrictions), and the direction of public-private partnerships.

Developing low-emission industry allows countries to position themselves and their companies as suppliers for conscious procurers and bypass taxes and levies, such as those imposed and planned by the EU on higher-emission goods. The systematic reconfiguration and recalibration of global systems for the transition presents opportunity for developing nations to develop clean industrial capacity, use it to enter new export markets, and develop technical expertise with significant second-order effects on growth.

Key Takeaways

Key Takeaway:

Integrated Energy Systems

Achieving net zero demands real-time coordination between generation, storage, consumption, and conversion across multiple energy sources and uses. This includes modernizing outdated grid infrastructure that was built for one-way power flow, not for bidirectional, distributed generation. The grid must evolve into a highly responsive, sophisticated platform that handles a high share of variable renewables, integrates devices like EVs and heat pumps, and dispatches demand-side assets by responding dynamically at residences, charging EVs, and other distribute assets to level fluctuations in power supply.

Storage is the foundation of this flexibility. While batteries balance short-term imbalances, long-duration and seasonal storage solutions, such as thermal, pumped hydro, or hydrogen, are required to buffer deeper fluctuations. These must be co-optimized with energy conversion systems like electrolyzers, smart heat networks, and vehicle-to-grid infrastructure to smooth volatility.

Demand response, whether via smart appliances or industrial load shifting. must be digitally integrated to turn passive consumers into active participants. Integrated systems extract value from every unit of energy by reusing heat, co-optimizing electrons and molecules, and reducing curtailment, and emphasizing interoperability. These systems create resilience, not just emissions reductions, by providing grid independence for critical facilities, microgrids during climate shocks, and more affordable and bountiful power for communities left behind by legacy infrastructure.

AI and machine learning technologies serve as the system's central nervous system, enabling predictive control, anomaly detection, asset optimization, and price-responsive dispatch across millions of distributed devices. These models forecast solar and wind generation, predict grid congestion, optimize storage cycles, and enable transactive energy markets in which buildings and vehicles act as autonomous agents bidding in real-time; human monitoring is likely insufficient for the future complexity of the energy system.

These benefits require regulatory modernization, market redesign, and public-private coordination. If successful, integration provides a force multiplier: lowering costs, enhancing reliability, and accelerating electrification across buildings, transport, and industry. Without it, we build more generation but operate it inefficiently, adding to the societal burden of the transition by sub-optimally drawing resources.

Key Takeaways

Key Takeaway:

Systematic and Institutional Adaptability

The perspectives presented in this presentation, carving seemingly rigid technoeconomic pathways to net zero by 2050, are only potential illustrations of how this can occur given our current knowledge. A complex task in building Integrated Assessment Model (IAM) assumptions is thinking about the rate of technological improvement (which is a useful proxy for productivity or economic growth), which does not even approach the type of improvement that may occur. The price of solar panels, for example, has fallen precipitously over the last 15 years due to virtuous cycles of investment, deployment, competition, and refinement; 15 years ago, industry participants projected a far more gradual price decrease. Alternatively, as with Enhanced Geothermal Systems (EGS), a technological breakthrough may fundamentally upend the way a technology is deployed and utilized.

These changing dynamics mean that the corresponding policy and capital environment must maintain a state of adaptive flux. While predictable policy is a cornerstone of long-term capital investment, the ability for policy to adjust to changing circumstances will not only ease the logistical pathways to the transition but will also ensure a more efficient allocation of resources, reducing the societal and economic tradeoffs.

This may come in many forms, particularly when considering public-private partnerships, and the deployment of capital from both sources. Consider an example of a country which has successfully manufactured windmills, to the extent to which it has built export capabilities. This was partially achieved by government schemes to lower the cost of capital offered by banks, coordination with local suppliers, and to create workforce training initiatives. Now suppose a combination of green-steel manufacturing and robotics make another country suddenly more competitive in both pricing and efficiency savings. What does the first country do? How does it weigh localized economic losses against the global coordination required to enable the transition? It may find it appropriate to switch manufacturing to component pieces, which can be assembled by robots overseas. It may seek to produce its own green-steel, allowing later-stage manufacturing to move overseas. Or it may invest in value-additive processes; by either choosing to compete directly, or to find specializations where it can win, such as floating windmills.

An incalculable number of these quandaries and game-theory dynamics will exist and further complicated by the inherent competition between nations and firms. As technology, particularly decarbonization technologies due to their interrelation with industrial capacity, advances and systems grow more complex, developing the flexibility to reposition and refresh policy approaches will minimize economic frictions and limit social backlash.

02

Industry Sectors

- Apparel and Textiles
- Automotives
- Aviation
- Buildings and Construction
- Communications & Telecom
- Consumer Goods
- Chemicals
- Energy
- Financial Services
- Food & Beverage
- General Manufacturing & Industry
- Healthcare
- Information Technology
- Shipping & Logistics
- Mining & Extractives
- Professional Services

Apparel and Textiles

The apparel and textiles industry encompasses the production, processing, and distribution of fabrics and garments. It includes several stages: the production of textiles and fabrics from raw materials, the transformation of those fabrics into apparel and accessories, distribution to customers, and end-of-life disposal.

Overview

- The global fashion industry accounts for an estimated 3-8% of total GHG emissions, and the industry's emissions are expected to increase by about 30% by 2030 if no action is taken.
- Raw material production and processing, manufacturing, and transport form the bulk of emissions from the apparel and textiles industry.
- Upcycling, refurbishment, and alternate business models such as rentals are vital in shifting the industry away from energy and materials-intensive native manufacturing.

Key Decarbonization Levers

Upstream:

- Low-Carbon Plastics
- Livestock and Methane Solutions
- Regenerative Agriculture
- Forestry Solutions
- Biome Conservation

Own Operations:

- Renewable Energy
- Efficient Heating and Cooling
- Efficient Transport
- Energy Efficiency
- Passenger EVs

Downstream:

- Recycling and Circularity

Automotives

The automotive industry relies on decarbonization of its manufacturing processes, net-zero carbon emissions over the lifecycle of their vehicles, and an amenable policy and infrastructure environment to fully decarbonize.

Overview

- Private cars and vans alone are responsible for ~10% of global energy-related CO_2 emissions.
- While manufacturers have proactively invested in electrifying their new vehicle lines, complete decarbonization relies on technological developments which make electric vehicles as reliable and affordable as internal combustion engines around the world, in addition to programs which quickly and effectively bring old cars off the road.

Key Decarbonization Levers

Upstream:

- Low-Carbon Steel
- Low-Carbon Aluminum
- Renewable Energy

Own Operations:

- Energy and Electricity Storage
- Efficient Heating and Cooling
- Passenger Transport
- Public Transport
- Efficient Trucking
- Freight and Logistics

Downstream:

- Recycling and Circularity

Aviation

The aviation industry is reliant on advancements in the efficiency and affordability of sustainable aviation fuels to replace existing emissions. Old planes and systems must also be replaced with adapted models and solutions.

Overview

- Aviation accounts for about 2.5% of global CO_2 emissions.
- Solutions include sustainable aviation fuel (SAF), refreshed aircraft design (accompanied by the retirement of old planes), modernization of approaches to navigating global airspace, and operational improvements across the value chain.
- SAFs, in addition to other alternate energy sources such as hydrogen or batteries, need to develop in both technological maturity and cost competitiveness to become widespread within the commercial aviation industry.

Key Decarbonization Levers

Upstream:

- Hydrogen (Green and Blue)
- Low-Carbon Chemicals and Plastics
- Low-Carbon Steel
- Low-Carbon Aluminum

Own Operations:

- Renewable Energy
- Efficient Heating and Cooling
- Aviation Decarbonization

Downstream:

- Recycling and Circularity
- Carbon Capture Utilization and Storage (CCUS)

Buildings and Construction

The building and construction industry requires the utilization of replacement materials and innovative processes at new builds, and the retrofitting and renovation of existing stock.

Overview

- The operations of buildings account for 30 percent of global final energy consumption and 26 percent of energy-related emissions.
- In addition to switching to renewable energy sources, lighting, refrigerants, cooling, and heating all require specific attention.
- In construction, process improvements combined with low-carbon solutions for materials, including through circularity and recycling initiatives, create a pathway for new constructions to have zero emissions.

Key Decarbonization Levers

Upstream:

- Low-Carbon Cement
- Low-Carbon Steel
- Low-Carbon Aluminum
- CCUS

Own Operations:

- Renewable Energy
- Grid Technologies
- Efficient Heating and Cooling
- Data Center Cooling
- Efficient Appliances
- Building Envelopes

Downstream:

- Recycling and Circularity

Communications & Telecom

The communications and telecom industry produces most of its emissions indirectly, often through the disposal or use of products and services.

Overview

- While the specific source varies, most emissions for the telecom industry fall within Scope 3.
- These Scope 3 emissions come from network services and the production of handsets and modems, in addition to downstream emissions from the use and disposal of customer equipment.
- Decarbonization within Scopes 1 and 2 is relatively straightforward, involving fleet emissions and electricity generation, but may be more complicated in the case of hardware manufacturing.

Key Decarbonization Levers

Upstream:

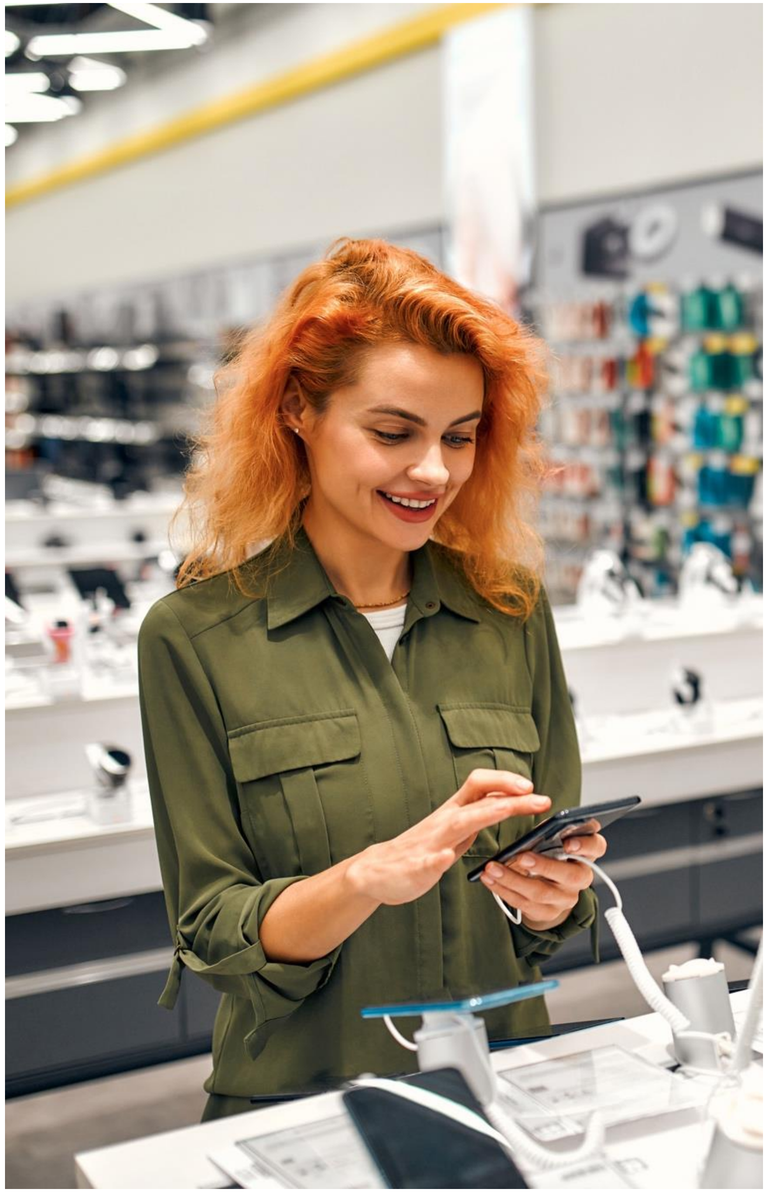
- Renewable Energy
- Low-Carbon Steel
- Low-Carbon Aluminum
- Low-Carbon Chemicals and plastics

Own Operations:

- Renewable Energy
- Grid Technologies
- Data Center Cooling

Downstream:

- Recycling and Circularity



Consumer Goods

The consumer goods industry encompasses companies that manufacture and sell products directly to individuals and households for their personal use. It is a broad sector including everything from finished food and beverages to disposables, electronics, and personal care items.

Overview

- Consumer goods industries often have complex and varying value chains, contributing to diverse emissions sources which can be hard to mitigate when outside direct control.
- Holistic programs which address impacts from raw material extraction and processing, manufacturing, transport, consumer use, and end-of-life management allow for the full mitigation of a product's emission profiles and provide the feedback loops for product updates and iteration with lower lifecycle emissions profiles.

Key Decarbonization Levers

Upstream:

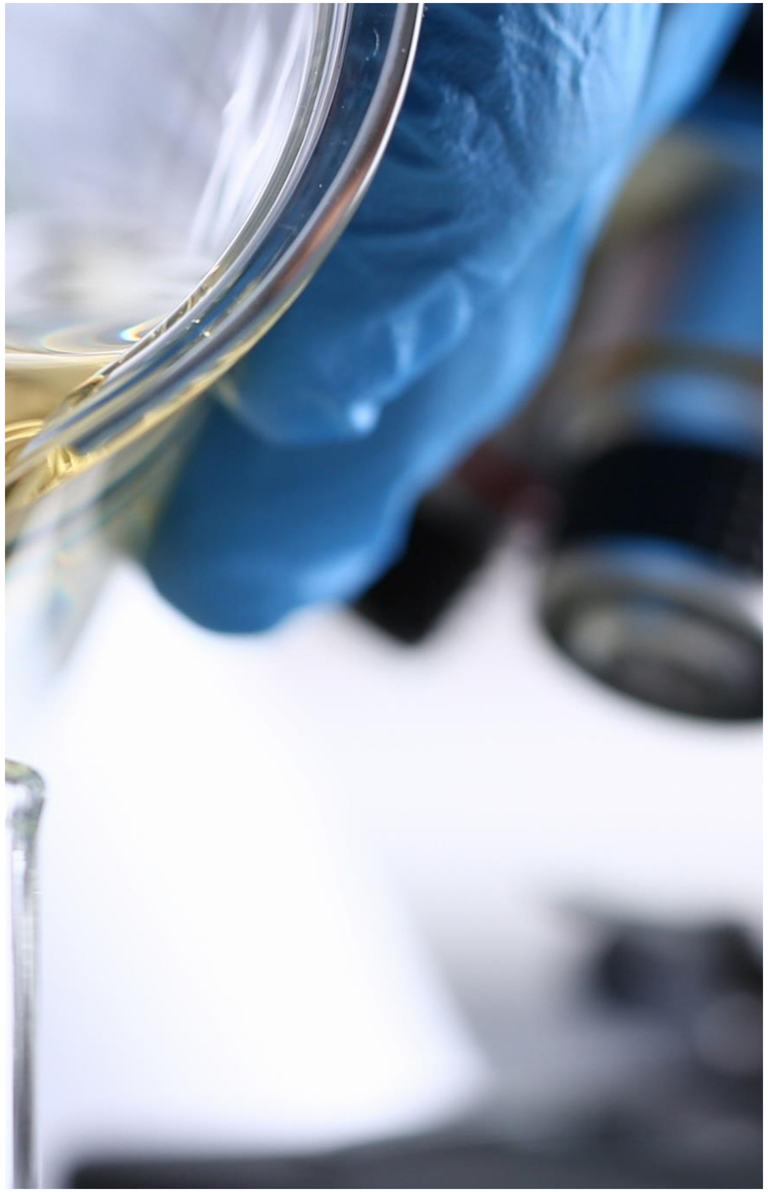
- Renewable Energy
- Afforestation, Reforestation, and Restoration
- Regenerative Farming and Nitrogen Management

Own Operations:

- Efficient Trucking
- Efficient Freight and Logistics
- Low-Carbon Chemicals and Plastics

Downstream:

- Recycling and Circularity



Chemicals

The chemicals industry faces a complex pathway to decarbonization due to the use of fossil fuels as feedstock for several fundamental products.

Overview

- Emissions in the chemical industry are difficult to abate outside of switches to renewable energy, as heat generation and certain chemical processes are still largely reliant on fossil fuels in crucial contexts; their replacement requires the success and scale of still-nascent technologies and their pilots.
- Investments in efficiency to reduce the amount of energy used and increase the amount of energy conserved, particularly in the form of heat, across processes and facilities can have significant impacts in lowering the emissions profile of the industry.

Key Decarbonization Levers

Upstream:

- Hydrogen (Green and Blue)
- Renewable Energy
- Biomass

Own Operations:

- Efficient Trucking
- Efficient Freight and Logistics
- Low-Carbon Chemicals and Plastics

Downstream:

- Recycling and Circularity
- CCUS

Energy

While the relationship between switching to renewable energy sources and decarbonization is well understood, grid modernization and expansion has remained underinvested and underprioritized.

Overview

- Energy sector decarbonization is dependent on the shift from fossil fuels to renewable energy sources. Net-zero scenarios call for the sector to decarbonize by 2040.
- This is reliant on the electrification of existing and new elements of the physical economy and the development of expanded and modernized grid infrastructure.
- Remaining fossil emissions will either have to be offset or sequestered.

Key Decarbonization Levers

Upstream:

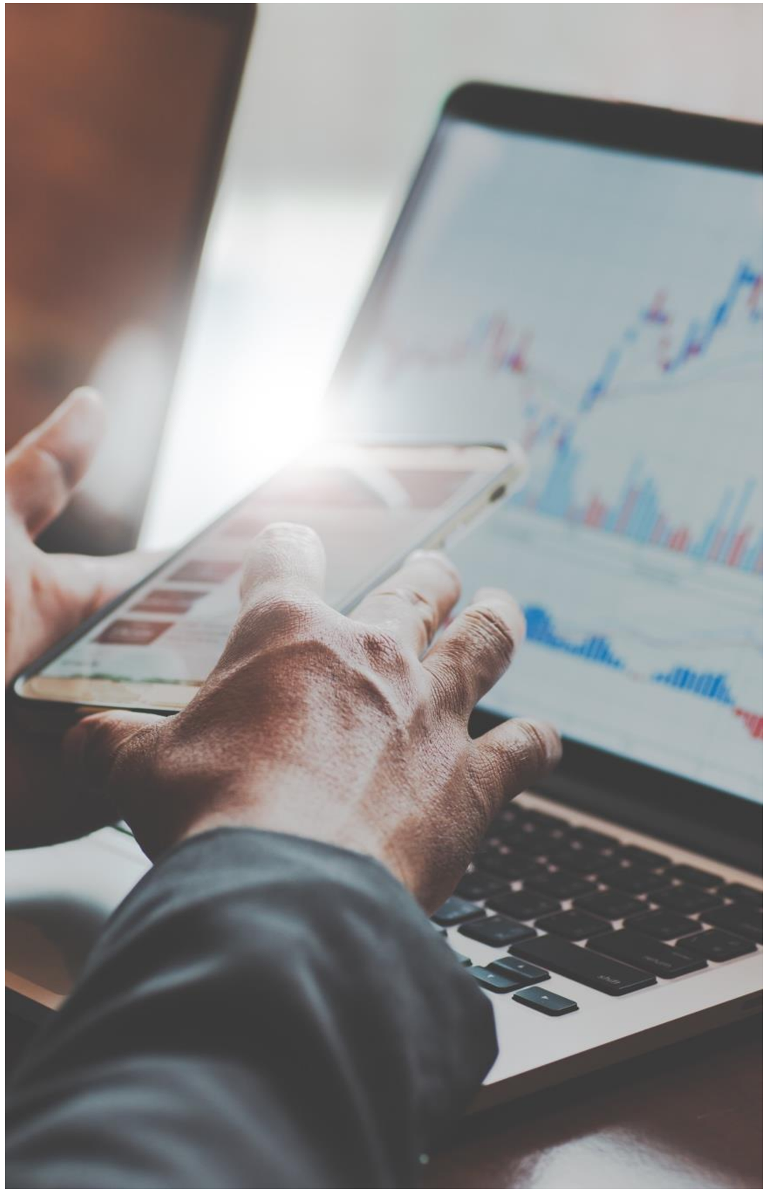
- Hydrogen (Green and Blue)
- Low-Carbon Aluminum
- Low-Carbon Steel

Own Operations:

- Renewable Energy
- Grid Technologies
- Energy and Electricity Storage

Downstream:

- Recycling and Circularity
- CCUS



Financial Services

Financial services companies serve a critical role in decarbonizing their portfolios and thereby decarbonizing the broader economy.

Overview

- Financial services companies can decarbonize their own operations through relatively straightforward electrification and renewable energy procurement.
- Decarbonization of their Scope 3 investment and client portfolios is a more complex task and involves transitioning away from investing in high-emitting industries, developing financing mechanisms to accelerate the green transition, pricing and adaptation to climate risk, and using voting powers and term sheets to stipulate climate strategies at applicable companies.

Key Decarbonization Levers

Upstream:

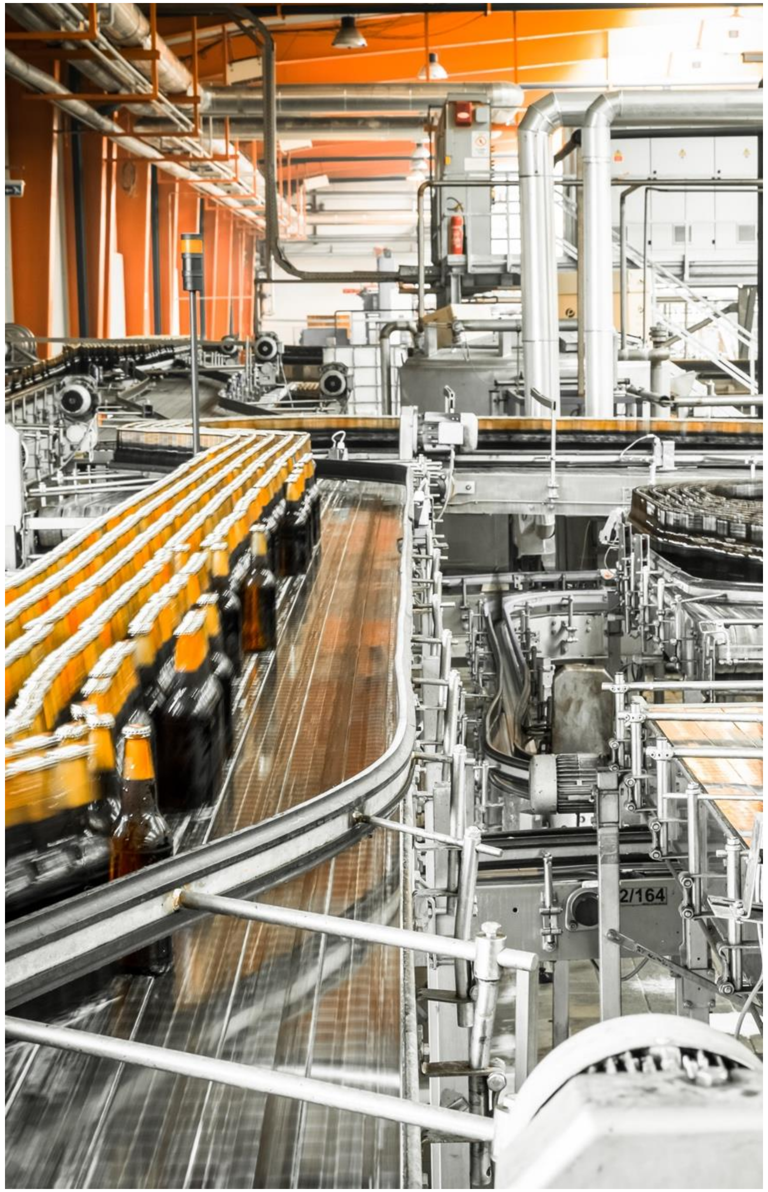
- Renewable Energy
- Grid Technologies

Own Operations:

- Efficient Appliances
- Building Envelopes
- Enabling Financing across All Levers

Downstream:

- Recycling and Circularity



Food and Beverage

The food and beverage industry has significant exposure to agriculture, which has a unique emissions profile due to the crop, land, and water nexus, which can be addressed through natural climate solutions.

Overview

- Raw materials for the sector from agriculture contribute the bulk of the emissions. This includes livestock methane emissions, fertilizer emissions, and reducing emissions from on-farm energy use. Production of agricultural products makes up 16 percent of energy use in the U.S.
- A unique source of emissions in the value chain comes from disposal. As these items degrade, methane is released in landfills, making food loss and waste reduction a critical decarbonization action.

Key Decarbonization Levers

Upstream:

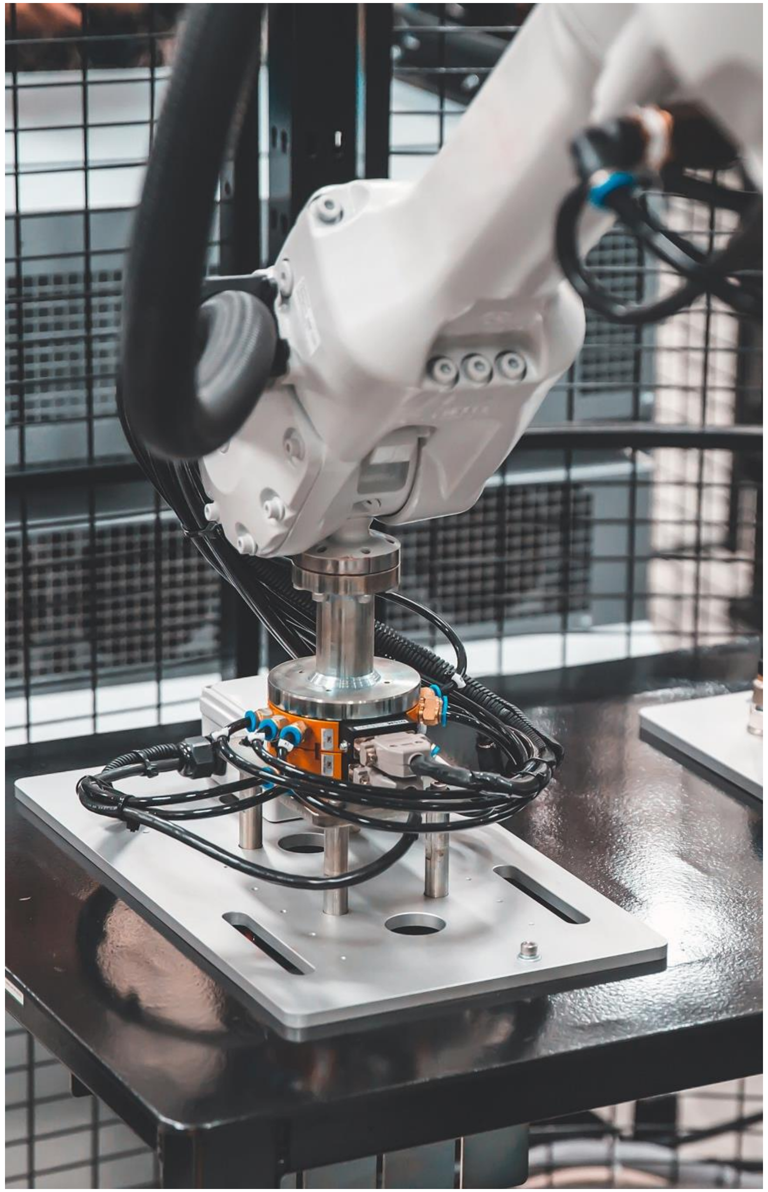
- Ecosystem Conservation
- Afforestation, Reforestation, and Restoration
- Regenerative Farming and Nitrogen Management
- Agricultural Methane Solutions

Own Operations:

- Efficient Trucking
- Efficient Freight and Logistics
- Low-Carbon Chemicals and Plastics

Downstream:

- Recycling and Circularity



General Manufacturing and Industry

Industry emissions from hard-to-abate sectors require significant investment and research to scale decarbonization solutions to widespread adoption at competitive prices.

Overview

- Industry emissions come from the energy used to run large manufacturing processes, in addition to technology and process-specific emissions that are produced from chemical processes underlying the manufacture of certain goods and materials.
- Developing localized, abundant renewable energy sources that can meet the demands of heavy industry is crucial to decarbonization, in addition to R&D and financing mechanisms which accelerate the development and deployment of lower-carbon manufacturing practices.

Key Decarbonization Levers

Upstream:

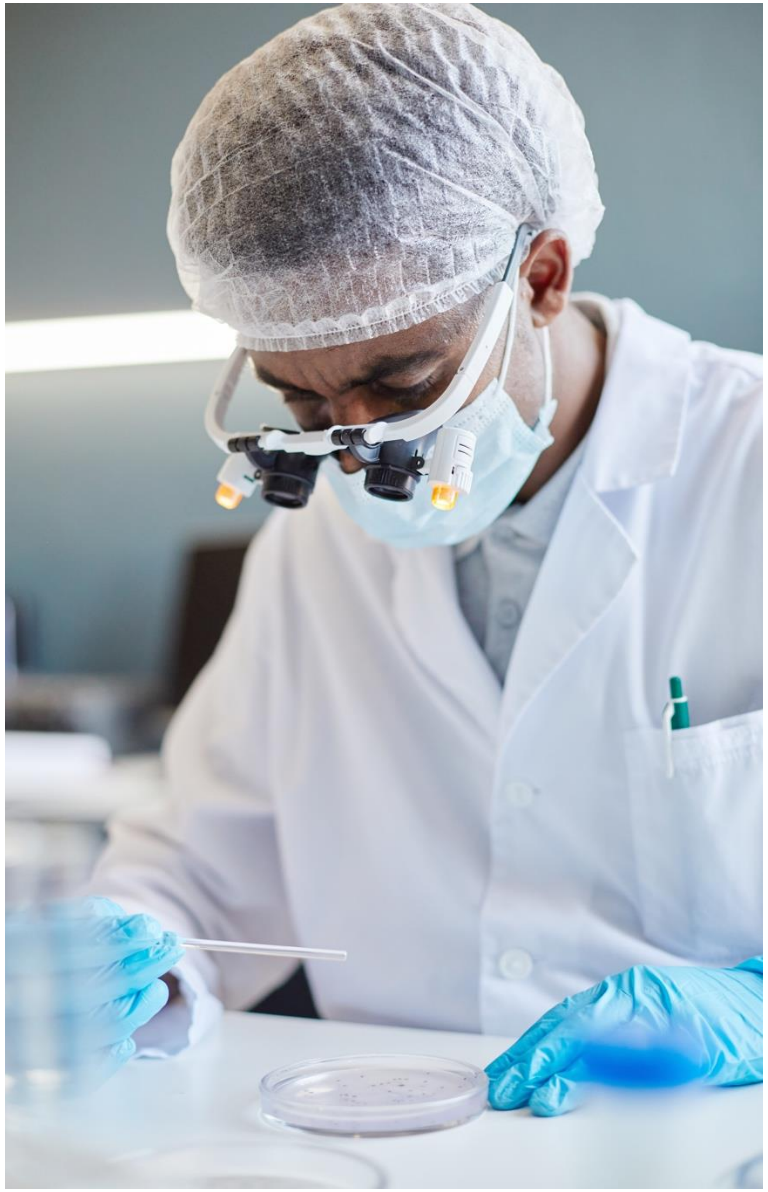
- Low-Carbon Cement
- Low-Carbon Steel
- Low-Carbon Aluminum
- Low-Carbon Chemicals and Plastics
- Energy and Electricity Storage

Own Operations:

- Renewable Energy
- CCUS
- Grid Technologies

Downstream:

- Recycling and Circularity
- Efficient Trucking
- Efficient Freight and Logistics



Healthcare

Healthcare companies may have emissions profiles similar to other industries but may also consider more specific levers such as efficient appliances and equipment, refrigerants, and retrofits of specialized infrastructure.

Overview

- The heterogeneous, sprawling nature of the healthcare industry means that decarbonization pathways will differ depending on business type.
- Hospitals, clinics, and other 'built-environment' facilities will have strategies akin to large office buildings, pharmaceutical companies will have an approach akin to the chemical industry, and any organization or system with a large investment portfolio may find their own operations much easier to decarbonize than their investments.

Key Decarbonization Levers

Upstream:

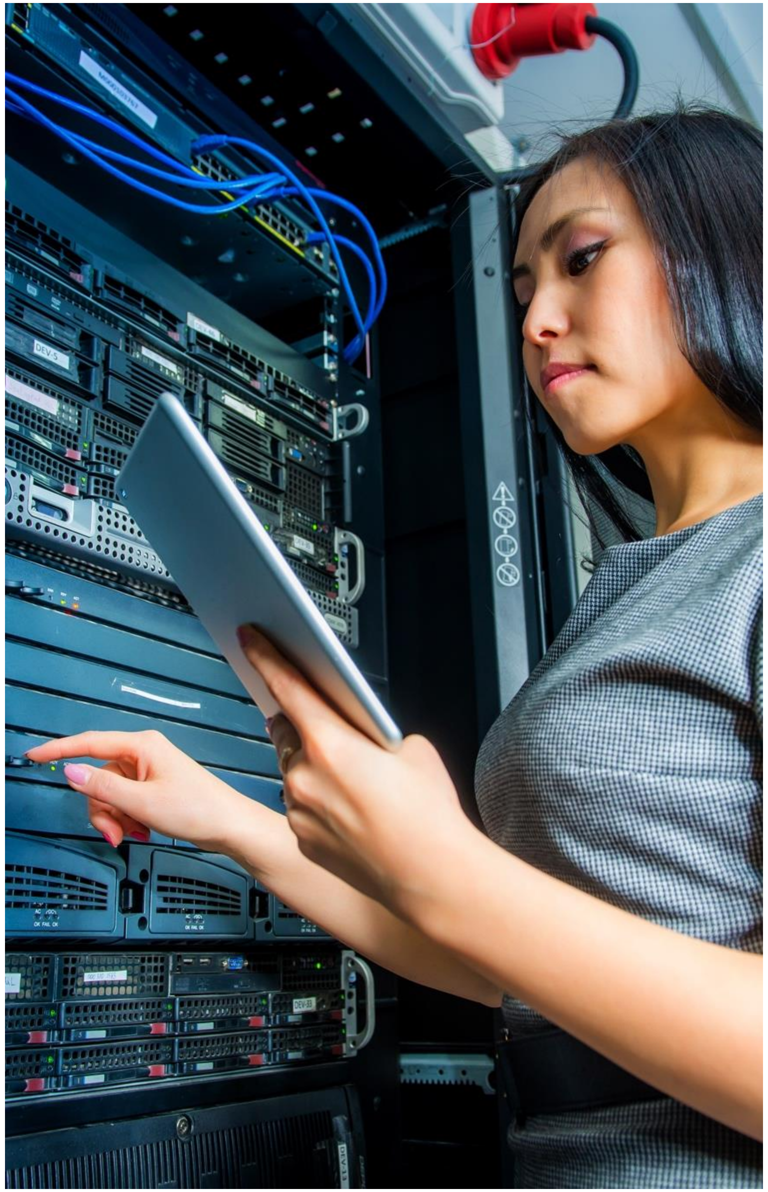
- Building Envelopes
- Low-Carbon Cement
- Low-Carbon Chemicals and Plastics
- Efficient Trucking
- Efficient Freight and Logistics

Own Operations:

- Renewable Energy
- Efficient Appliances
- Efficient Heating and Cooling

Downstream:

- Recycling and Circularity



Information Technology

Information technology companies do not only have emissions from data centers—the manufacture and transport of their goods is often energy-intensive, as is the footprint of their employees and offices.

Overview

- The information technology industry has seen a rapid surge in power demand as data centers for artificial intelligence have been built out with both speed and scale. With the high ceiling of how large and power-hungry these data centers may become, sourcing renewable energy as much as possible is paramount for keeping the sector on track.
- Other emissions may come from product manufacturing, transport, emissions from land use change for data center and other physical buildouts, and the operation of an organization's own facilities.

Key Decarbonization Levers

Upstream:

- Grid Technologies
- Energy and Electricity Storage
- Low-Carbon Chemicals
- Refrigerants

Own Operations:

- Renewable Energy
- Data Center Cooling
- Efficient Appliances

Downstream:

- Recycling and Circularity

Shipping and Logistics

Shipping relies on the development of sustainable fuels and energy sources which are still relatively nascent in their widescale adoption.

Overview

- The shipping industry must switch to lower or zero-emissions fuels as they become technologically feasible and available. Investment in ammonia and hydrogen fuel cell technologies have shown promise, as have methanol liquid fuels.
- At the same time, new fueling infrastructure will have to be built around the world to refuel and recharge vessels.
- Additional decarbonization also must take place at the intermediate, ground transport level.

Key Decarbonization Levers

Upstream:

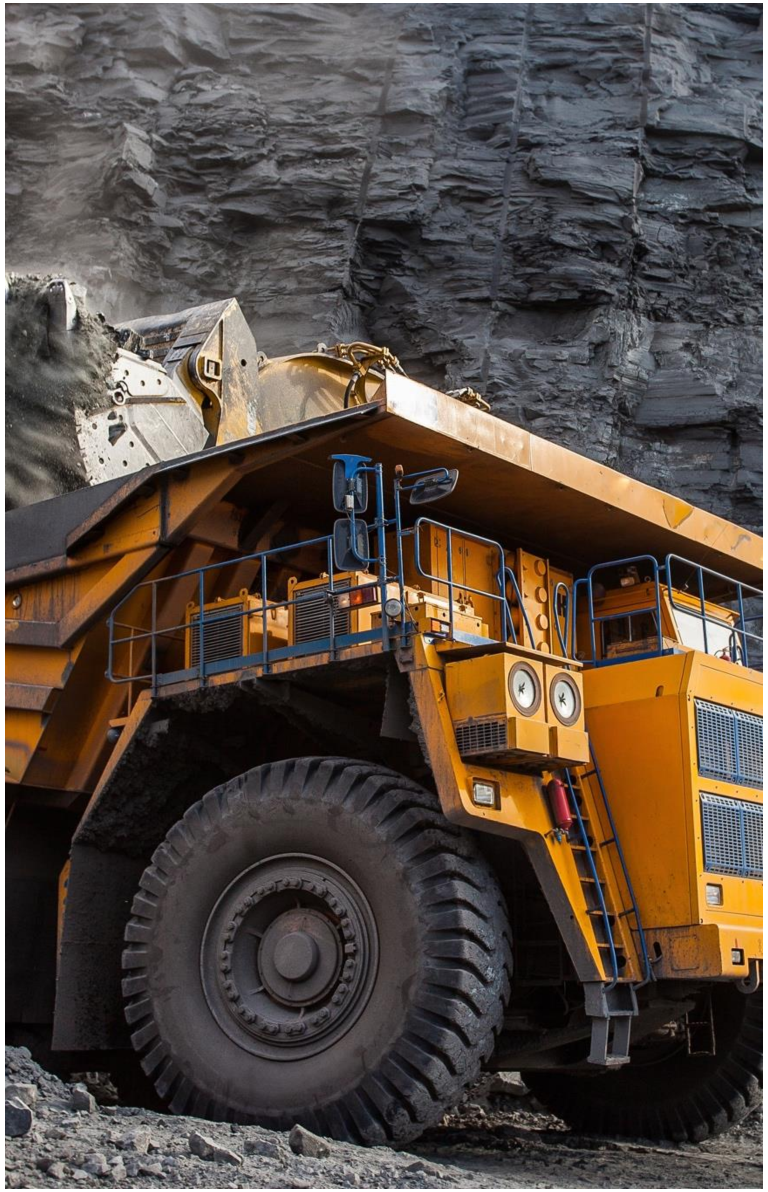
- Low-Carbon Steel
- Hydrogen (Green and Blue)
- Renewable Energy
- Efficient Freight and Logistics

Own Operations:

- Efficient Shipping
- Efficient Trucking
- Energy and Electricity Storage

Downstream:

- Recycling and Circularity



Mining and Extractives

The mining industry has a unique role in both producing the critical inputs of the energy transition, while consuming a large amount of energy and producing coal.

Overview

- Mining decarbonization takes two forms: reducing operational emissions through common methods such as renewable energy, process efficiencies, and new industrial technologies, and the shift of a mining company's operations away from resources which contribute to purchased Scope 3 emissions, such as coal. Additionally, land use emissions related to deforestation may have to be offset or remediated.
- At the same time, the mining industry has a crucial role to play in the extraction of critical minerals needed for the energy transition, including nickel, cobalt, lithium, and rare earth metals.

Key Decarbonization Levers

Upstream:

- Low-Carbon Steel
- Low Carbon Chemicals and Plastics
- Low-Carbon Hydrogen
- Grid Technologies

Own Operations:

- Renewable Energy
- Energy and Electricity Storage

Downstream:

- Recycling and Circularity

Professional Services

The professional services industry is not a large emitter within its own operations but has the opportunity to lead and direct other industries toward best practices.

Overview

- Professional services companies have cut their emissions significantly post COVID-19 by reducing their travel and can reach net zero through building and operations decarbonization, reducing travel or choosing greener alternatives, and actively engaging their supply chains.
- These firms can engage their clients, develop sustainability practices and thought leadership, and serve as centralized enablers to spread best practice and pathway alignment through the economy.

Key Decarbonization Levers

Upstream:

- Low-Carbon Chemicals and Plastics
- Low-Carbon Hydrogen

Own Operations:

- Renewable Energy
- Energy and Electricity Storage
- Building Envelope
- Efficient Appliances
- Passenger Transport
- Public Transport

Downstream:

- Recycling and Circularity

03

Lever Library

ELECTRICITY AND ENERGY

- Bioenergy
- Energy and Electricity Storage
- Geothermal
- Low Emission Hydrogen
- Grid Technologies and Modernization
- Hydropower
- Nuclear
- Solar
- Wind

TRANSPORT

- Light-Duty and Micromobility
- Maritime Decarbonization
- Aviation Decarbonization
- Freight Decarbonization
- Public Transport

INDUSTRY

- Low Carbon Cement
- Low Carbon Steel
- Low Carbon Aluminum
- Chemicals
- CCUS

Buildings

- Efficient Fixtures
- Building Envelopes
- Data Center Cooling
- Refrigerants
- Efficient Heating and Cooling

FLAG AND WATER

- Afforestation, Reforestation, and Restoration
- Ecosystem Protection and Conservation
- Agricultural Methane Solutions
- Regenerative Farming & Nitrogen Management

Electricity and Energy

Bioenergy

Bioenergy refers to energy derived from organic matter, also known as biomass. It includes applications such as heat and electricity generation and conversion to biofuels and biogas.

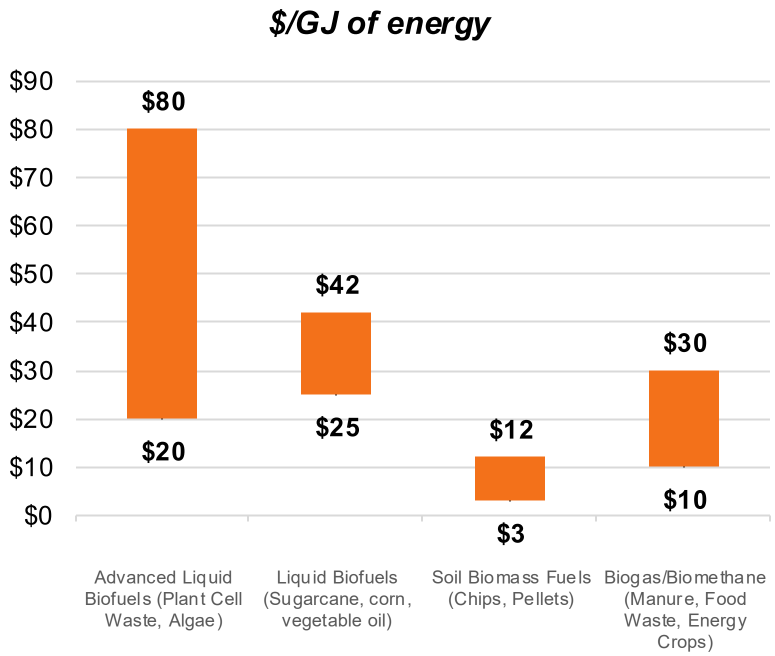
Lever Details

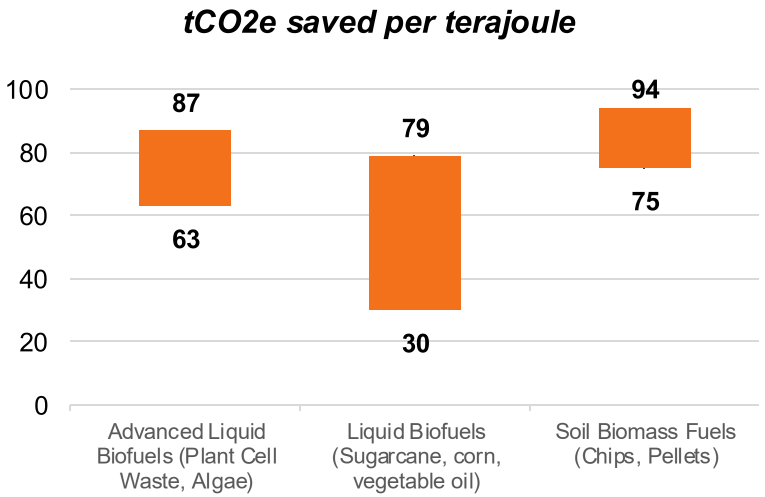
Industry:

- Energy
- Food and Beverage
- Chemicals
- Aviation
- Shipping and Logistics
- Financial Services

Cost Assumptions and Details

- **Feedstock cost drives >50% of final energy cost.** Energy cost will vary naturally alongside commodity fluctuations, the feedstock used, and final use across geographies.
- **Availability of raw materials and dedicated supply chain infrastructure create fluctuations in price** across geographies. Countries emphasize and develop programs to support differing bioenergy sources based on their localized availability, in addition to considerations related to economic development and value chain sustainability.
- **Bioenergy use releases carbon into the atmosphere, but this is considered neutralized** as feedstock production initially captures this carbon. Costs may rise in the case of carbon negative projects, where CCUS technologies may be applied. Alternatively, costs may be offset through the industrial repurposing of CO_2, such as in in dry ice, soda, cosmetics, detergent, and plastics production.

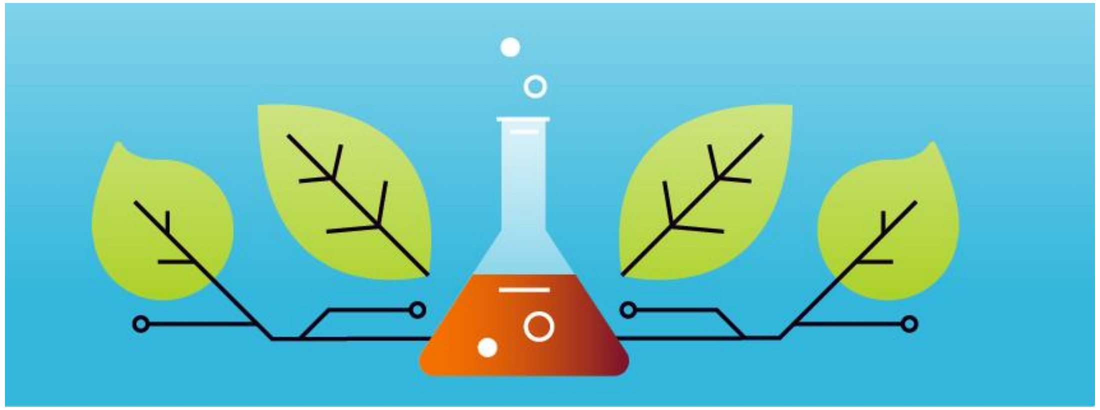




Bioenergy

External Factors, Dependencies, and Systemic Change Opportunities

- **Transport, buildings, and heavy industry** are expected to form the bulk of the **increase in demand of bioenergy** over the next five years. Transport will increasingly utilize liquid biofuels, while industry and buildings will largely consume solid biomass, for both electricity generation and heating.
- In **developing countries**, there is a large push **to incorporate bioenergy solutions for cooking fuel.** This has the potential to significantly decarbonize the sector in these geographies, in addition to providing local value chain workforce and other economic and natural capital opportunities.
- The amount of feedstock that can be produced is heavily dependent on available land, and the ability to collect and process feedstock from waste streams. Bioenergy **production must balance sustainability and nature-related considerations.** The utilization of land, water, and other resources for feedstock and resource development should have a net-positive development on both GHG emissions and the health of the natural environment and local peoples.
- **Policy support should be directed to those solutions that successfully create net-positive effects in GHG emissions** or have the most potential to do so in the future. The European Union, the United States, and Brazil have each established frameworks for standardization of sustainability in biofuel production. Developing widely accepted international standards would both support sustainable global development and facilitate the creation of deeper markets.



Key Impacts Outward on Nature and People

Upstream

Deforestation risk (especially woody biomass) and **increased water and fertilizer use for crops**. Social risks related to **shifting crop mixes, deforestation, and the treatment of agricultural labor.**

Operations

Emissions from processing of feedstock, in addition to other pollutants that may be released. Social risks from **effects on nearby communities, including air quality, sound, odor, and land use.**

Downstream

GHG benefit will vary based on the **combustion efficiency and leakages**, in addition to the **total portion of bioenergy in blended solutions**. Social considerations include **clean cooking access, potential increased costs of fuels, electricity, and heat, and local workforce opportunities.**

Bioenergy

Vision for net zero: where does the lever fit in a 2050 net zero world?

Bioenergy is used as a dense, storable fuels and as a source of firm power. It provides an alternative to fossil gas, coal, and oil in high-temperature heat and dispatchable generation and can supply liquid fuels in long-haul aviation and deep-sea shipping where batteries or hydrogen are insufficient. Its sustainability rests on the prioritization of advanced feedstocks: agricultural and forestry residues, organic wastes, and cellulosics, with any dedicated energy crops confined to marginal or degraded land. Modern, certified bioenergy thus distinguishes itself from traditional biomass, which net-zero pathways phase out entirely.

In the near term, the deployment of rapid substitutions through residue-based combined heat and power (CHP), biomethane from anaerobic digestion, and the first commercial bioenergy with carbon capture and storage (BECCS) projects, particularly at facilities with high-purity biogenic CO_2 streams and access to transport and storage infrastructure, should be emphasized. In the 2030s, these discrete projects should consolidate into integrated hubs where feedstock upgrading, carbon capture, and fuel synthesis co-locate, allowing bioenergy to link with hydrogen and CO_2 networks. By the 2040s, bioenergy's role will ideally evolve into a dual service: as a reliability product providing firm capacity that complements variable renewables, and as a forestry-enabled climate service delivering durable removals on the order of several hundred million tons annually.

To realize this pathway to net zero, companies should map their operations and emissions profiles against bioenergy's unique capabilities and identify relevant actions and investments. Utilities and industrials may invest in certified feedstock contracts, modular CHP, and BECCS pilots co-located with CO_2 transport infrastructure. Food and beverage companies can invest in anaerobic digestion and biomethane upgrading, embedding nutrient-return systems that preserve soil health. Aviation and shipping can sign long-dated offtakes that ladder from hydroprocessed esters and fatty acids (HEFA) fuels in the 2020s to advanced and synthetic SAF and marine fuels in the 2030s and 2040s, while airports and ports invest in blending, storage, and bunkering systems. Chemical clusters can integrate conversion technologies and CO_2 capture into regional hubs, in coordination with emerging hydrogen corridors. Across all sectors, finance has a critical role to play: standardizing contracts for carbon removals, SAF, and marine fuels; embedding sustainability criteria such as those in RED III and leveraging blended finance to expand access in emerging markets. Policy engagement is equally important, such as supporting SAF blending mandates, maritime fuel-intensity standards, carbon-removal crediting frameworks, and capacity payment mechanisms that secure BECCS revenues. By aligning capital investments with policy trajectories and industry-specific offtakes, companies can help scale bioenergy into a reliable and verifiable energy source in a net-zero future.

Who to partner with?

- Providers include Drax, Enviva, and Nature Energy (Shell)

Where to find more information?

- IEA
- Project Drawdown
- U.S. Department of Energy

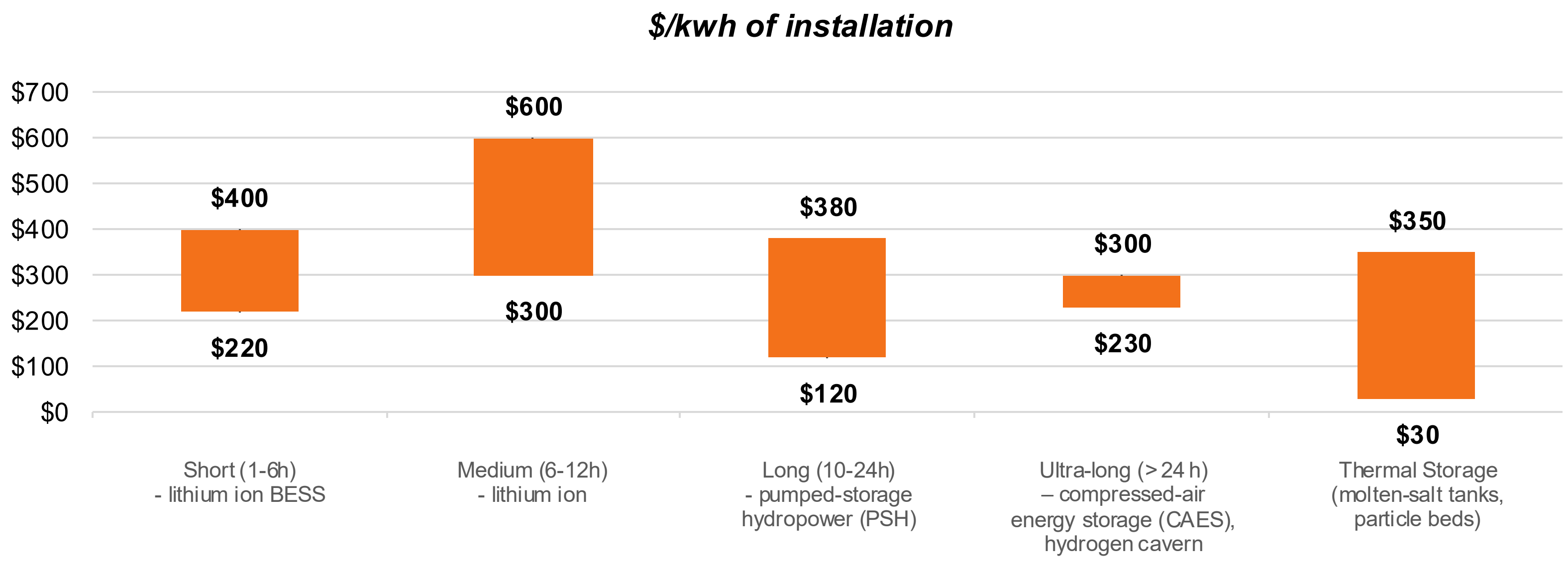
Energy and Electricity Storage

Energy and Electricity Storage systems are those which allow energy to be stored for later use. These primarily consist of batteries and Pumped Storage Hydropower.

Lever Details

Industry:

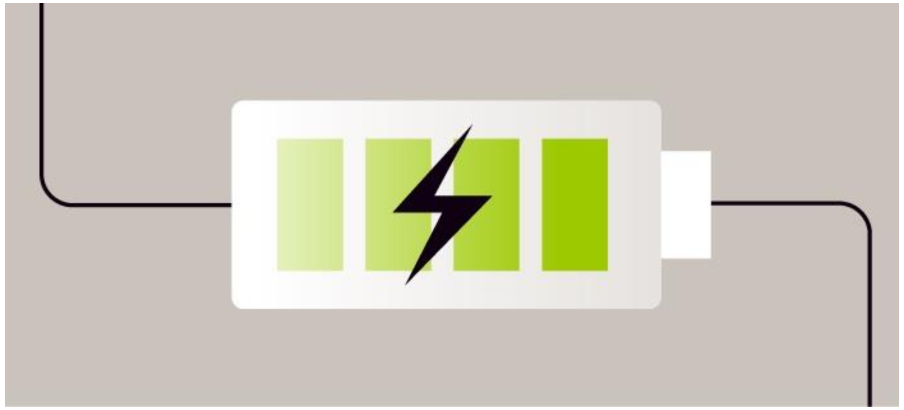
- Energy
- Information Technology
- Automotives
- Buildings and Construction
- Chemicals
- Mining and Extractives
- Financial Services



Cost Assumptions and Details

- **Pumped storage hydropower** (PSH) and **lithium-ion batteries** have differing cost and use profiles. PSH is **a large-scale, long-duration solution, while lithium-ion batteries are more versatile**, offering **faster response times and shorter-duration storage.** While PSH is more strictly economical, it is **not always the preferred solution** within a dynamic, distributed, intermittent grid.
- Increased **duration requirements** increase **the installation costs of batteries**. Other costs to consider are **permitting and planning costs, and depreciation and replacement** costs.
- Lithium-ion battery are **highly sensitive to fluctuations in the price of lithium**, as well as nickel, cobalt, and graphite. These may move due to natural supply and demand market fluctuations, but also have varied due to geopolitical pressures, such as the war in Ukraine.
- The **'learning rate' for battery prices continues to drive prices down** despite fluctuations in raw material price and will continue to influence underwriting calculations.

Energy and Electricity Storage



External Factors, Dependencies, and Systemic Change Opportunities

- Batteries are **deeply dependent on localized supply chains and critical minerals. China** undertakes **more than half of global processing** for lithium and cobalt and has almost **85% of global battery cell production capacity.** The availability and affordability of these minerals, and the robustness and expansion of the supply chains which process them, is critical to expanding battery technology alongside net-zero pathways. **Tariffs and geopolitical tensions** present critical threats to maintaining an open supply of affordable batteries.
- Further cost declines in batteries (and battery installations) are essential in bringing down the total cost of intermittent renewable energy projects down. **Innovations in sodium-ion and solid-state batteries** have the potential to bring costs down, as they **avoid exposure to lithium costs.**
- Policy support to expand battery installation is critical. This may be done in coordination with the private sector, which can **own and operate battery assets for profit,** and the transportation and passenger vehicle sector, which relies on a network of batteries to facilitate the introduction of electric vehicles.
- **Pumped-storage hydropower expansion** relies on the construction of dams and supporting hydropower facilities, which require a significant amount of permitting and planning to process, due to their scale, compared to li-ion storage infrastructure.
- More **resilient supply chains** which minimize carbon footprint and other impacts are crucial to the sustainability and expansion of this industry. This includes the **recycling of batteries as a source of critical minerals.**

Key Impacts Outward on Nature and People

Upstream

Environmental and social risks related to **mineral extraction**, particularly in developing markets and geopolitically sensitive areas. This extraction has been linked to **child labor, natural habitat destruction, and armed conflict.** Potential for **emissions from fossil fuel use during the manufacturing phase.**

Operations

Risk **of fires from lithium-ion batteries, land-use effects** from utility scale project deployment. Community and labor safety concerns related to **maintenance and electrical exposure.**

Downstream

Risks related to the **disposal and proper recycling of batteries** at the end of their life, particularly related to their **composite materials.** This includes labor conditions at **waste and recycling sites.**

Energy and Electricity Storage

Vision for net zero: where does the lever fit in a 2050 net-zero world?

Energy and electricity storage enables variable renewables and flexible demand, used where shifting, firm capacity, and fast system services are essential. It facilitates a pathway to replace fossil-fueled peakers and spinning reserves, to displace diesel back-up in critical facilities and data centers, and to unlock the full value of wind and solar by absorbing surplus generation and reducing curtailment. Applications span behind-the-meter peak shaving and resilience, distribution-level congestion relief, bulk-system energy shifting and adequacy, and black-start and frequency services. Its sustainability rests on responsible mineral sourcing and processing, chemistries with lower critical-material intensity, rigorous safety standards, and circularity through repair, repurposing, and recycling. Pumped-hydro and thermal storage strengthen this case when sited to minimize land and water impacts.

In the near term, modular deployments of 1–4-hour batteries at utility and behind-the-meter sites should be prioritized, alongside refurbishment of pumped-hydro assets and conversion of data-center UPS systems into grid-interactive storage, with software to stack frequency, capacity, and congestion-relief services. From the early 2030s, as variable renewables scale, storage should progress from ancillary support to large-scale energy shifting and capacity provision; long-duration options (flow, thermal, gravity, compressed-air, or hydrogen buffers) should advance from pilots to early commercial procurement through clear flexibility and resource-adequacy products, bankable offtakes, and standardized performance warranties. In the mid- to late 2030s, portfolios should increasingly diversify and interoperate with demand response and electrified heat to reduce curtailment and firm peak and shoulder periods. By the 2040s, a mature storage mix should provide dependable capacity across weather and seasons, enabling 24/7 carbon-free operations, smoothing electrified loads, and lowering system costs by avoiding overbuild and deferring transmission upgrades.

To realize this pathway to net zero, energy utilities may invest in hybrid renewables-plus-storage PPAs, long-duration procurements, and capacity or resource-adequacy contracts that value duration and availability; and look to streamline interconnection, adopt safety codes, and structure performance-warranted revenue stacks. Information-technology companies can replace diesel generators with batteries and long-duration options, pair storage with on-site solar for 24/7 carbon-free portfolios and enroll campuses and data centers in demand-response and virtual-power-plant programs. Automotives can enable managed charging and vehicle-to-grid capabilities, stand up second-life battery lines for stationary use, and standardize warranties and telemetry so grid operators can confidently procure EV flexibility. Buildings and construction actors should deliver storage-ready designs, integrate thermal and battery storage with heat pumps and controls, and use microgrids to harden critical facilities. The chemical sector can anchor hubs with industrial thermal storage and electrolyzers operated as controllable loads backed by hydrogen storage, reducing demand charges and providing grid services. The mining sector can deploy storage-centric microgrids to displace diesel in remote operations. Financial services can support by scaling project and asset-backed finance for storage fleets; offering degradation and performance insurance; standardizing contracts for capacity, ancillary services, and resiliency; and supporting policy engagement on market designs that compensate duration, long duration energy storage (LDES) targets, safety standards, recycling mandates, and critical-minerals transparency.

Who to partner with?

- Providers include Tesla, CATL, and BYD

Where to find more information?

- IEA
- Project Drawdown
- U.S. Department of Energy
- NREL
- Batteries: From China's 13th to 14th Five-Year Plan

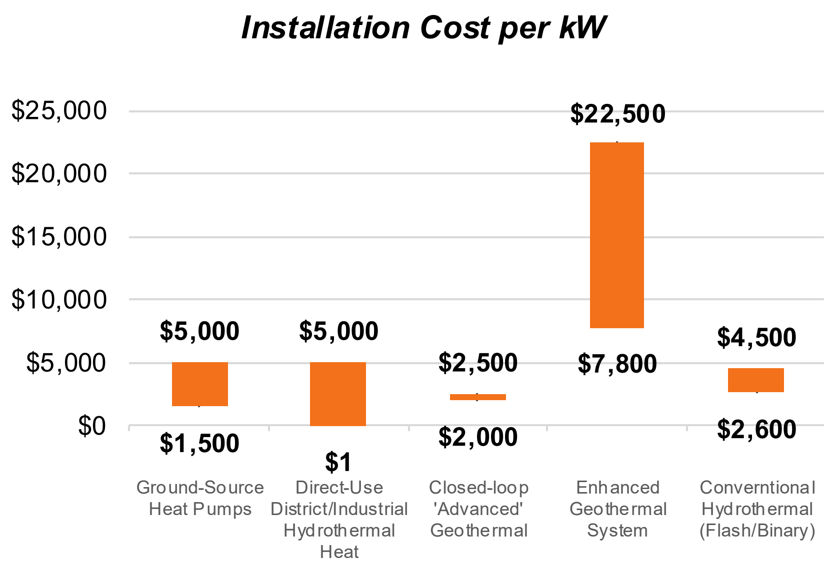
Geothermal

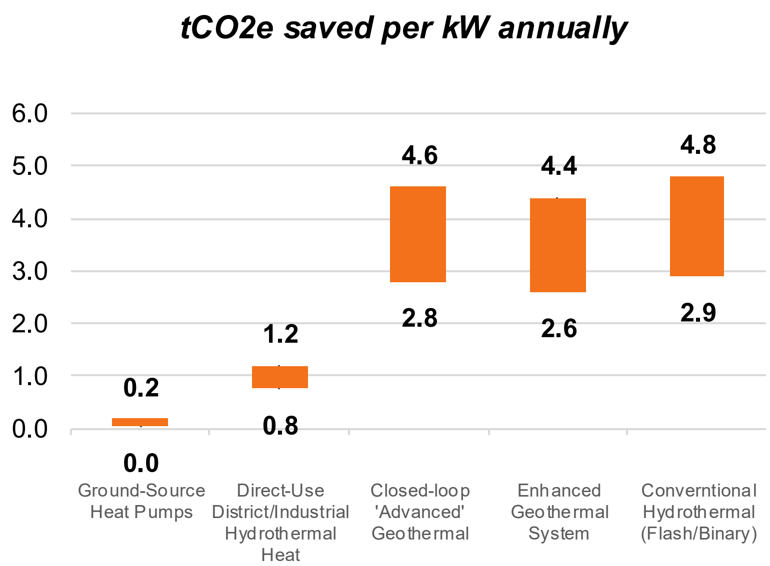
Geothermal energy refers to the heat harnesses from within the Earth, which is harnessed for heat, cooling, and electricity These may include systems of varying complexity.

Lever Details

Industry:

- Energy
- Buildings and Construction
- Mining and Extractives
- Chemicals
- Information Technology
- Food and Beverage
- Financial Services





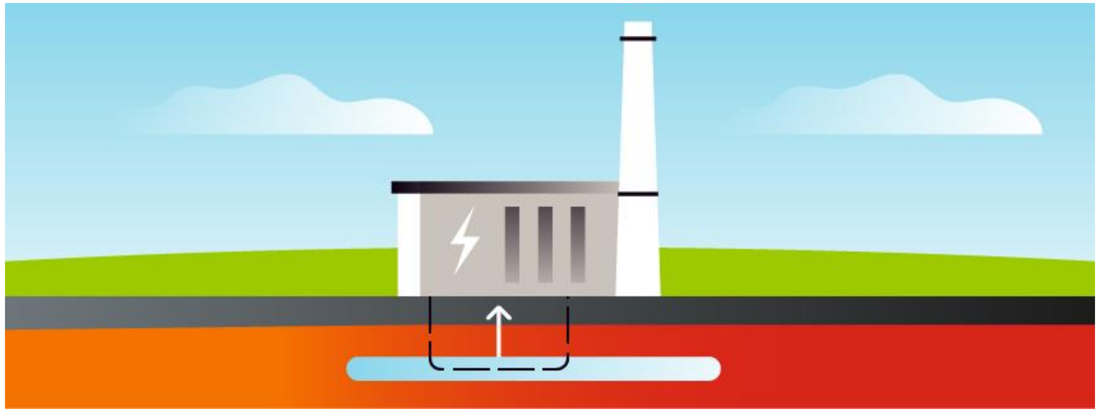
Cost Assumptions and Details

- Geothermal energy project cost **varies with the depth of the drilling**. Deeper projects cost more but are often **more efficient and reliable** in terms of resource availability.
- The **drilling success rate**, which may vary if the project is in a proven source field, or if the project is ‘greenfield’, adds to the total project cost.
- **The underlying cost of capital** may vary significantly, as geothermal energy does not have the same market maturity as other renewable sources.
- **Local factors** such as the makeup of the underlying rock, the surface footprint and land value used for a particular project, and land lease vs purchasing dynamics all further influence price.
- The **complexity and design of the system, as Enhanced Geothermal Systems (EGS)** and closed loop projects grow in deployment, also affect cost significantly.

Geothermal

External Factors, Dependencies, and Systemic Change Opportunities

- Geothermal energy **relies on several external factors**, listed in the previous slide, to **become price competitive** around the world with both other renewable energies and fossil fuels. It most directly competes with fossil fuels because it **does not have the same intermittence as other renewables.**
- The **potential repurposing and redirection of oil and gas (O&G) resources to geothermal overcomes several challenges** related to the availability of labor (across skill levels and roles), financial capital, and infrastructure. The drilling and sensing capability of the O&G sector, in addition to several other tasks and pieces of analyses its workers perform, are readily transferable to geothermal exploration and development.
- **Policy mechanisms are needed to push the O&G sector to increasingly invest in geothermal capabilities**, from direct subsidies or financing facilities to lower the cost and risk of geothermal, to carbon taxes and other punitive measures to dissuade further fossil fuel production and exploration. At the same time, permitting and authorization processes need to be sped up, to not create a backlog of projects which further discourages risk capital.
- **The learning rate in EGS projects** to make them cost-competitive with the other energy sources is crucial. The technical potential of EGS, which accesses deeper heat supplies, can supply enough energy for each continent; for example, tapping just 1 percent of potential continental geothermal capacity would meet Africa's projected energy needs in 2050.



Key Impacts Outward on Nature and People

Upstream

Risks related to **land and water use** at drilling sites, including **biodiversity, pollution, and ecosystem destruction.** Potential **induced seismic activity** from drilling. Risks related **to workforce safety, treatment, fair upskilling and reskilling,** in addition to **noise pollution and drain of local resources.**

Operations

Chemical solutions to maintain brine chemistry within geothermal wells **often create GHG emissions**, which would **require abatement or offsetting**. Risks related to **safety during facility operation.**

Downstream

Risks related to **well abandonment**, and the **recycling and reuse of equipment and chemicals** that are used and generated over the life of the facility.

Geothermal

Vision for net zero: where does the lever fit in a 2050 net zero world?

Geothermal is used where firm, always-on, low-carbon heat and power are essential. It helps replace coal and gas in baseload electricity, to substitute fossil boilers with high-availability process heat and district heat, and to stabilize electrified systems by delivering inertia and ancillary services independent of weather. Applications range from high-enthalpy power plants to direct-use heat for industrial processes and buildings, and ground-source heat pumps that slash building energy intensity. Its sustainability rests on closed-loop reservoir management with full reinjection, rigorous induced-seismicity and groundwater safeguards, careful siting to minimize land and water impacts, and end-to-end monitoring of brine handling and air emissions; modern geothermal thus distinguishes itself from legacy, lightly monitored steam operations by prioritizing subsurface stewardship and high-integrity measurement.

In the near term, brownfield additions and proven hydrothermal resources should be prioritized for rapid, low-risk deployment, alongside district-energy interconnections and campus- and neighborhood-scale ground-source heat pumps, while pilot programs in enhanced geothermal systems (EGS) that leverage modern oil-and-gas drilling, monitoring, and stimulation practices build a bankable pipeline. Through the 2030s, as resource appraisal improves and learning rates drive down drilling and completion costs, EGS and advanced closed-loop designs should scale to commercial projects, and, where chemistry allows, co-production of critical minerals from brines should be developed to strengthen project economics and supply chains. By the 2040s, geothermal's role should be to provide dependable, dispatchable zero-carbon power and high-temperature heat that complements variable renewables across seasons, anchors district heating and industrial process heat and lowers system costs by reducing curtailment and long-duration storage needs.

To realize this pathway, energy utilities may invest in resource appraisal, exploration drilling, and bankable power and heat offtakes, pairing firm geothermal Power Purchase Agreements (PPAs) and capacity payments with risk-mitigation tools such as exploration insurance and loan guarantees. The construction industry can make projects "geothermal-ready" by designing and financing district-energy networks and large shared borefields, integrating thermal storage and heat-pump plants. The mining sector should contribute directional-drilling expertise, rigs, and subsurface services to cut well costs and timelines and co-develop mineral recovery from geothermal brines under robust water stewardship. Chemicals and other heat-intensive industries can site expansions near geothermal fields to replace gas boilers with continuous process heat, using hybrid configurations that combine geothermal with heat pumps and electrified backup. Information-technology operators can co-locate data centers with geothermal power and district-energy schemes to secure 24/7 carbon-free electricity and heat reuse pathways that improve overall system efficiency. Financing services can standardize heat and power purchase agreements, underwrite exploration risk, structure concessional tranches for first-of-a-kind EGS, and align policy engagement on streamlined drilling permits, subsurface rights clarity, thermal-network regulation, and parity mechanisms.

Who to partner with?

- Providers include Ormat Technologies, Calpine, and Fervo Energy

Where to find more information?

- IEA
- NREL
- Project Drawdown
- U.S. Department of Energy
- Enhanced Geothermal Systems for Clean Firm Energy Generation, Nature

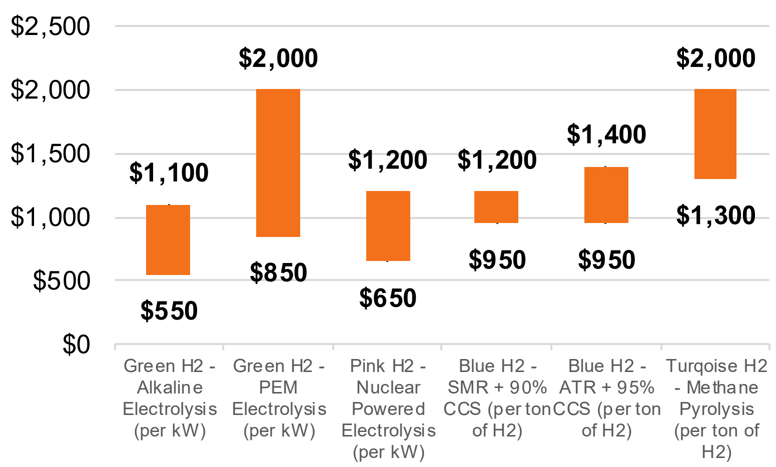
Low-Emission Hydrogen

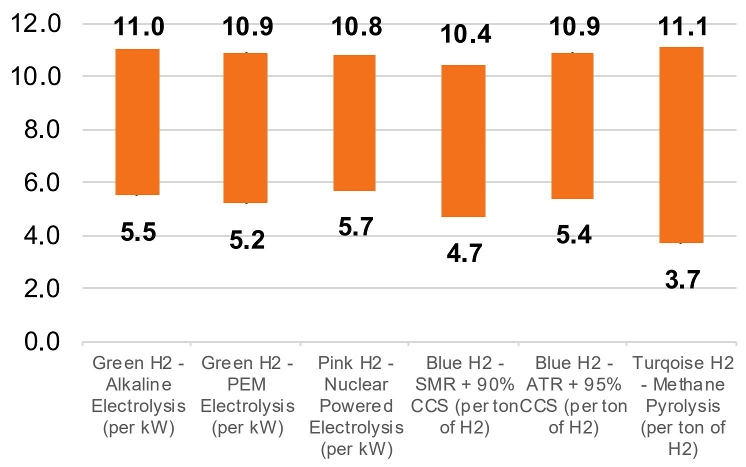
Low-emission hydrogen is produced using renewable or nuclear energy, or by capturing carbon emissions from fossil fuels used for hydrogen production. Green hydrogen is produced from electrolysis using renewable energy, while blue hydrogen is produced from natural gas using CCUS.

Lever Details

Industry:

- Energy
- Chemicals
- General Manufacturing & Industry
- Aviation
- Shipping and Logistics
- Mining and Extractives
- Buildings and Construction





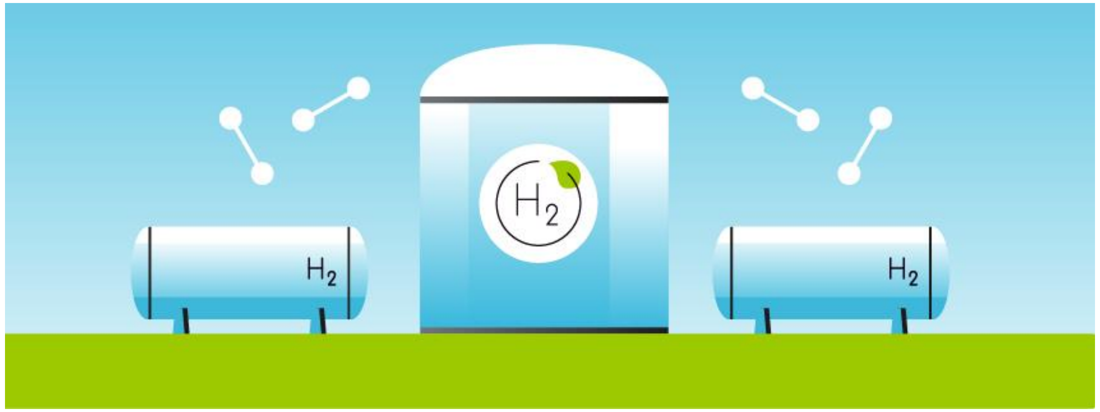
Cost Assumptions and Details

- The largest determinant of hydrogen production costs are the input price of **electricity, gas** (in the case of blue hydrogen), and other inputs such as **heat, water, and labor.**
- Electrolyzer capacity factors, or the percentage of time they are operating at full capacity, affect production costs.
- **Renewable PPAs** help **underwrite hydrogen production** by providing guarantees as to the greatest cost inputs.
- Additionally, as hydrogen is increasingly integrated into industrial processes and other energy system uses, the **need to store and transport it will increase**, which will add to embedded costs.
- The capture rate of green hydrogen projects affects costs: **higher capture rate technologies** are more advanced and have **higher costs today.**

Low-Emission Hydrogen

External Factors, Dependencies, and Systemic Change Opportunities

- Hydrogen production suffers from a **large gap between announced projects and those which come to fruition.** This is attributed to **uncertainties around future demand, certification and regulation, and a lack of infrastructure to transport and store hydrogen.**
- Hydrogen demand is currently dominated by **legacy industry uses,** such as oil refinery and ammonia production. **Novel applications** in industry and long-distance transport **account for less than 0.1 percent of demand today**, whereas they account for almost **40 percent of demand by 2030** in the IEA Net Zero scenario.
- **Accelerated policy and investment action** is required to close these gaps. **Targeted loans, retrofitting, and repurposing** to establish **transport infrastructure** is crucial in moving hydrogen from where it is generated **(most use is currently on-site).** Storage facilities for both hydrogen and captured carbon need to be identified and developed**. Amenable policy infrastructure** such as faster permitting, auctions, and public procurement can stimulate demand.
- Several hydrogen technologies and uses have still **not been deployed at scale**, including capture rates in line with net-zero targets. **Focused innovation efforts** across private and public sectors is needed to realize both technological progress and implementation.



Key Impacts Outward on Nature and People

Upstream

Risks related to the **extraction of water for electrolysis** such as depletion and local resource stress. Risks related to **land use**, if large-scale projects displace or disrupt local populations.

Operations

The **energy used** in production **must be renewable**, otherwise the carbon-positive benefits are offset. **Risks of methane leakages** in blue hydrogen production, and CO2 leakages of sequestered hydrogen.

Downstream

Risks related to **ammonia slip**, where unreacted ammonia is emitted after combustion or catalytic processes. Risks related to **hydrogen embrittlement**, where **metals can lose their ductility and become brittle** due to the presence of hydrogen.

Low-Emission Hydrogen

Vision for net zero: where does the lever fit in a 2050 net zero world?

Low-emission hydrogen complements electrification and direct use of renewable power, used where energy-dense molecules or a clean reducing agent are essential. It replaces grey hydrogen in refineries and ammonia plants; to displace coal/coke in ironmaking via hydrogen-based direct reduced iron (DRI); to substitute fuel oil and natural gas in select high-temperature industrial heat; to act as seasonal storage and limited peaking fuel for power systems; and to supply clean molecules for maritime fuels (e-ammonia/e-methanol) and aviation e-fuels. Its sustainability rests on strict guardrails: for electrolysis, additional, temporally matched, and deliverable low-carbon electricity with prudent water stewardship; for fossil-based routes with capture, high methane-leak control and ≥90-95% CO_2 capture with permanent storage; and for all routes, robust certification and MRV.

In the near term, rapid substitutions should target replacing grey hydrogen with low-emission supply in existing chemical uses (refining, ammonia, methanol), enabled by electrolysis tied to clean power and by implementing carbon capture where transport and storage is available. Industrial pilots should advance for hydrogen-DRI/EAF steel and burner retrofits, while flexible electrolyzers that can modulate load and provide grid services, alongside salt-cavern or depleted-field storage and pipeline repurposing, should be developed where geology and safety standards permit. Through the 2030s, activity should scale into bankable supply chains anchored by large offtake contracts: dedicated renewables should feed multi-gigawatt electrolysis, CCUS-enabled reformers should operate in gas-advantaged regions with verified storage, shared corridors and port infrastructure should connect producers to industrial clusters and shipping-fuel markets; and certification should be tightened to validate emissions reductions. By the 2040s, hydrogen should supply near-zero-carbon feedstocks for chemicals and steel, producing synthetic fuels at scale for maritime and aviation, and act as storage that complements variable renewables.

To realize this pathway, energy utilities may invest in hybrid renewables-plus-electrolyzer projects that operate as flexible loads, secure long-term PPAs for low-carbon power, develop hydrogen storage and safe transmission, and structure hydrogen purchase agreements or contracts-for-difference that value firmness and verified carbon intensity. Chemicals producers can retrofit ammonia and methanol plants for low-emission hydrogen, integrate CO_2 capture to supply power-to-liquids (PtL) synthesis, and co-locate electrolysis with process steam and oxygen integration to improve site efficiency under credible certification. Industry should progress from fuel-switch pilots to hydrogen-DRI/EAF lines, convert high-temperature furnaces where electrification is not feasible, upgrade safety systems, and redesign processes to use incorporate green hydrogen use. Aviation stakeholders can sign long-dated offtakes for e-kerosene, support PtL hubs near captured-CO_2 and hydrogen supply, and limit direct hydrogen uses to niche ground power or short-haul demonstrations while prioritizing SAF pathways. Shipping should pursue corridor-based offtakes for e-ammonia or e-methanol, invest in bunkering, storage, and crew safety, and order fuel-flexible or ‘ammonia/methanol-ready’ vessels to hedge technology risk.

Who to partner with?

- Providers include Thyssenkrupp Nucera, ACWA Power, and Hydrogenious

Where to find more information?

- IEA
- EU Rules for Renewable Hydrogen
- IRENA
- NREL Hydrogen
- Hydrogen Council
- China Hydrogen Alliance
- Hydrogen Financing for Development

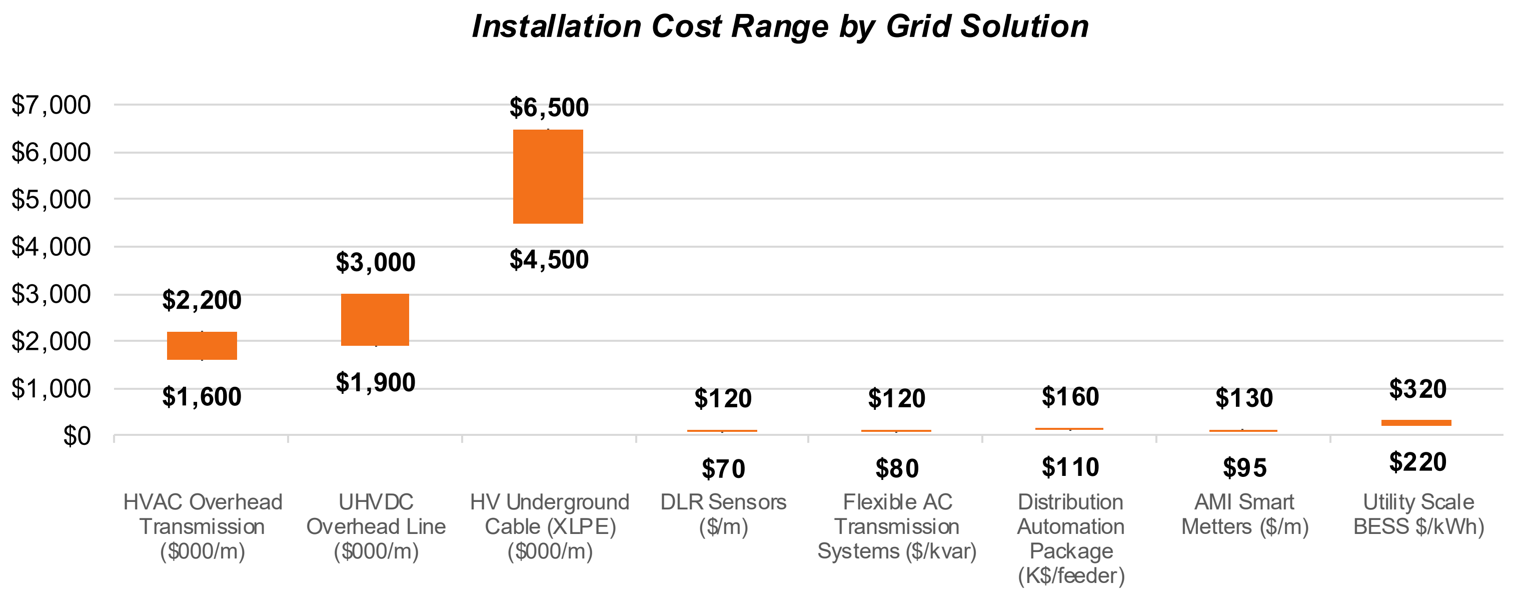
Grid Technologies and Infrastructure

Grid technologies and infrastructure include the physical transmission and distribution infrastructure which makes up electrical grids, including smart grid technologies.

Lever Details

Industry:

- Energy
- Information Technology
- Communications & Telecom
- Buildings and Construction
- Automotives
- Financial Services
- Professional Services



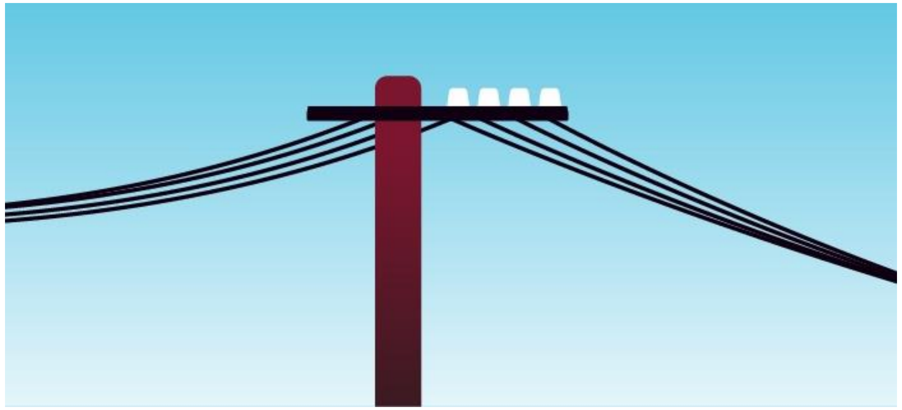
Cost Assumptions and Details

- As electricity demand has burgeoned recently around the world, the **supply of cables, transformers, materials, and other components** need to build accompanying grid infrastructure **has tightened**. This starts at the commodity level and impacts each stage of the currently-constrained value chain. This has led to price increases, further **limiting the buildout of grid infrastructure** alongside generation projects.
- **Land permitting, acquisition, and other use costs** may vary significantly. In countries with **more stringent land use or eminent domain laws, costs may rise.**
- **Labor costs** are another significant component, due to **long project lengths and skilled labor demands.** These can consist of a large portion of build and operation cost.
- **Financing and state support** significantly influences project viability. Investments which are **green-bond compliant** may have lower costs; many transmission and distribution (T&D) companies will report EU Taxonomy-aligned CAPEX.

Grid Technologies and Infrastructure

External Factors, Dependencies, and Systemic Change Opportunities

- The grid needs to **be both modernized and expanded**, to cope with the **increasing complexity and load** from a more **intermittent, distributed, and sizeable power system.** This requires a significant amount of capital and policy attention.
- Grid projects often take **longer to come online** (from ideation to delivery) **than generation projects**, leading to a **global mismatch** where an **estimated >1,650 GW of renewable energy projects have been completed but are waiting to be connected to the grid.** An even greater amount of capacity has not broken ground despite other amenable conditions due to weak grid infrastructure.
- **Efforts are needed at the international, national, and local level** to drive grid development and modernization. **International cooperation can** identify areas of the grid supply chain that are constrained, **and pool technical knowledge, capital, and resources** to easing these. Supportive policy is required to encourage private companies to invest in expansion and modernization, including **low-cost capital, tax abatements, and public co-investment.**
- **Land-use and zoning requirements** will likely have to be overridden to successfully expand the grid within the timeframe required for the transition. This would have to involve **public awareness and engagement campaigns, and likely mechanisms to compensate landowners and local stakeholders.**



Key Impacts Outward on Nature and People

Upstream

Mineral and raw material processing impacts on environment and local labor. **Energy used** during the extraction and processing process, particularly in emerging markets, **may not be renewable.**

Operations

Risks related to land clearing, bird collisions, local electromagnetic field (EMF)concerns, **indigenous land rights**, visual impacts of widespread infrastructure, **cybersecurity vulnerabilities and attacks,** and maintenance worker treatment and safety. Risks related to the **failure to build renewable energy supply, and grid infrastructure supporting further fossil fuel deployment.**

Downstream

Risks related to the **disposal and reuse of grid components and equipment**, including their composite materials and minerals.

Grid Technologies and Infrastructure

Vision for net zero: where does the lever fit in a 2050 net zero world?

Grid technologies and infrastructure are the enabling key to variable renewables, electrification, and flexible demand, used where transmission, distribution, and digital control deliver clean kilowatt-hours when and where they are needed. They provide a pathway to replace fossil peakers and redundancy with smart capacity; advanced inverters, storage integration, and demand response, while expanding transfer capability via reconductoring, Flexible Alternate Current Transmission Systems (FACTS), and high-voltage direct current (HVDC) backbones that minimize curtailment and unlock high-quality wind and solar. Applications span bulk transmission and offshore interconnection, distribution automation and non-wires alternatives, DER management and microgrids for resilience, and data and cybersecurity layers that coordinate millions of devices. Their sustainability rests on doing more with less land; uprating existing corridors, dynamic line ratings, topology optimization, and targeted undergrounding where risk is highest, while embedding interoperability, safety, and privacy so modern grids distinguish themselves from legacy, one-way networks that net-zero pathways phase out.

In the near term, grid-enhancing technologies and process reforms must be scaled, including advanced distribution automation and protection, feeder hosting-capacity mapping, dynamic line ratings and topology optimization on priority corridors, and standardized advanced-inverter settings (including grid-forming modes). Interconnection queue reforms and targeted non-wires procurements should prioritize storage, demand response, and microgrids where they can relieve constraints faster than traditional upgrades. In the 2030s, investment should accelerate into capacity and digitalization, such as high-capacity reconductoring of AC lines, regional HVDC spines and back-to-back ties, meshed offshore transmission, and digital substations, co-located with flexible loads (EV charging, heat pumps, electrolyzers) and orchestrated by Distributed Energy Resource Management Systems (DERMS), advanced metering infrastructure (AMI), and real-time telemetry and controls. By the 2040s, the grid should provide dependable transfer and ramping capability across seasons and regions, enabling 24/7 carbon-free operations, with coordinated transmission-distribution-DER operations and locational flexibility to minimize curtailment.

To realize this pathway, energy utilities may invest in T&D upgrades, HVDC links, digital substations, and DER markets, structuring capacity and flexibility contracts that value duration, response speed, and availability, while aligning with interconnection and cost-allocation reforms. IT firms can deploy cloud-edge data platforms, AI-driven forecasting, and cybersecurity operations that meet utility-grade requirements, while telecom operators extend fiber and 5G for grid-critical latency and reliability and harden networks with clean backup. The construction sector should deliver “grid-ready” assets, with EV-capable wiring, thermal and battery storage, advanced controls, and integrate with demand-response programs and microgrids. Automotives should enable managed charging and vehicle-to-grid capabilities and stand up second-life battery supply for stationary storage. Financial Services have a critical role to play in scaling regulated asset base (RAB) models, green bonds, securitization of distributed assets, and insurance for performance and cyber risk, while professional services accelerate planning, permitting, community engagement, and independent MRV of reliability and emissions outcomes. Policy engagement is crucial, including support for regional transmission planning and cost allocation, performance-based regulation for distribution, interoperability and cybersecurity standards, flexibility market design, and predictable siting timelines

Who to partner with?

- Providers include Hitachi Energy, Siemens Energy, and Schneider

Where to find more information?

- IEA
- U.S. Department of Energy Grid Modernization Initiative
- EU Ten-Year Network Development Plan

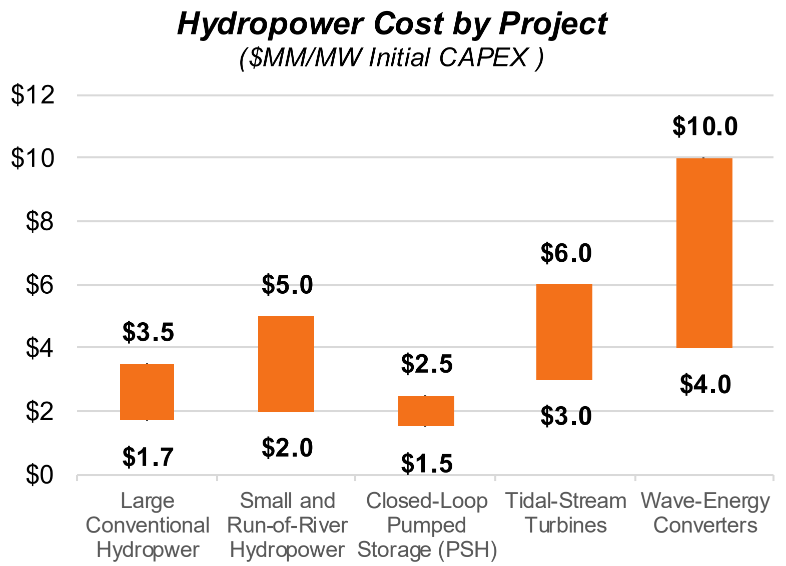
Hydropower

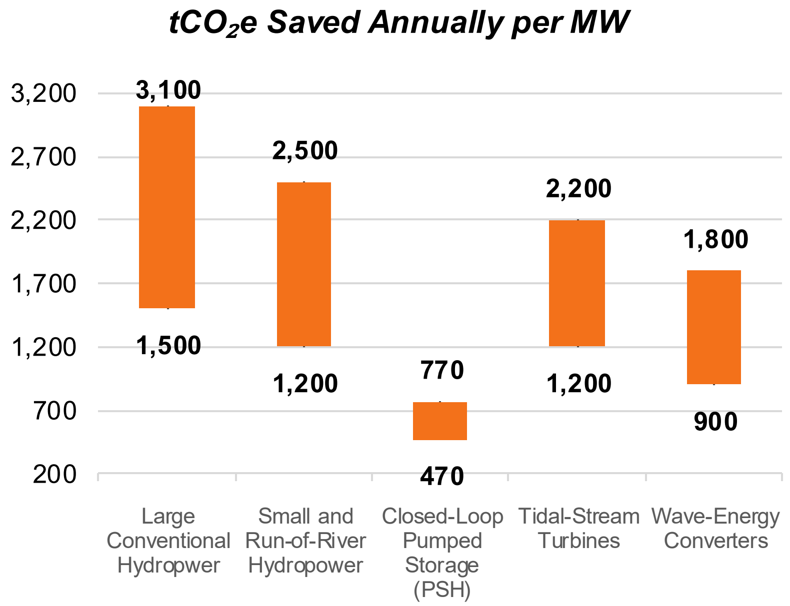
Hydropower includes large and smaller hydropower projects (e.g., large-scale hydropower dams, small scale tidal energy), including those that may be deployed in open waters, and hydropower-driven energy storage.

Lever Details

Industry:

- Energy
- Mining and Extractives
- Buildings and Construction
- Chemicals
- Shipping and Logistics
- Financial Services
- Professional Services





Cost Assumptions and Details

- **Project economics** are dominated by **site characteristics**. An increase of 100m in dam height or 300m in head-race tunnel length can raise conventional hydropower CAPEX by 10-15 percent.
- For Pumped Storage Hydropower (PSH), every additional meter of gross head typically lowers CAPEX by ~60 $/kW because **smaller reservoirs can deliver the same energy.**
- **Tidal and wave projects** remain sensitive to marine construction cost (vessel day-rates), device reliability, and array size. **Doubling the turbine rotor diameter or moving to slip-joint foundations** cuts levelized cost of energy (LCOE) by 1-25 percent.
- **Maintenance and operational costs** may vary based on plant design and characteristics, in addition to the cost of local labor. Some plants may require significant constant adaptive work, while others may be able to run "as-is" for long periods of time.

Hydropower

External Factors, Dependencies, and Systemic Change Opportunities

- **Permitting reform is needed** across major markets **to accelerate project timelines.** Hydropower has been used in some form for hundreds of years and today serves as the world's largest source of renewable energy. However**, project timelines and cost push governments to look to other sources,** and total generation has even fallen in recent years due to droughts.
- **Hydropower provides unique benefits** by serving as a power source that is **renewable, relatively easy to store, has limited intermittency**, and may be constructed using largely native materials and expertise in many markets. Policymakers should recognize these benefits and develop targeted financing mechanisms and public-private partnerships to move hydropower projects forward.
- Due to lengthy construction timelines and high upfront costs, **the effective cost of capital** is a crucial determinant of project cost and if a project moves ahead. Developing both supply-side and demand-side initiatives, such as PPAs and localized industry projects built alongside the plant, may lower the inherent risk of the project.
- Many hydro plants require **renovation and repair to continue their operation into the 21st century,** become more efficient, and generate more power.

Key Impacts Outward on Nature and People

Upstream

Risks related to **land acquisition, ecosystem fragmentation, and construction carbon footprint. Indigenous and community consent processes** and potential displacement are critical to manage.

Operations

Risks of **altered river hydrology, fish migration barriers, sediment trapping, reservoir methane, and tidal collisions**. Occupational safety risks in dam maintenance and offshore servicing.

Downstream

Risks related to **dam decommissioning, sediment management, and rehabilitation of reservoir lands.** Risks related to removal or repowering of marine devices and subsea cables; **recycling of composite blades and generators.**

Hydropower

Vision for net zero: where does the lever fit in a 2050 net zero world?

Hydropower provides firm, flexible, low-carbon power and long-duration energy shifting. It provides a pathway to replace coal and gas in baseload and mid-merit generation, to displace fossil-fueled peakers through rapid ramping and inertia, and to supply black-start and frequency services that stabilize increasingly electrified systems. Applications span run-of-river plants, reservoir hydro, conversions of non-powered dams, and pumped-storage hydropower that absorbs surplus renewable generation and returns it on peak or across days and seasons. Its sustainability rests on rigorous water stewardship and social safeguards; environmental flows, fish passage, sediment management, methane monitoring and mitigation in warm reservoirs, climate-resilient design, and benefit-sharing with affected communities.

In the near term, refurbishment and upgrades of existing plants should be emphasized (new runners, generators, and control systems), along with grid-oriented flexibility upgrades (digital governors, advanced controls), selective electrification of low-impact non-powered dams, and early closed-loop or off-river pumped storage; co-location with floating PV and updated operating rules should cut curtailment, while climate-informed hydrology, sediment management, and reservoir methane mitigation become standard in permitting. Through the 2030s, investment should scale toward portfolios guided by basin-level planning that co-optimizes water, energy, and ecosystems; closed-loop pumped storage should expand, transmission reinforcements should target hydro corridors, and nature-positive measures should be embedded with digital twins and advanced forecasting to manage drought and extremes. By the 2040s, hydropower should deliver dependable, rampable capacity and seasonal balancing that complements variable renewables, provides black-start and inertia services, and lowers total system cost by deferring grid reinforcements, while adaptive reservoir operations sustain 24/7 carbon-free operations and enhance resilience to prolonged droughts and extreme weather.

Energy utilities may prioritize life-extension and uprates, hybrid wind/solar-hydro portfolios, closed-loop pumped storage tied to capacity and ancillary-service contracts, and digitalization for flexibility, while engaging in basin planning and drought-resilience programs. Mining and extractives can replace diesel with hydro-backed microgrids where feasible, convert pit lakes or dewatered workings into pumped-storage reservoirs, and contribute drilling, geotech, and environmental expertise to lower project risk. Chemicals and other electro-intensive industries can secure firm, low-carbon power via long-term PPAs with hydro and pumped storage, co-locate flexible electrolysis or thermal loads that soak up off-peak output, and integrate heat-recovery where appropriate. Information technology firms can co-site data centers with hydro for 24/7 carbon-free electricity and deploy forecasting, supervisory control and data acquisition (SCADA), and cybersecurity layers that monetize flexibility. Financial services have a critical role to play by structuring long-tenor project finance, regulated-asset-base or availability models for pumped storage, hydrology and revenue-stability insurance, and sustainability-linked instruments tied to ecological performance and community outcomes, while professional services accelerate permitting, FPIC and impact assessment, engineering assurance, and independent MRV. Policy engagement should focus on extending the useful life of assets and easing the permitting process for new, environmentally and socially compliant projects.

Who to partner with?

- Providers include Andritz, Voith, and Orbital Marine Power

Where to find more information?

- IEA
- Ocean Energy Europe
- NREL

Nuclear

Nuclear includes large and small-modular fission reactors, with fusion not yet mature enough for consideration.

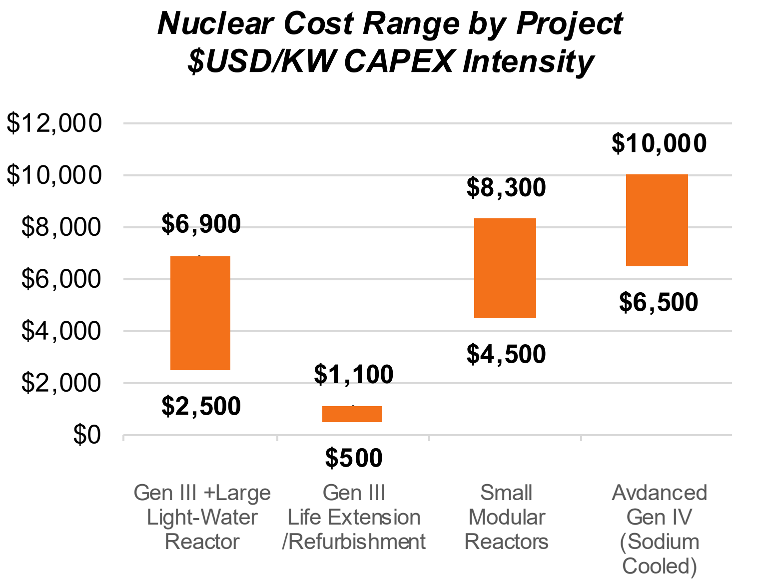
Lever Details

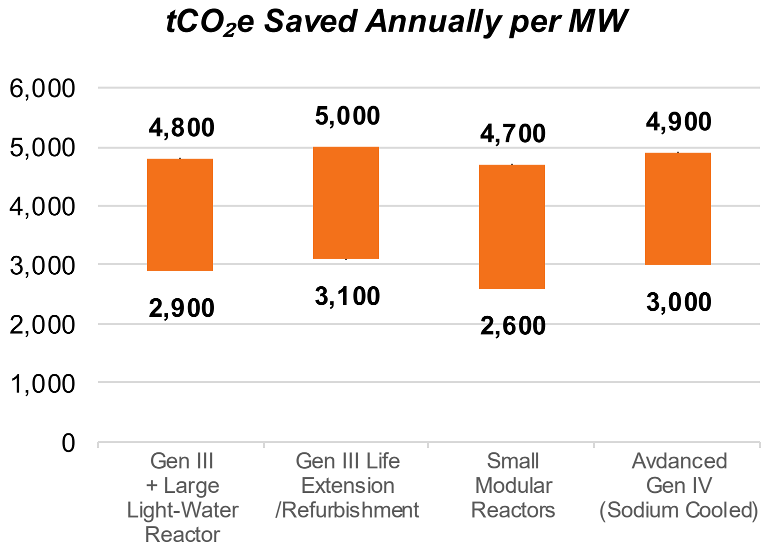
Industry:

- Energy
- Healthcare
- Information Technology
- Financial Services
- Mining and Extractives
- General Manufacturing and Industry
- Professional Services

Cost Assumptions and Details

- Project price **varies significantly around the world.** While projects in the U.S., and even in nuclear-forward France, have run over budget and timeline in recent years, **China has established a cohesive, native nuclear plant value chain,** which has enabled it to bring down costs through **replicable project approaches.**
- **Small modular reactors** are often **more expensive** than large reactors when adjusting for generation intensity, due to the inherent benefits of replicability.
- **Construction time, labor costs, useful lifespans, and project type and complexity** all determine total costs.
- **Financing rates** are crucial due to project timelines: unclear demand-side economics may raise the cost of projects funded through private mechanisms, while purchase agreements and state financing mechanisms, preferably deployed in harmony, bring down project risk and interest costs.





Nuclear

External Factors, Dependencies, and Systemic Change Opportunities

- Nuclear energy has faced **public opposition and geopolitical roadblocks** that have tempered its deployment since its invention. Fears of **negative effects from nuclear waste, site accidents, and local exposures** have led to community opposition to local facilities, while the global market for radioactive materials has had to grapple with restrictions and oversight imposed to stop enrichable materials falling into malevolent possession. These dynamics have **embedded costs and timeline delays** into any strategy focusing on the expansion of nuclear power.
- **Industrial, financing support and directed policy** is needed to **bring down the cost and improve the design of small modular reactors (SMRs)**, which may be deployed across a range of localized energy demands, such as district heating and data centers. In the long-run, **SMRs present the best opportunity to bring down the cost** of nuclear projects to other renewable energy sources, **once their supporting infrastructure is established.**
- Specialized financing mechanisms, including the inclusion of nuclear power within green bond taxonomies, can assist in bringing down financing costs. **Developing public-private partnerships**, both for financing and demand-side purchase agreements, creates the **strongest foundation for the flywheel of innovation, deployment speed, and affordability.**

Key Impacts Outward on Nature and People

Upstream
Uranium mining may cause land disturbance, including effects to water, biodiversity, and local communities. **Risks of infringement of indigenous land rights** due to mining. Enrichment and mining processes may be energy-intensive and not use renewable energy.

Operations
Risks of severe accidents, which may cause significant radiation poisoning, damaging the health of people and the environment. **Risks to labor, particularly health and safety.**

Downstream
The **decommissioning of nuclear power plants** includes a large amount of **waste, which should be recycled and reused as much as possible to avoid negative impacts.** Risks related to the **handling and safe disposal of nuclear waste**, particularly in less mature markets.

Nuclear

Vision for net zero: where does the lever fit in a 2050 net zero world?

Nuclear provides firm, low-carbon baseload power where variability or seasonal gaps cannot be covered by wind, solar, or batteries alone. It replaces coal and gas in the power sector, offers high-temperature steam and heat for industrial processes, and produces isotopes essential for medical applications. SMRs and advanced designs extend these uses by bringing flexible, dispatchable generation to smaller grids, remote locations, or industrial sites. Unlike bioenergy or hydrogen, nuclear does not rely on continuous feedstock supply chains; its sustainable use rests on strong safety regulation, robust waste management, and long-term stewardship of spent fuel.

In the near term, deployment should focus on life-extension and upgrades of the existing fleet, including digital modernization, component replacements, and flexible operations, while first-of-a-kind small modular and advanced reactors progress through licensing, fuel qualification, and early demonstration at brownfield sites (including retired coal plants) with clear programs for waste management and workforce readiness. Through the 2030s, modular and advanced designs should begin to scale, with standardized designs and factory fabrication reducing schedule risk; projects should integrate with hybrid energy systems, including district heat, desalination, high-temperature industrial heat, and hydrogen production, using thermal storage to load-follow variable renewables, under dedicated financing structures that de-risk capital. By the 2040s, nuclear should serve both as a backbone of reliable clean electricity, especially where local renewable resources or land availability are constrained, and as a climate service providing dense, continuous high-temperature heat for industry and synthetic fuels.

To realize this pathway, industries need to integrate nuclear into their decarbonization planning by aligning capital investment, risk management, and policy engagement. Energy utilities can secure financing frameworks that make long-lived nuclear assets bankable, often via capacity payments, regulated asset base models, or sovereign guarantees. Healthcare providers can plan for stable isotope supply chains anchored in nuclear medicine production, while information technology and data centers can leverage nuclear's baseload stability for 24/7 carbon-free electricity portfolios, particularly aligned alongside data center buildouts. Financial services have a critical role in standardizing risk allocation, supporting investment frameworks and taxonomies that recognize nuclear's contribution to net zero, and enabling blended finance models for SMRs in emerging markets. Mining and extractives companies should ensure responsible uranium sourcing and long-term waste stewardship, embedding community engagement and environmental safeguards. Heavy industry can evaluate nuclear heat and hydrogen as substitutes for fossil fuels in high-temperature processes, while professional services will be needed to provide legal, engineering, and risk-advisory expertise. Policy engagement may include supporting licensing reforms to shorten approval times, advocating for nuclear's inclusion in clean-energy standards and taxonomies, and backing public–private partnerships that de-risk experimental projects.

Who to partner with?

- Providers include GE Hitachi, Westinghouse, and Terrestrial Energy

Where to find more information?

- IEA
- Nuclear Energy Agency
- World Nuclear Association
- International Atomic Energy Agency
- China Atomic Energy Authority

Solar

Solar includes panels mounted on the ground for utility and industry, in addition to residential and other applications.

Lever Details

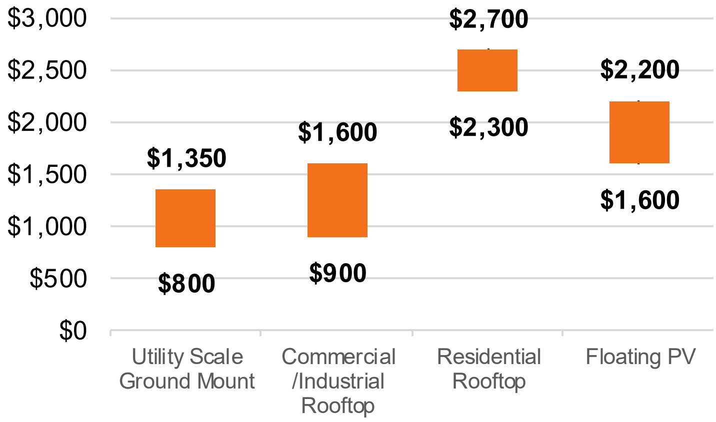
Industry:

- Energy
- Buildings and Construction
- Information Technology
- Mining and Extractives
- Financial Services
- Consumer Goods
- Professional Services

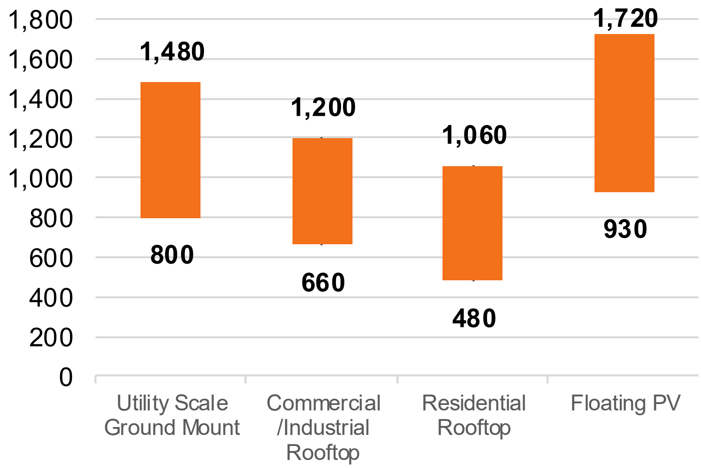
Cost Assumptions and Details

- The price of solar installation around the world has **fallen significantly over the last fifteen years**, driven by efficiencies in manufacturing and supply chains.
- Most modern commercial systems **will cost between $1-2/W. Operation and maintenance costs may run from $0.01-0.05 annually,** varying with system type and local conditions.
- The **largest variations** of final cost for solar installation **come from "soft costs"**: labor, permitting, and interconnection costs which vary significantly based on location.
- **Premium, high-efficiency panels** (e.g., n-type, bifacial) or advanced inverter systems **can raise upfront costs** but may increase energy yields, as can rooftop or residential installations.
- Subsidies and public financing mechanisms are an effective tool to reduce lifetime costs.

Solar Power Cost by Project $USD/KW CAPEX Intensity



tCO_2e Saved Annually per MW



Solar

External Factors, Dependencies, and Systemic Change Opportunities

- Continued improvements to **manufacturing efficiency** and supply chain integrations are **projected to continue to drive prices down**. **Steel prices** affect total projects costs.
- **Regional gaps in cost may continue** to persist due to embedded soft costs. **Geopolitical tensions** and trade dynamics **may affect global supply** and affordability.
- **Interconnection queues** are **the main bottleneck**; **storage and transmissions projects need to be approved** and developed **for the glut of solar panel supply to be fully deployed.**
- Tailwinds for both manufacturing subsidy and deployment exist around the word, but **oversupply may lead to a pullback in manufacturing investment** and an eventual increase in prices.
- **Recycling regulations** have become more common as the lifetime effects of PV modules have come under scrutiny.

Key Impacts Outward on Nature and People

Upstream

Mining of silica, metals, and rare metals used in solar PV manufacturing can result **in land degradation, water pollution, and habitat loss. Polysilicon production can be energy intensive**, and facilities and regions where it has been produced have been scrutinized for **labor rights violations.**

Operations

Cell and module manufacturing can involve **hazardous chemicals, improper handling or disposal can contaminate soil and water** and endangerment of workers. Manufacturing facilities and assembly plants may **still rely on fossil-based electricity.**

Downstream

Large **ground-mounted solar farms** can affect **local ecosystems, migratory pathways, or agricultural land.** End-of-life PV modules contain valuable but also potentially **toxic materials.** Inadequate recycling infrastructure can lead to **e-waste challenges.**

Solar

Vision for net zero: where does the lever fit in a 2050 net zero world?

Solar is used wherever low-cost, zero-carbon electricity and low-temperature heat are essential. It provides a pathway to replace coal and gas in grid generation, to displace diesel in remote and backup power, and to electrify end-uses by pairing photovoltaic output with heat pumps, induction, and EV charging. Applications range from utility-scale PV and concentrated solar thermal with thermal storage to distributed rooftop and community solar, building-integrated PV, agrivoltaics, floating PV, and process heat for food, beverage, and light industry. Its sustainability relies on responsible minerals and polysilicon sourcing, tight labor-rights and traceability controls, high module efficiency and long lifetimes, and circularity via repair, repowering, and recycling.

In the near term, utility-and distribution-scale PV, hybrid-solar-plus-storage' with 1–4-hour batteries, and rooftop/community projects should be accelerated, supported by advanced inverter settings (including grid-forming modes), streamlined interconnection and hosting-capacity processes, and tariff designs that reward flexibility (e.g., smart EV charging, pre-heating/cooling) to defer traditional upgrades. Through the 2030s, deployment should scale on the back of higher-efficiency modules (bifacial, TOPCon, tandem), widespread trackers and digital controls that shape output to grid needs, and targeted additions of long-duration storage where curtailment rises; PV should increasingly co-optimize with flexible loads (electrolyzers, heat pumps, charging depots) and expand via reconductored corridors and selective HVDC links, while concentrating solar thermal with thermal storage and solar industrial heat mature in high-DNI (direct normal irradiance) regions with dual-use siting (agrivoltaics, rooftops, parking canopies) becoming standard. By the 2040s, solar paired with storage and grid enhancements should deliver rampable capacity and contribute to multi-day balancing, while improved siting, forecasting, and geographic diversity enable 24/7 carbon-free operations; circular supply chains (repair, reuse, and high-recovery recycling) should keep materials in productive use and lower system costs over time.

To realize this pathway to net zero, energy utilities can contract hybrid PPAs, procure long-duration storage to firm solar output, and invest in transmission, dynamic line ratings, and DER orchestration to minimize curtailment and improve capacity value. Buildings and construction actors can make assets 'solar-ready' through codes and design, deploy rooftop and building-integrated PV tied to heat pumps, thermal/battery storage, and EV charging, and standardize warranties and digital measurement for bankable performance. IT firms can secure 24/7 carbon-free portfolios by combining on-site PV, storage, and demand shifting with granular PPAs and participation in virtual power plants. Mining and extractives can replace diesel with solar-hybrid microgrids, co-site PV with remediation and water assets, and commit to responsible procurement and end-of-life recycling. Financial services can scale capital via project finance, tax equity or green securitizations, performance insurance, and standardized contracts that price flexibility and curtailment risk, while supporting traceability and recycling mandates that protect asset value. Policy engagement across these sectors should prioritize streamlined siting and interconnection, community and rooftop solar frameworks, fair net billing and flexibility markets, modernized building codes, import and supply-chain traceability standards, and end-of-life recycling requirements.

Who to partner with?

- Global providers include Swinerton, Mortenson, Sterling and Wilson, and Bechtel—the industry is large and fragmented, and local options are often suitable.

Where to find more information?

- SEIA (Solar Energy Industries Association)
- IEA Renewables Market Report
- Project Drawdown – Distributed Solar Photovoltaics

Wind

Wind includes onshore and offshore wind power generation projects.

Lever Details

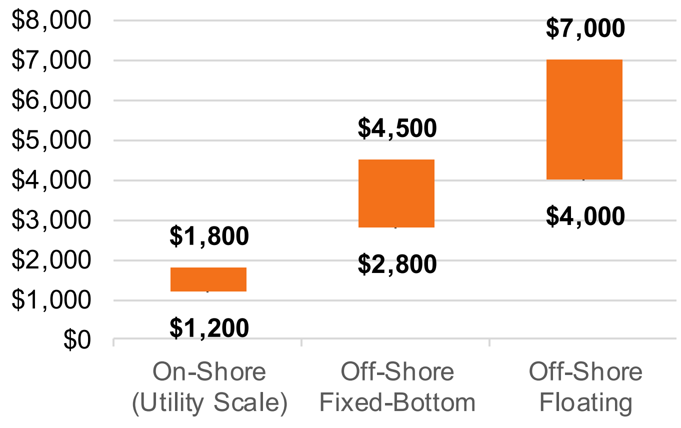
Industry:

- Energy
- Buildings and Construction
- Mining and Extractives
- Shipping and Logistics
- Financial Services
- General Manufacturing & Industry
- Professional Services

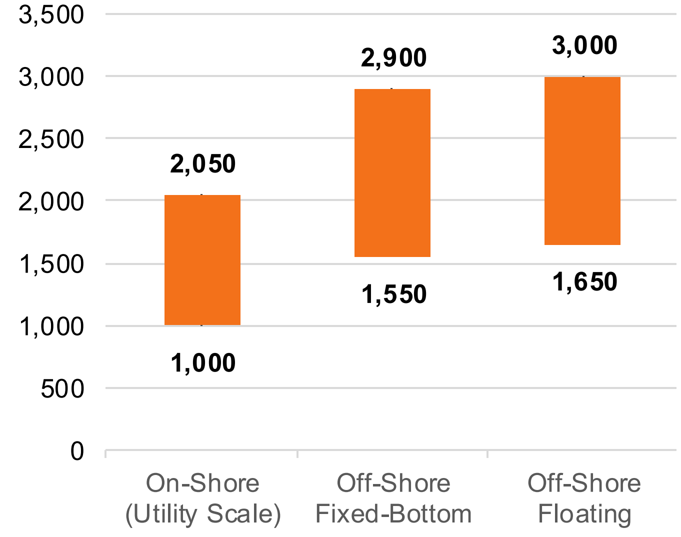
Cost Assumptions and Details

- **On-shore wind farms** are currently significantly **cheaper than offshore farms** both upfront and annual O&M costs. However**, offshore farms offer the potential to access stronger winds** and **build larger facilities.**
- The **deeper and more distant the offshore wind project**, the **higher the projected development cost.**
- The **turbines themselves form the largest cost driver** for a wind farm, with the rest of the costs stemming from **foundations, cables, and electrical equipment.**
- Offshore turbines are likely to have **higher capacity factors,** allowing them to pay back investment faster.
- Wind farms are **sensitive to fluctuations in steel prices,** in addition to other metals such as aluminum.
- **Moderate constraints in some components** have **led to price fluctuations, but Chinese capacity is anticipated to grow** to meet **expected demand for announced projects.**

Wind Power Cost by Project $USD/KW CAPEX Intensity



tCO_2e Saved Annually per MW



Wind

External Factors, Dependencies, and Systemic Change Opportunities

- Wind has **recently struggled in deploying at scale** compared to solar due to issues in **transmission and grid connectivity, permitting processes, community opposition, intermittency, land use impacts, and costs.**
- Developing a pathway to economically deploying offshore wind **circumvents issues of permitting, community, and land**, while increasing challenges related to transmission infrastructure. **Ports need to be upgraded to be able to handle the blades for offshore wind turbines,** which can be as large as 120m. **Floating wind farms,** which may be deployed further from land and where building solid foundations is not realistic, **are now being commercialized for the first time,** and are expected to **fall in price in the coming years.**
- **Supply chain constraints** for certain parts, such as nacelle bearings, weigh on global development times. **Grid congestion in Europe and the U.S.** has led to **curtailment penalties**: storage and grid modernization are crucial enablers of expanding intermittent wind energy.
- As a result of structural headwinds, **wind energy companies have struggled in the public markets,** deterring new entrants and more investment. The public sector needs to develop **an amenable policy infrastructure to amend this sentiment.**

Key Impacts Outward on Nature and People

Upstream

Steel and copper, both critical materials for turbine production, have **high lifetime CO_2 emissions.** Risks related to **mining for rare earths for magnets**. Risks related to labor practices and energy use in component manufacturing facilities.

Operations

Risks related **to bird collisions, noise, and impacts on marine mammals**. Risks related to **labor safety, particularly offshore, and erosion of blades and their supporting infrastructure.**

Downstream

Blades and other components can form a significant source of waste if not disposed, recycled, and reused correctly. **Supporting offshore wind infrastructure** such as undersea cables must be responsible decommissioned.

Wind

Vision for net zero: where does the lever fit in a 2050 net zero world?

Wind complements solar to act as the fulcrum of variable, clean, cheap energy generation. It replaces coal and gas in bulk generation, to displace diesel in remote microgrids, and to electrify end-uses through power purchase agreements that hedge energy costs while cutting embodied emissions in products and services. Applications span utility-scale onshore wind, fixed-bottom offshore wind in shallow waters, and floating offshore wind that opens deep-water resource basins; hybrid 'wind-plus-storage' plants firm output and provide grid services, while co-location with electrolysis enables low-emission hydrogen in resource-rich nodes. Sustainability rests on responsible sourcing of steel, copper, and rare-earth materials, wildlife and fisheries safeguards, community benefit frameworks, blade-to-blade recycling and repowering, and careful siting and transmission planning.

In the near term, onshore build-out and repowering should be accelerated, deploying taller towers and larger rotors on existing sites, alongside fixed-bottom offshore projects in permitted areas; hybridization with 1–4-hour batteries, advanced forecasting, wake steering, curtailment minimization, and condition-based maintenance should be used to raise capacity value and availability while streamlined siting, community benefits, and wildlife safeguards keep projects bankable. Through the 2030s, deployment should expand along transmission-ready corridors: floating offshore should scale into deep-water provinces as ports, installation vessels, and HVDC backbones mature; onshore repowers should continue where land and transmission are constrained; and wind should increasingly co-optimize with long-duration storage, flexible industrial loads, and electrolyzers to absorb surplus output and stabilize grids under market designs that reward flexibility. By the 2040s, diversified wind fleets, geographically distributed across onshore, fixed-bottom, and floating sites, should provide dependable seasonal balancing in portfolios with storage and transmission, lowering total system cost by reducing fuel risk, deferring peakers through smart siting and hybrid portfolios, and enabling 24/7 carbon-free operations, with circular blade and nacelle supply chains standardized.

Energy utilities can secure long-dated PPAs or contracts-for-difference, invest in reconductoring and HVDC for interconnection, build hybrid wind-plus-storage portfolios, and digitalize O&M to mitigate weather and price cannibalization risk. Buildings and construction owners can make adapt assets via virtual PPAs and demand-flex programs that align HVAC, thermal storage, and EV charging with wind output, and incorporate low-carbon materials from wind-powered suppliers. Financial services scale project finance, tax equity, and green securitizations; underwrite resource, curtailment, and merchant risks; fund domestic manufacturing of towers, nacelles, blades, and cables; and support blade-recycling infrastructure. Heavy industry may sign 24/7 carbon-free portfolios that blend wind with storage and demand flexibility, time energy-intensive processes to windy hours, and localize component production with verified low-carbon inputs. Professional services can accelerate permitting and community engagement, fisheries and wildlife assessments, seabed and geotechnical studies, contracting and claims management, and independent MRV (monitoring, reporting, and verification) for performance, biodiversity, and socio-economic outcomes. Cross-cutting policy priorities include streamlined siting and offshore leasing, timely transmission planning and cost allocation, port modernization, recycling and decommissioning standards, and market designs that properly value capacity, flexibility, and congestion relief.

Who to partner with?

- Providers include Vestas, Orsted, Principle Power, and Siemens Gamesa

Where to find more information?

- IEA
- NREL
- Global Wind Energy Council
- EU Status Report
- U.S. Department of Energy
- Evolution of floating offshore wind platforms: A review of at-sea devices

Transport

Light-Duty and Micro-Mobility

Includes passenger electric vehicles, 2-and-3-wheel EVs, e-bikes and scooters, and light-duty vans. Includes shared mobility solutions.

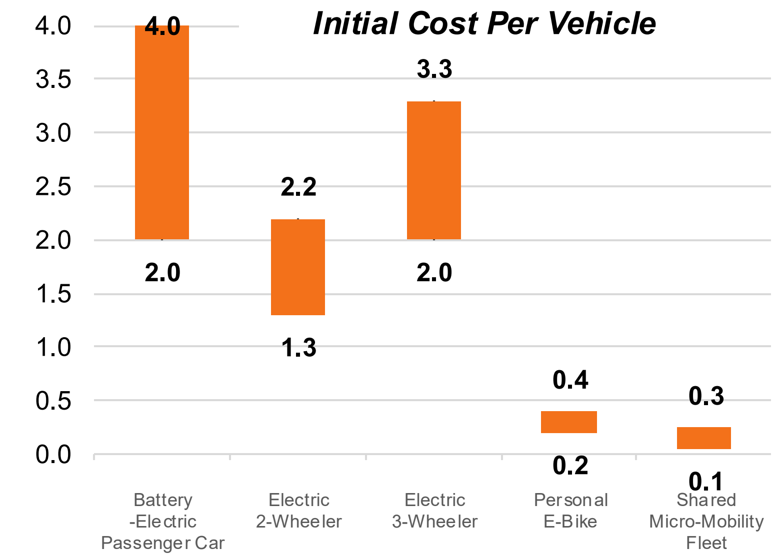
Lever Details

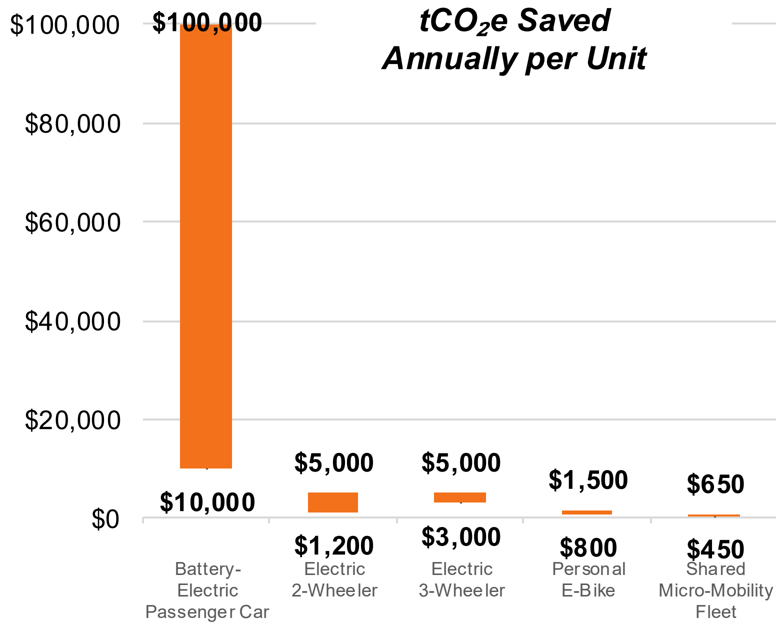
Industry:

- Automotives
- Consumer Goods
- Shipping and Logistics
- Information Technology
- Energy
- Financial Services
- Professional Services

Cost Assumptions and Details

- Electric vehicle prices **vary around the world,** particularly for four-wheeler passenger cars. **Innovation and competition in China has unleashed a wave of affordable options**, which are frequently sold for higher prices abroad due to **industry and trade dynamics.**
- **Smaller, lighter solutions** are often **cheaper**. Batteries are a large cost determinant. **Large vehicles require larger and more sophisticated batteries.**
- Two-and three-wheelers often use **battery leasing models,** particularly in the developing world, **shifting the initial investment burden** from the consumer.
- Consumers **save on fuel costs to some extent** but **must pay for charging and other maintenance costs.**
- **Shared mobility solutions** bring down individual cost burdens.

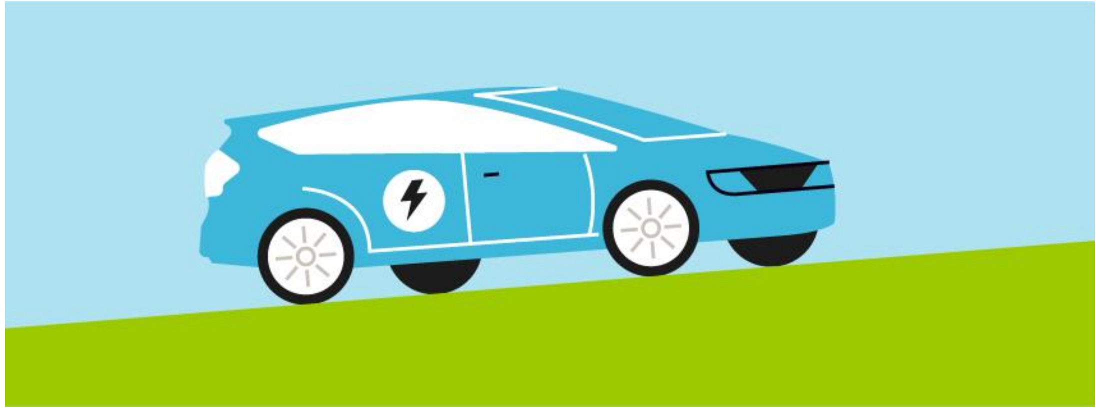




Light-Duty and Micro-Mobility

External Factors, Dependencies, and Systemic Change Opportunities

- **Electric vehicle (EV) acceptance** remains contingent on **affordability and reliability.** In the developed world, EVs are yet to offer **the same diversity and quality of passenger vehicles at comparable prices** to their combustion-engine counterparts. **In the developing world, the default is to purchase the most affordable vehicle possible,** which outside of China, **is typically not an EV** in the four-wheeler market.
- At the same time, **vehicles need to both complete longer trips without charging, with lower fluctuations in battery usage across conditions**, and a **far larger network of public chargers** needs to be established**. EV charger deployment is deeply uneven**, and this dynamic is reflected in heterogenous consumer uptake around the world.
- **Policy mandates are crucial** to enabling the EV transition. While China has both the industrial capacity and technical expertise to supply the world with affordable EVs within the foreseeable future, **vehicle manufacturing is a particularly sensitive industry due to the native industrial base and employment** it creates. Either countries allow their domestic producers, outside of the luxury market, to fold against market forces, or they significantly subsidize, support, and enforce domestic EV production and the retirement of combustion engines.



Key Impacts Outward on Nature and People

Upstream
Risks related to **lithium, cobalt, and nickel mining impacts**, particularly in vulnerable and unstable regions. Labor risks related to switching from fossil fuels, and related **displacement of jobs and economic activity.**

Operations
Risks related to **battery fires, vehicle safety, and product affordability and reliability.**

Downstream
Risks related to **battery waste, e-waste from vehicles**, including retired combustion-engine vehicles, and **tire-particulate pollution.**

Light-Duty and Micro-Mobility

Vision for net zero: where does the lever fit in a 2050 net zero world?

Light-duty and micro-mobility are demand-side complements to public transport and active travel, used where short-to-medium range trips can be electrified with small batteries and high utilization. They replace gasoline in passenger cars and vans through battery electric vehicles, and to displace two-stroke and small combustion engines with e-bikes, e-mopeds, and e-cargo bikes for personal travel and last-mile logistics. Applications span private and shared cars, car-share and ride-hail fleets, neighborhood electric vehicles, and compact delivery form factors that outperform vans in dense areas. Their sustainability involves right-sizing vehicles, efficient power electronics and motors, chemistries with lower critical-material intensity, high safety standards for batteries and chargers, and circularity via repair, second life, and recycling.

In the near term, rapid substitutions should emphasize mass-market battery-electric vehicles, with plug-in hybrids as a transitional option, alongside fleet conversions for ride-hail, delivery, and corporate pools, and large-scale uptake of e-bikes and e-cargo bikes; ubiquitous Level-2 workplace and depot charging, targeted DC fast charging on corridors, and digital routing/charging tools and tariffs should be deployed to cut total cost of ownership and range uncertainty. Through the 2030s, mobility systems should mature around managed charging, vehicle-to-home/grid where it is cost-effective, and battery-swap, all paired with renewable PPAs, depot microgrids, and distributed storage; cities should mainstream protected micromobility lanes, secure parking and charging facilities, curb-management and building codes that accommodate small electric vehicles at scale, and interoperable payments/roaming to simplify use. By the 2040s, light-duty electrification and micromobility should deliver a dual service: aggregated, controllable electric load and distributed storage that provide grid flexibility and reliability, and system optimization that lowers total vehicle-kilometers traveled through sharing, pricing mechanisms, higher occupancy, and right-sizing of form factors, delivering enduring reductions in energy use, congestion, and urban air and carbon emissions.

To realize this pathway, the automotive industry should commit to dedicated EV platforms and right-sized models, diversify chemistries toward lithium iron phosphate (LFP) and sodium-ion where feasible, standardize telematics for managed charging and vehicle-to-grid, and offer battery warranties and certified reuse channels that stabilize residual values. Consumer goods companies can electrify employee commutes with universal transit and e-bike benefits, convert retail and service fleets to EVs, and shift last-mile to e-cargo bikes and compact EVs. Shipping and logistics should electrify urban and suburban routes first, redesign routes for micromobility throughput, and build depot charging optimized for dwell times and load profiles. Technology firms can deliver fleet-as-a-service platforms that integrate dispatch, telematics, charging orchestration, and grid signals, enabling participation in demand response and virtual power plants. Energy companies should deploy interoperable charging networks, tariff structures that reward off-peak and flexible charging, and on-site solar-plus-storage at depots to hedge costs. Financial services can scale green auto loans, leases, and asset-backed securitizations for EVs, e-bikes, and charging, underwrite performance and battery-health insurance, and offer transition finance for depot and building upgrades. Policy engagement across these sectors should support strong efficiency and tailpipe standards, e-bike incentives and safe-infrastructure build-out, building codes for charging facilities and wiring readiness, interoperability for payments and connectors, and market designs that compensate flexible charging and distributed storage.

Who to partner with?

- Providers include BYD, Tesla, and Hyundai

Where to find more information?

- IEA
- BloombergNEF
- UNEP
- NREL

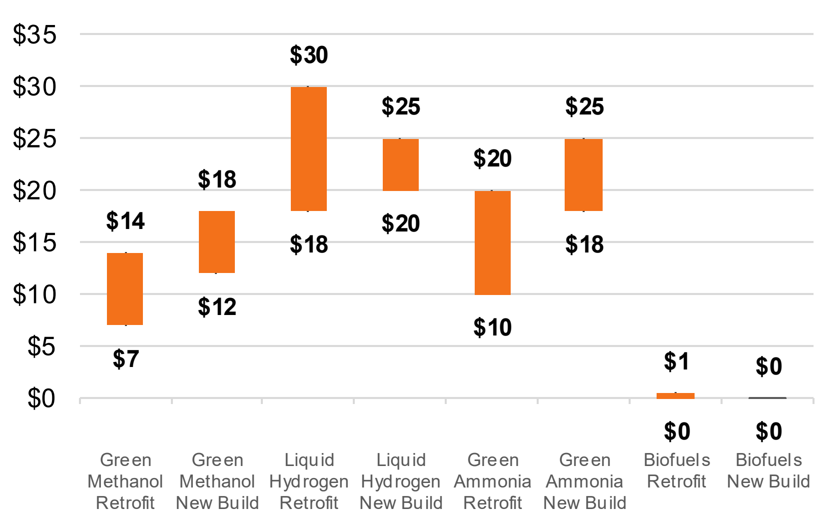
Maritime Decarbonization

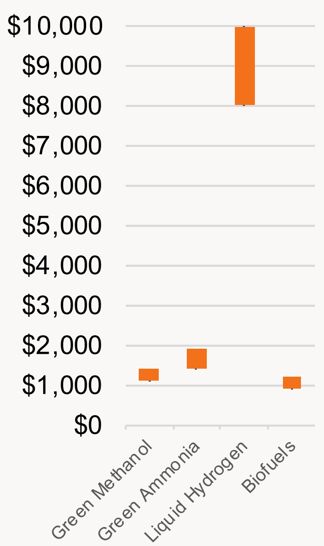
Includes ship retrofitting, manufacturing, and sustainable fuel costs

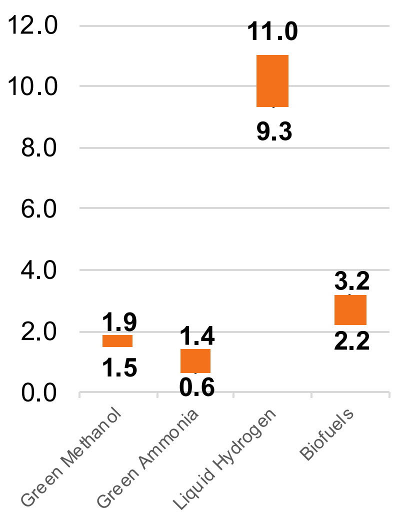
Lever Details

Industry:

- Shipping and Logistics
- Energy
- Mining and Extractives
- Consumer Goods
- Chemicals
- Automotives
- Financial Services







Cost Assumptions and Details

- The **fuel that is used**, and the **accompanying potential upgrades** which a ship would need to be able to process the fuel, is the main determinant of costs.
- **Certain ships and voyages** are best **suited** to **different types of fuels**. For example, green methanol may work best with large container ships, ammonia with bulkers and crude carriers, and liquid hydrogen within short voyages.
- This is due to the **cost determinant properties** of each fuel, such as **required tank volume and tank positioning within the ship.**
- While **biofuels may appear the cheapest** to integrate, there is a **ceiling in the amount of feedstock** that can realistically be processed into fuels, and value chain restrictions pertaining to integrating this into all ships. **Additionally, biofuels are indexed to agricultural cycles**, **while clean ammonia and methanol prices are expected to fall over time.**

Maritime Decarbonization

External Factors, Dependencies, and Systemic Change Opportunities

- The **International Maritime Organization targets net-zero "by or around 2050"** and has indicative 2030 and 2040 checkpoints in place. The EU developed Fuel EU Maritime, a regulation with requirements for average GHG intensity decreases for ships trading within Europe, in force from the start of 2025.
- **Forty global hub ports have committed to a 'green-corridor' dynamic** with aligned bunker standards.
- **Uptake of sustainable fuels** largely relies on achieving price competitiveness in green ammonia, methanol, and hydrogen. Each of these are **dependent on the scale and cost of electrolyzers** which provide the hydrogen underlying them.
- At the same time, **incentives and financing mechanisms** to get shipbuilders and operators to direct capital expenditures toward sustainable builds and retrofits are needed. These may be in the form of subsidies or tax rebates and credits.
- **Developing a pipeline of sustainable vessels** provides a **demand-side lever for sustainable fuel production.** Co-developing and coordinating projects, with public-private partnership, can ensure this scales alongside net-zero pathways.

Key Impacts Outward on Nature and People

Upstream
Risks related to **GHG emissions and resource depletion from energy and water use for H_2 production.** Risks related to **mining** for battery and fuel-cell **metals**.

Operations
Risks related to **ammonia toxicity** due to leakages or improper handling, the unwanted **release of nitrogen oxides, crew safety, methanol fires, and battery fires.**

Downstream
Risks related to the **safe recycling and reuse** of legacy vessels and infrastructure, **particularly in developing markets where much of this work is done**.

Maritime Decarbonization

Vision for net zero: where does the lever fit in a 2050 net zero world?

Maritime decarbonization is used where high-energy-density molecules and ocean-going range are needed. It includes the replacement of heavy fuel oil and marine gas oil by combining demand reduction (speed optimization, routing, hull and propeller upgrades, wind-assist) with zero- and near-zero-carbon fuels, principally e-ammonia and e-methanol over time, with sustainably sourced biofuels as transitional options and full electrification for short-sea and port equipment. Shore power cuts at-berth emissions, while hybridization and digital operations raise asset efficiency. Its sustainability relies on life-cycle carbon integrity (additional, time-matched renewable electricity for electrolysis; high capture rates and permanent storage for any CO_2 used in e-fuels; stringent controls on methane slip; verified advanced bio-feedstocks), robust safety management for new fuels (toxicity, NOx/N_2O), and transparent chain-of-custody.

In the near term, efficiency retrofits and operational measures should be prioritized, including weather routing, speed optimization, hull/propeller upgrades, and waste-heat recovery, alongside shore power at major berths, electrification of yard equipment, and targeted pilots on defined routes using bio-methanol or bio-LNG (liquefied natural gas); “ammonia-ready” and “methanol-ready” newbuilds and selective dual-fuel conversions should be pursued to avoid technology lock-in while safety, crew training, and fuel-quality assurance are embedded from the start. Through the 2030s, activity should scale into green fuel corridors and port hubs where large-scale electrolysis and nitrogen synthesis or CO_2 supply co-locate with bunkering, storage, and emergency response systems, matched to long-term vessel offtakes; short-sea routes should fully electrify (with hybrid batteries on larger ferries), and wind-assist on deep-sea vessels (e.g., rotor sails, kites) should mature to cut fuel demand and capex per ton of abatement. By the 2040s, the sector should deliver predictable, competitively priced low-carbon freight at scale across major lanes, with verifiable book-and-claim, lifecycle-tracked fuels supplemented by targeted biofuels for residual niches; systems integration with ports, grids, and fuel producers should provide reliable logistics while efficiency gains and digital operations keep costs and emissions on a downward path.

To realize this pathway, the shipping industry should order fuel-flexible vessels, commit to long-dated green-fuel offtakes, participate in green-corridor coalitions, standardize shore-power interfaces, and integrate digital twins for slow-steaming and routing; Energy providers should develop renewable PPAs, electrolyzers operated as flexible loads, e-ammonia/e-methanol synthesis, storage, and safe bunkering, tying port hubs to hydrogen and CO_2 networks; Mining companies should decarbonize bulk terminals and export chains, co-site renewable-to-fuel projects at resource ports, and deploy wind/solar-hybrid microgrids to cut auxiliary diesel. Consumer goods cargo owners should adopt green-freight procurement with book-and-claim and service-level agreements on life-cycle carbon intensity, smoothing demand with multi-year contracts. Chemicals firms should scale e-fuel and sustainable bio-intermediate production, secure feedstock certification, and implement NOx/N_2O controls. Financial services firms should structure sustainability-linked loans and Poseidon-aligned ship finance, aggregate offtakes, and deploy contracts-for-difference or price floors to bridge green-fuel premia. Policy engagement across these actors should back International Maritime Organization-aligned GHG-intensity standards, FuelEU-style route incentives, shore-power mandates, port-infrastructure funding, and interoperable certification so fuel carbon intensity is comparable and enforceable.

Who to partner with?

- Providers include Orsted-Maersk, MAN Energy Solutions, and Wärtsilä

Where to find more information?

- IEA
- FuelEU Maritime
- Poseidon Principles
- Maersk Mc-Kinney Mooler Center for Zero Carbon Shipping

Aviation Decarbonization

Includes airplane retrofitting, manufacturing, and sustainable aviation fuels

Lever Details

Industry:

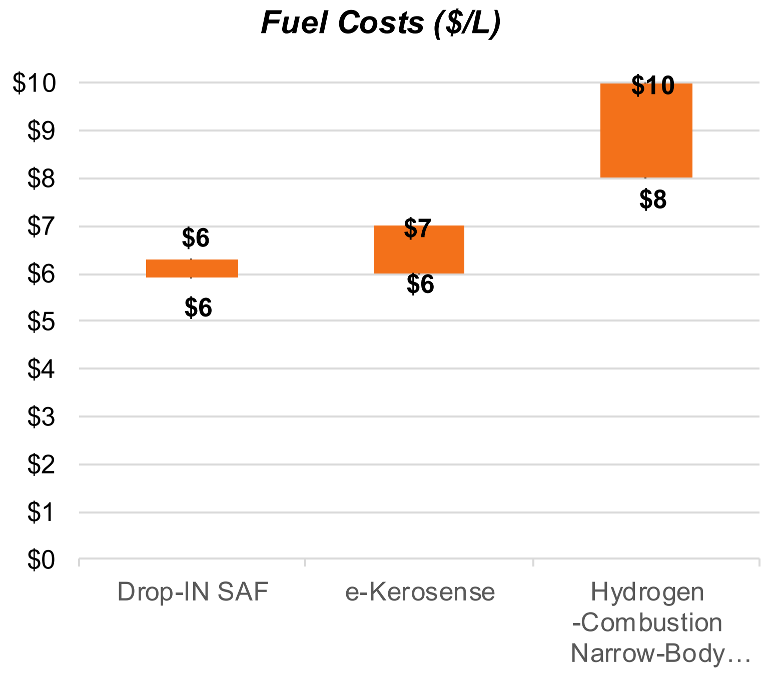
- Aviation
- Energy
- Chemicals
- Information Technology
- Financial Services
- Consumer Goods
- Healthcare

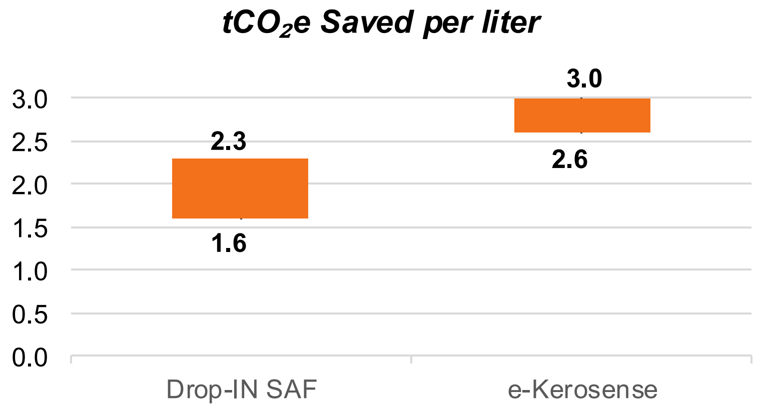
Current Cost Premium:

Low

Cost Assumptions and Details

- **Airplanes** that use most common sustainable aviation fuels **do not need significant retrofitting** to be adapted; these costs may be as low as $200k. This is relatively low in the context of the cost of a plane.
- However, **the price of sustainable aviation fuel**, which is the main financial concern of commercial airline operators, **continues to present at least a >2x premium over traditional fossil fuels.**
- **Hydrogen-combustion technologies** offer a pathway to complete decarbonization, but **involve a fundamental redesign of aircraft**, and are not currently commercially ready.
- Additional capital costs may include **efficiency and digitization solutions** which **bring down the amount of fuel a plane uses.**
- **Each fuel is reliant on its underlying value chain for price competitiveness.** As individual technologies and their corresponding production capacities advance, prices will come down.





Aviation Decarbonization

External Factors, Dependencies, and Systemic Change Opportunities

- The **United States has outlined a goal of 3 billion gallons of SAF use a year by 2030**, while the **EU Refuel mandate** has enforced a **2 percent blend as of 2025, rising to 70 percent by 2050.**
- **Global SAF capacity is less than 0.1 percent of annual jet fuel demand;** the technology is functionally in its commercial infancy, and significant effort is needed from industry and government to scale production affordably and quickly.
- **Airline companies are highly exposed to the fluctuating price of fuel.** Mandates which force them to purchase potentially expensive fuels will have significant impacts on the industry and are likely to find limited long-term traction. Subsidies to develop hydrogen and other e-fuel infrastructure to bring down costs are crucial in enabling a net zero pathway for the industry.
- Additionally, **significant investment is needed in developing planes which can use hydrogen fuels in longer-haul flights.** This may be done through public-private partnerships and industry collaboration.

Key Impacts Outward on Nature and People

Upstream

Risks related to **land and resource use for SAF feedstock, including potential carbon effects of deforestation**. Risks related to emissions from **electrolyzer power demand for H2 fuels.**

Operations

Risks related to **fire safety, LH_2 boil-off, which can lead to safety hazards, and methanol slip.** Risks related to **increased costs of air travel,** with implications for equity of access, and **potential economic impacts from airline restructurings, consolidations, and bankruptcies.**

Downstream

Risks related to the safe **recycling of legacy aircraft** and their **component digital infrastructure.**

Aviation Decarbonization

Vision for net zero: where does the lever fit in a 2050 net zero world?

Aviation decarbonization includes the replacement of fossil jet fuels with sustainable aviation fuels and power-to-liquids e-kerosene, while cutting burn through lighter airframes, advanced aerodynamics and engines, and operational improvements in routing, speed, and weight. Applications span passenger and cargo fleets on short-, medium-, and long-haul routes, with full electrification limited to very short regional segments and hydrogen confined to niche use cases; ground operations electrify and airports supply shore power. Its sustainability relies on life-cycle integrity: additional and time-matched renewable power for electrolysis, high-purity captured CO_2 for e-fuels, advanced bio-feedstocks (wastes, residues, cellulosics) under strict chain-of-custody, control of methane and NOx where relevant, and monitoring of non-CO_2 climate effects such as contrails.

In the near term, rapid substitutions should emphasize HEFA SAF from waste oils and fats, with airport blending, custody, and quality systems certified to American Society for Testing and Materials (ASTM) standards; fleet renewal and retrofits (drag/weight reductions, winglets), electrification of ground support equipment, and digital flight operations to cut fuel burn and contrails should be prioritized, while first commercial e-fuel plants co-locate renewable power, water, and captured CO_2 with pipeline or on-airport logistics. Through the 2030s, activity should scale into integrated fuel hubs where advanced pathways: cellulosic Fischer-Tropsch and alcohol-to-jet, grow alongside power-to-liquids, supported by hydrogen and CO_2 networks, higher certified blend limits, and long-term offtakes; new airframes should lock in structural efficiency via open-fan or ultra-high-bypass engines, longer and laminar wings, and lighter materials, while hydrogen aircraft remain niche and battery-electric serves short flights. By the 2040s, aviation should operate as a reliability product for global mobility powered predominantly by SAF and e-kerosene with rigorous MRV and chain-of-custody, minimizing non-CO_2 effects through operational measures and relying on verifiable, durable removals only for a small, demonstrably hard-to-abate residue.

Aviation stakeholders: airlines, lessors, and airports, should commit capital to long-dated SAF and e-fuel offtakes with cost-indexed pricing, accelerate fleet renewal and aerodynamic/engine upgrades, electrify ground operations, and build on-airport blending, storage, and hydrant capacity. The energy sector should develop renewable PPAs and transmission for electrolyzers, supply deionized water and oxygen/heat integration, secure CO_2 offtake from capture projects, and finance e-fuel plants with contracts-for-difference or price floors. Chemicals firms should build advanced SAF refineries and PtL synthesis, secure certified feedstocks, and integrate carbon capture with clear accounting for stored versus recycled CO_2. Technology firms should deliver flight-ops optimization, contrail-avoidance forecasting, book-and-claim registries, and granular emissions MRV that reconcile ticket-level claims with plant-level data. Financial firms should standardize SAF and e-fuel offtake contracts, structure project finance and leasing with sustainability-linked covenants, hedge power and feedstock risks, and deploy blended finance to crowd in capital where learning curves are steep. Consumer goods shippers should procure green airfreight with multi-year, lane-specific contracts that smooth demand and signal volumes to fuel hubs, while healthcare can anchor reliable cold-chain corridors using verifiably low-carbon uplift.

Who to partner with?

- Providers include Airbus, Boeing, and Electra.aero

Where to find more information?

- IEA
- ReFuelEU Aviation
- International Council on Clean Transportation
- Airbus ZEROe
- NASA Transformational Tools and Technologies

Land Freight Decarbonization

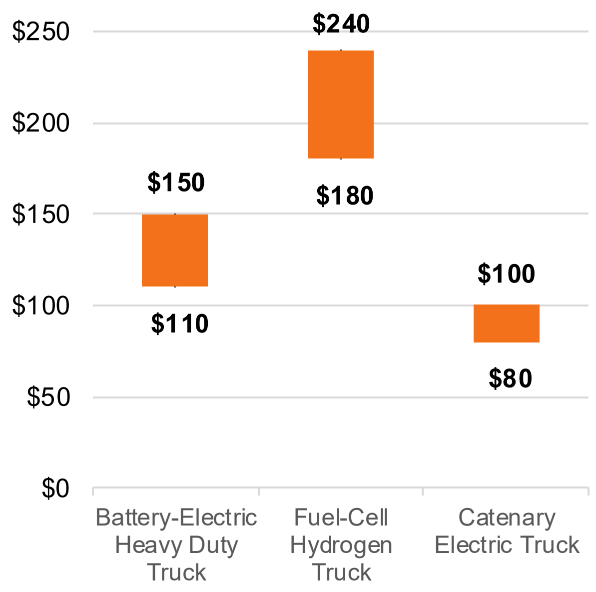
Includes efficient trucking, net-zero rail, and supporting logistics and infrastructure.

Lever Details

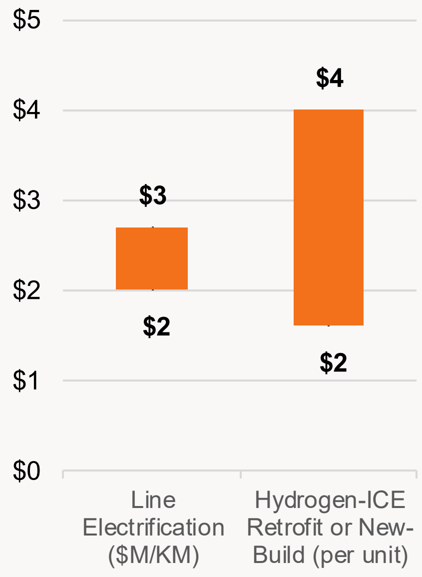
Industry:

- Shipping and Logistics
- Automotives
- Energy
- Mining and Extractives
- Consumer Goods
- Chemicals
- Information Technology

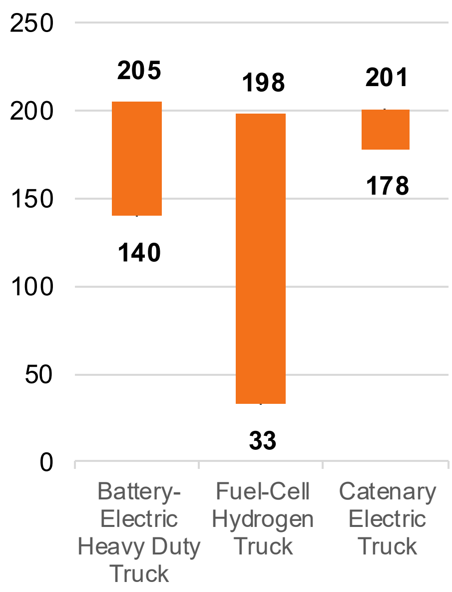
New Vehicle Cost ($K)



Rail Costs ($M)



tCO_2e Saved Annually per unit



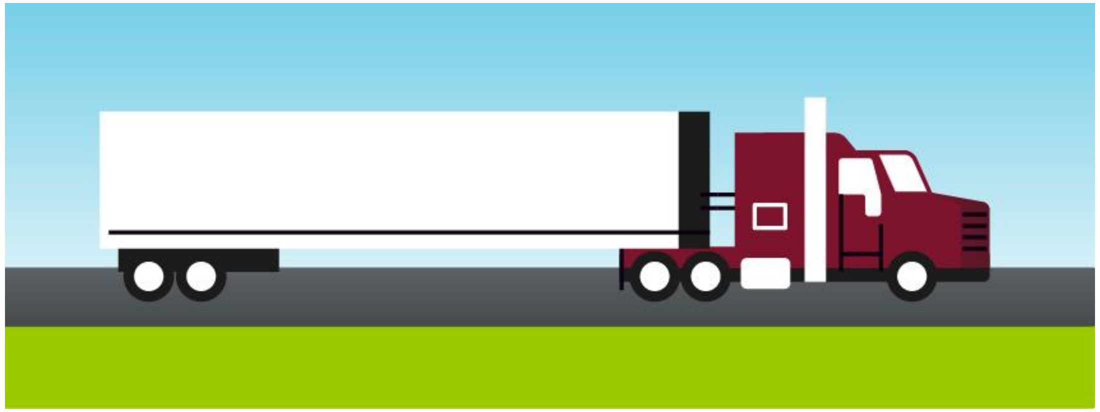
Cost Assumptions and Details

- Embedded costs include the **cost of renewable energy, batteries, and charging infrastructure** (the cost of which may be **partially passed on or undertaken by freight carriers).**
- **Improvements in battery costs** have the **largest impact** in decreasing the premium for electric trucks.
- **Locomotive and line electrification costs vary significantly around the world**, particularly between developed and developing nations. **Soft costs such as labor, permitting, and planning timelines** raise these costs compared to emerging markets.
- **For longer distances**, batteries may not be tenable or inefficient, **so bringing down the cost of hydrogen fuel is critical**. This is reliant in technological and capacity advances in the industry.

Land Freight Decarbonization

External Factors, Dependencies, and Systemic Change Opportunities

- **More than 90 percent of the world's zero-emission buses and trucks are in China.** However, **emissions standards in the EU also support a path to widespread adoption in line with net-zero pathways.** Additionally, **production and technological capacity is distributed between the U.S., China, and Europe.** Deployment is not only limited by costs: **the charging infrastructure is simply not widespread enough** to make electric trucking economically and logistically feasible at present.
- **Emerging markets** are largely restricted by costs**, but charging infrastructure needs to be preemptively developed** and planned to lay the groundwork **for when cost competitiveness is achieved.**
- **Rail is largely electrified in many places** in the world **complete decarbonization relies on retrofitting and system upgrades.** Emerging markets such as India and China have adopted ambitious electrification goals, particularly for new stock, and may serve as case studies for other developing countries to follow.
- Hydrogen fuels in trucking and rail require significant investment across the value chain. It is likely that **LH_2 production capacity must scale significantly** from present levels **before significant supporting infrastructure investments are made.**



Key Impacts Outward on Nature and People

Upstream

Lithium, nickel, and graphite mining impacts for batteries, **copper and steel related impacts** for catenary poles, including degradation of natural environments, community displacement, and labor conditions and rights. **Land and energy-use impacts for hydrogen production.**

Operations

Charging corridors may have impacts on grid stability and must be appropriately integrated. Risks related to **land-use impacts of new rail lines.**

Downstream

Risks related **to battery, overhead wire, and legacy vehicle and locomotive waste, recycling, and reuse.**

Land Freight Decarbonization

Vision for net zero: where does the lever fit in a 2050 net zero world?

Land freight decarbonization occurs where transporting goods requires reliable range, payload, and duty cycles that can be electrified or served by clean molecules. It includes the replacement diesel in trucks and switching locomotives with battery-electric drivetrains on urban and regional routes, to deploy hydrogen fuel-cell or catenary solutions on select long-haul corridors and steep grades, and to shift ton-miles to electrified rail wherever feasible. Applications span depot-based delivery and middle-mile, corridor trucking with megawatt charging or hydrogen refueling, intermodal hubs that knit trucks to rail, and yard and port equipment that electrify first. Sustainability includes right-sizing vehicles, high-efficiency power electronics and motors, low-GWP (global warming potential) refrigerants for cold-chain units, rigorous battery and hydrogen safety, and circularity through repair, second life, and recycling.

In the near term, substitutions should focus on battery-electric vans and medium/heavy trucks on predictable return-to-base routes, electrified yard tractors and terminal equipment, managed depot charging with load management, and targeted corridor DC fast charging; aerodynamic packages, low-rolling-resistance tires, driver-assistance, and digital routing should be deployed to cut energy use and empty miles immediately. Through the 2030s, deployment should expand into networked freight corridors and logistics hubs: multi-megawatt Megawatt Charging System (MCS) sites, hydrogen refueling where duty cycles and climates allow, battery-hybrid or fully electric locomotives, and high-capacity intermodal terminals co-located with renewable PPAs, on-site storage/microgrids, and grid upgrades; on high-volume lanes, e-highway/catenary segments may be warranted, while pricing and access rules should reward zero-emission utilization and backhauls. By the 2040s, land freight should deliver predictable, low-carbon logistics at scale via predominantly electrified trucking and largely electrified rail, with depot and corridor charging providing controllable load that supports grid reliability; system optimization (consolidation, mode shift, load-matching, and digital twins), should reduce total travel and costs, with advanced biofuels reserved for legacy niches.

Shipping and logistics operators should order battery-electric and fuel-flexible tractors matched to duty cycles, lock in long-dated charging and (where warranted) hydrogen offtakes along priority lanes, redesign networks around intermodal hubs and predictable dwell for charging, and offer green-freight contracts with auditable carbon intensity. Automotives should deliver dedicated electric truck vehicles across classes, MCS-ready interfaces, and fuel-cell models for specific range/payload cases, while standardizing telematics, battery warranties, and end-of-life recovery. Energy providers should interconnect depots at scale, build corridor charging with smart tariffs, co-site storage and on-site solar, and, where hydrogen is justified, develop safe production, storage, and refueling tied to credible certification; regulators should enable capacity markets and make-ready programs that cut connection lead times. Mining firms should secure responsible battery-mineral supply, electrify mine-to-rail haul and off-highway fleets, and support recycling streams that stabilize battery inputs. Chemicals companies should decarbonize their own bulk logistics first, supply low-global-warming thermal management fluids and lighter materials for trailers and bodies, and, where hydrogen is in scope, provide certified molecules and safety expertise.

Who to partner with?

- Providers include Tesla, BYD, and Hitachi

Where to find more information?

- IEA – Trucks and Buses
- IEA - Rail
- ICCT – Trucks
- ICCT – Rail
- Siemens eHighway White Paper

Public Transport

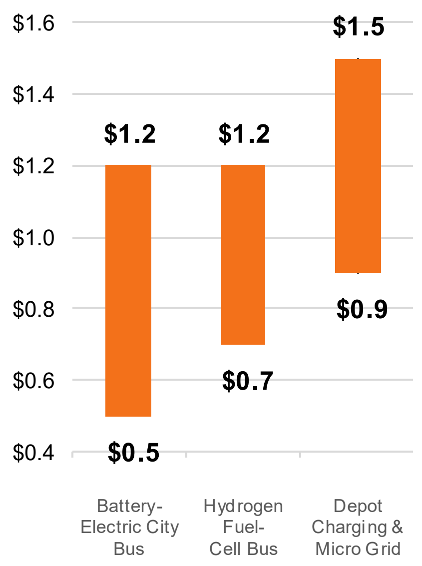
Includes buses, metro rail, and supporting infrastructure

Lever Details

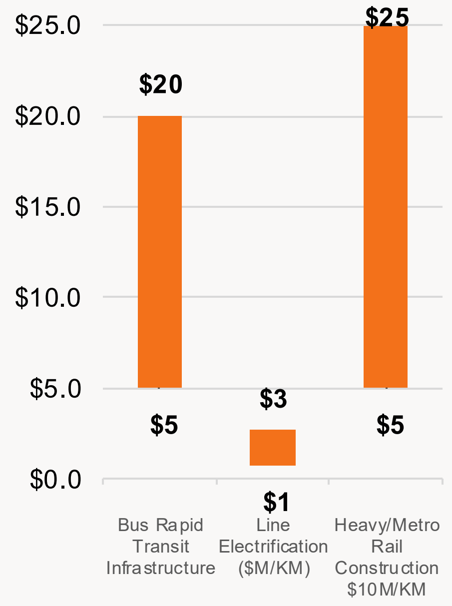
Industry:

- Food and Beverage
- Buildings and Construction
- Energy
- Information Technology
- Financial Services
- Professional Services
- Consumer Goods

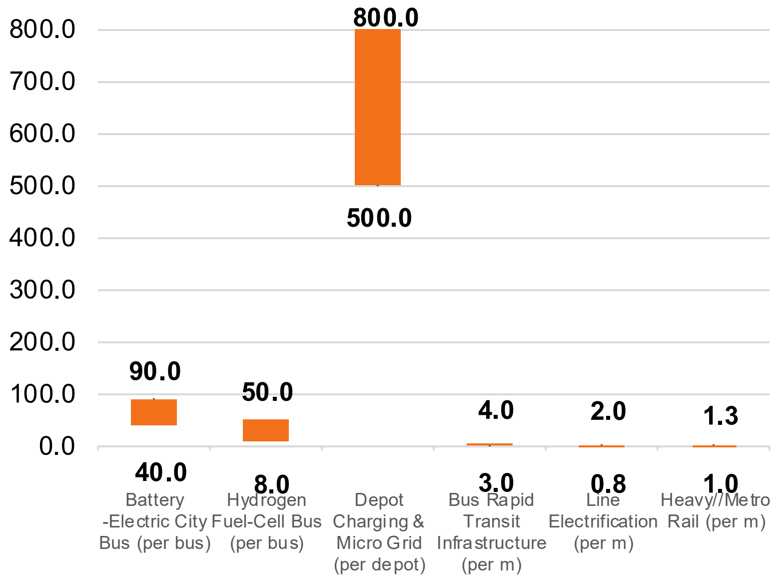
New Unit Cost ($M)



Rail Costs ($M)



tCO_2e Saved Annually



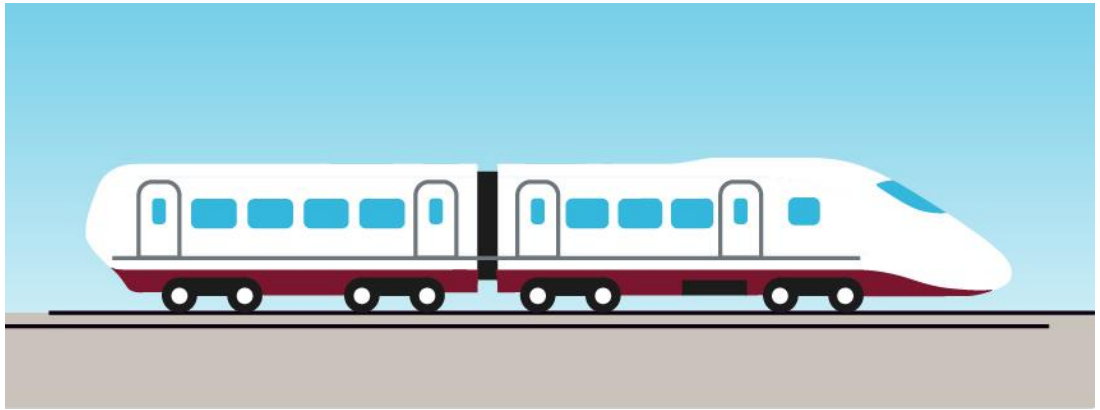
Cost Assumptions and Details

- The **largest determinant of total project costs** for large public transport projects, such as the construction of metro systems, **is the length and complexity of the planning and construction process.**
- Additionally**, local physical context may raise costs,** such as **drilling and terraforming requirements, public land acquisition, and the density and size of the project. Tunneling costs**, which vary significantly due to local geological and urban features, are a large determinant of project cost.
- **Electric bus costs** are reliant on the **price of batteries**, and the scale achieved by electric bus manufacturers. Costs may vary between countries, and by **integration of safety or smart features**. Several buses and transport systems are now equipped with **digital technologies which optimize their routes, idling, and other behaviors to facilitate energy efficiency**, but this comes with added investment.

Public Transport

External Factors, Dependencies, and Systemic Change Opportunities

- While the **electrification of public transport** is an ideal that may be worked toward by 2050, simply **increasing its use and scale has a significant effect** on lowering population emissions intensity from transport.
- **Building and upgrading public transport is expensive**. Costs are often **borne by city or other local administration**. To achieve scale, **funding and support should come from centralized resources at the national level,** including **technological and methodological resource** pooling to achieve cohesive approaches and realize economies of scale.
- The **willingness of the passenger to use public transport** remains a barrier in certain places. This may be due to **convenience, safety, or cost**. To the extent possible, these should be mitigated by inclusive and intelligent design, public safety measures, and financing mechanisms which may lower costs. At the same time, **the cost of public transport may have to rise to accommodate infrastructure expansion**; alternatively, taxes could be placed on private vehicles to incentivize switching.
- **Efficiency measures are an important intermediate step** on the journey to full decarbonization. These may include intelligent digital systems and operational design to optimize bus routes and fuel usage, or retrofits for more efficient design.



Key Impacts Outward on Nature and People

Upstream
Risks related to **mining for battery materials**, risks related to energy usage and **emissions in manufacturing processes**, risks related to **emissions from concrete production.**

Operations
E-bus grid integration must be appropriately planned. Risks related to **public safety, hydrogen leakage, and noise pollution.**

Downstream
Risks related to disposal, recycling, and reuse of **vehicles, batteries, and other materials.**

Public Transport

Vision for net zero: where does the lever fit in a 2050 net zero world?

Public transport replaces low-occupancy, fossil-fueled car and ride-hail trips with high-occupancy, increasingly zero-emission mobility solutions. It cuts energy use and emissions per passenger-kilometer by shifting travel to bus rapid transit, metro, light/commuter rail, and demand-responsive shuttles integrated with safe walking, cycling, and micromobility. In doing so, it displaces gasoline and diesel in urban travel, reduces peak congestion and grid stress, and lowers the embodied-carbon footprint of access to jobs, goods, and services. Modern public transport pairs electrified fleets with digital operations (real-time information, account-based ticketing, open data) and prioritizes reliability and accessibility so that mode shift is durable. Its sustainability case strengthens when fleets use renewable power, vehicles and batteries are designed for second life and recycling, and stations and depots are built or retrofitted to high-efficiency standards.

In the near term, agencies should prioritize fleet transitions that replace diesel/CNG (compressed natural gas) buses with battery-electric models supported by overnight depot charging, while installing transit-priority lanes and signal priority, introducing all-door boarding and fare capping with open payments, and upgrading real-time data and telemetry to improve reliability and accelerate mode shift. Through the 2030s, systems should scale into corridor-based operations: zero-emission buses add on-route or opportunity charging where duty cycles require it; rail electrification expands with battery or dual-mode multiple units on unelectrified branches; depots and hubs integrate solar and storage, predictive maintenance, and dynamic dispatch; and managed charging , supplemented by targeted, economics-driven vehicle-to-grid pilots, providing controllable load that supports local grid needs. By the 2040s, public transport should operate as a fully decarbonized, high-frequency network that delivers firm 'demand-reduction capacity' for the energy system: electrified fleets should run on contracted clean power with hourly matching where feasible, stations and depots function as efficient, resilient facilities, and mobility-as-a-service ties transit, micromobility, and first/last-mile logistics into a seamless, low-carbon system.

Commercialization and scale require sector-specific planning, capital alignment, and policy engagement that reflect this pathway. Buildings and construction players can provide transit-oriented development and energy-efficient stations and depots, aligning project phasing with dedicated bus lanes, rail rights-of-way, and utility upgrades. Energy providers may commit to timely interconnections, substation capacity, and renewable PPAs sized to depot and rail loads, while technology firms deliver account-based ticketing, open APIs (e.g., General Transit Feed Specification/General Bikeshare Feed Specification), and analytics that optimize schedules and charging. Financial services can make fleets bankable through green bonds, securitization of rolling stock, availability-based PPPs, and "charging-as-a-service" contracts that shift technology and residual value risk off agencies; they can also blend concessional capital to accelerate fleet turnover. Companies across sectors can play a role by offering employee incentives to utilize public transportation and working with relevant stakeholders to develop routes to their offices. Cross-cutting policy engagement should support zero-emission bus and rail programs, fare and payment interoperability, congestion and parking reform that prices road space fairly, and streamlined permitting for depots, chargers, and grid works.

Who to partner with?

- Providers include Siemens Mobility, Alstom, and Wrightbus

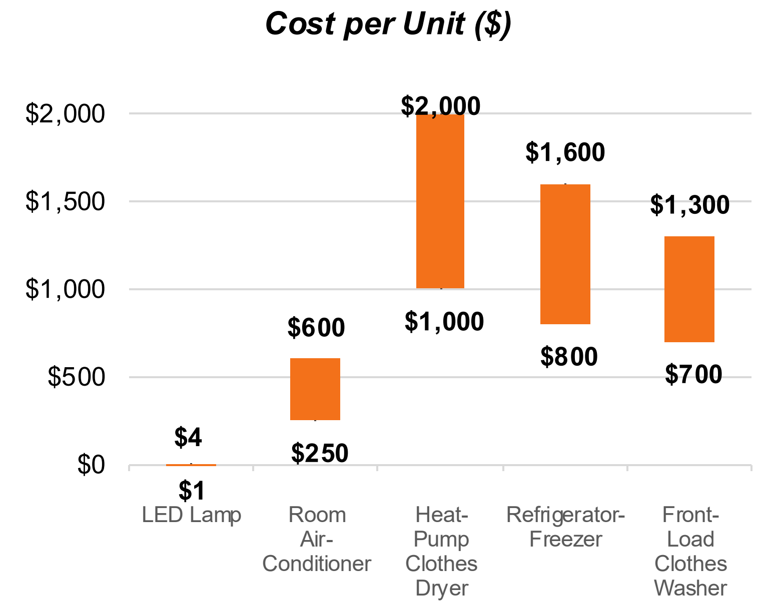
Where to find more information?

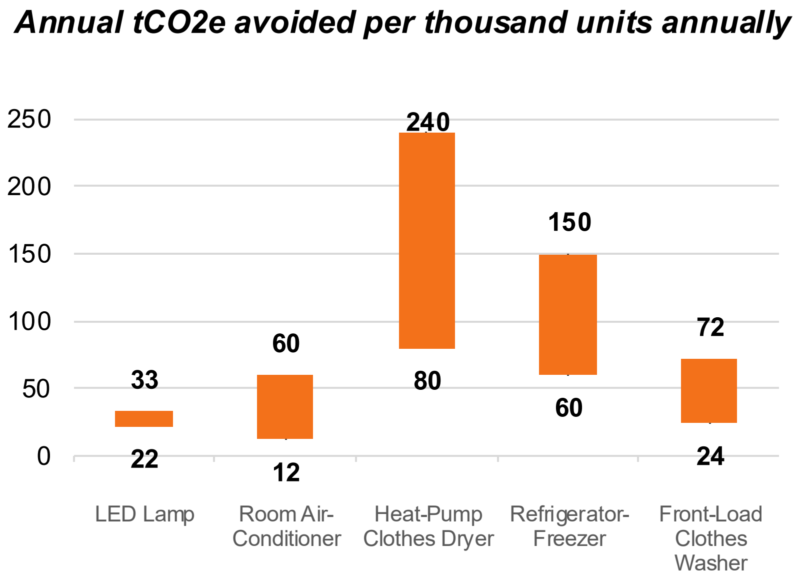
- International Association of Public Transport
- World Resources Institute
- International Transport Forum
- Hitachi

Buildings

Efficient Fixtures

Includes LED bulbs, efficient air-conditioning, dryers, washers, and refrigerators.





Lever Details

Industry:

- Buildings and Construction
- Consumer Goods
- General Manufacturing & Industry
- Information Technology
- Healthcare
- Professional Services

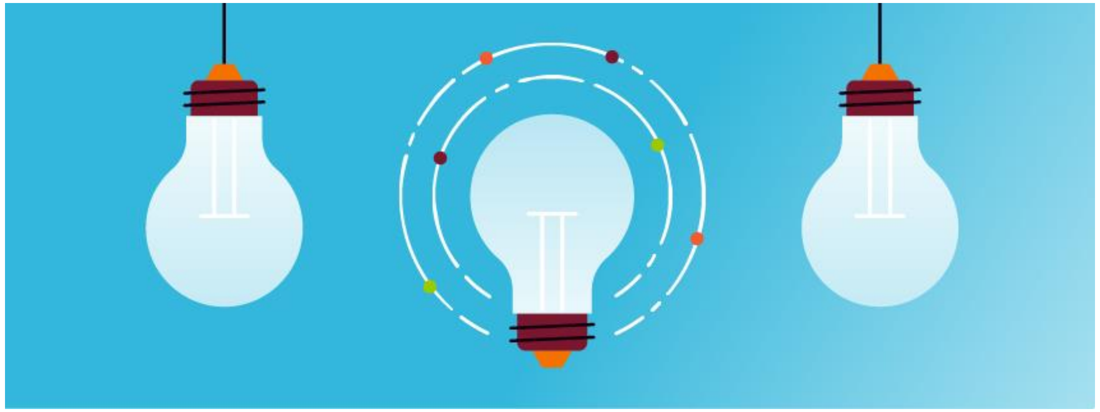
Cost Assumptions and Details

- Efficient fixtures represent the **replacement of existing electrical appliance stock** by modernized versions which **consume less electricity**. Appliances within households and other buildings form a large portion of their energy consumption.
- Cost premiums may appear significant due to high upfront costs, but energy efficient appliances **payback their investment** through lower energy bills over time.
- The **cost premium is thus best contextualized through** understanding the **relative energy savings** of individual appliances compared to their legacy alternatives. Payback periods will also vary depending on **usage frequency.**
- The technological maturity of the energy efficient options of each appliance is the main determinant of the relative cost premium. Countries with policy support such as **minimum-energy-performance standards, labeling mandates, and subsidies,** may have lower or no premiums for certain markets.

Efficient Fixtures

External Factors, Dependencies, and Systemic Change Opportunities

- **Adjusting the energy consumption of individual appliances** to meet immediate demands, **and load-shifting using "smart" IoT technologies** within a building or home presents an integrated path forward to reducing appliance energy consumption. These capabilities need to be increasingly commonplace.
- **Individual appliances may become more efficient** through advances in materials, design, and motor and variable speed drive development and optimization.
- Due to the **high upfront costs of efficient alternatives**, financing mechanisms are critical **in unlocking uptake amongst low-income consumers**, particularly as demand growth continues to surge in Asia-Pacific and Africa. These mechanisms may benefit from government support and design but can also be developed independently by manufacturers and distributors.
- **Regulation which mandates and promotes efficiency standards** for appliances is crucial is pushing manufacturers to innovate. The Chinese government has incorporated appliance energy efficiency into their Action Plan for Carbon Peaking Before 2030", combining manufacturing policy with demand side incentives for businesses, homes, and industry to purchase efficient appliances. Globally, awareness programs which emphasize the lifecycle cost savings of efficient options are crucial in facilitating wide-scale behavioral shifts.



Key Impacts Outward on Nature and People

Upstream

Rare-earth and cobalt mining for motors and other fixtures may lead to habitat loss and effects on local populations. **Water demand for semiconductor production** may lead to scarcity, labor exploitation may occur at both the extraction and processing phases. **Hazardous solvents** in factory lines producing fixtures and appliances may impact workers health

Operations

Risks of **increased net utilization** due to economic impacts of efficiency gains. **Refrigerant leaks** during use phase can create GHG emissions if not well-contained. Risks related to **affordability and access** of efficient appliances, particularly upfront costs.

Downstream

E-waste and fluid leakages from improper disposal may lead to waste and environmental damage, particularly as old stock is replaced.

Efficient Fixtures

Vision for net zero: where does the lever fit in a 2050 net zero world?

Efficient fixtures and appliances are the most direct way to cut energy demand at the point of use, delivering permanent load reductions that complement supply-side decarbonization. They replace inefficient lighting, HVAC systems, water fixtures, and appliances that lock in unnecessary energy and water consumption. By reducing demand intensity, efficient appliances free up renewable electricity for other end-uses, lower peak loads that would otherwise drive costly grid expansion, and minimize indirect emissions embedded in consumer goods and services. Their sustainability case is strongest when efficiency is combined with long lifespans, recyclability, and low-GWP refrigerants.

In the near term, rapid substitutions should focus on proven, widely available options: LED (light-emitting diode) lighting, induction cooktops, variable-speed drives for motors and fans, high-efficiency heat-pump appliances (water heaters, dryers, space-conditioning), and low-flow, pressure-balanced water fixtures, paired with smart thermostats and basic controls, bulk procurement, and codes/standards that retire the least efficient models. Through the 2030s, connected "grid-interactive" fixtures and appliances should become standard, integrating with building energy management and demand-response so loads can pre-heat/cool, shift water heating, and modulate motors away from peaks; common data models and device interoperability should enable automation, performance-based procurement, and verified savings across portfolios. By the 2040s, efficiency should operate as a systemic layer: appliances carry digital passports to enable repair, reuse, and high-recovery recycling; embedded controls and warranties support secure participation in flexibility markets; and fleets of devices act as dispatchable, low-cost demand resources within net-zero buildings and industries, delivering permanent load reductions and real-time flexibility that reduce the scale and cost of supply-side investments.

To realize this pathway, companies across sectors need to align capital investment, procurement, and policy engagement with efficiency as a first-order decarbonization lever. Buildings and construction companies can standardize efficient fixtures and appliances as part of zero-carbon building codes and invest in procurement systems that prioritize relevant certifications. General manufacturing and industry can integrate efficient motors, pumps, and process equipment, capturing both energy and cost savings while meeting tightening industrial energy-performance standards. Information technology and data center operators may invest in advanced cooling and server hardware efficiency, aligning with grid flexibility markets. Healthcare systems can reduce operating costs and emissions by adopting efficient HVAC, sterilization, and refrigeration systems that also improve resilience. Policy engagement may include supporting the strengthening of appliance efficiency standards, eco-design regulations, and demand-side flexibility frameworks, while financial institutions and corporates work together to scale green leasing, performance contracting, and blended finance.

Who to partner with?

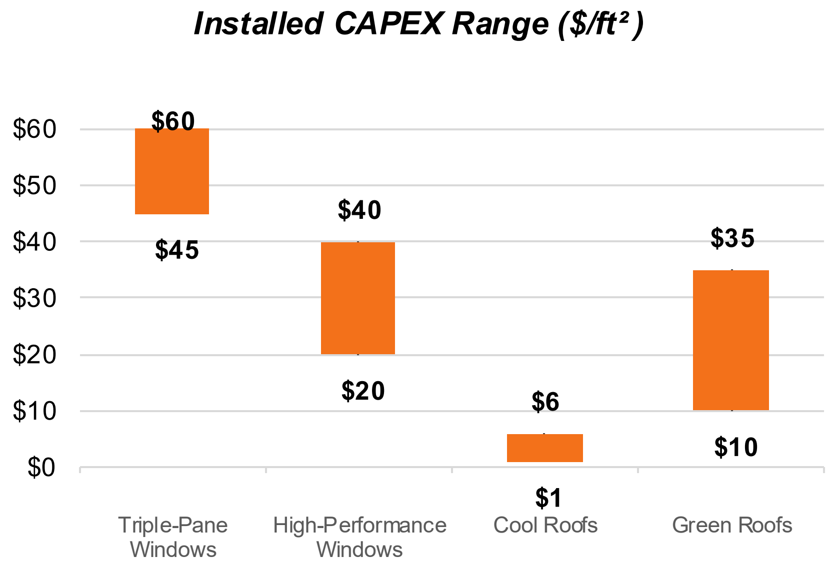
- Large appliance producers are often the leaders in efficiency, such as Daikin, LG Electronics, and Signify.

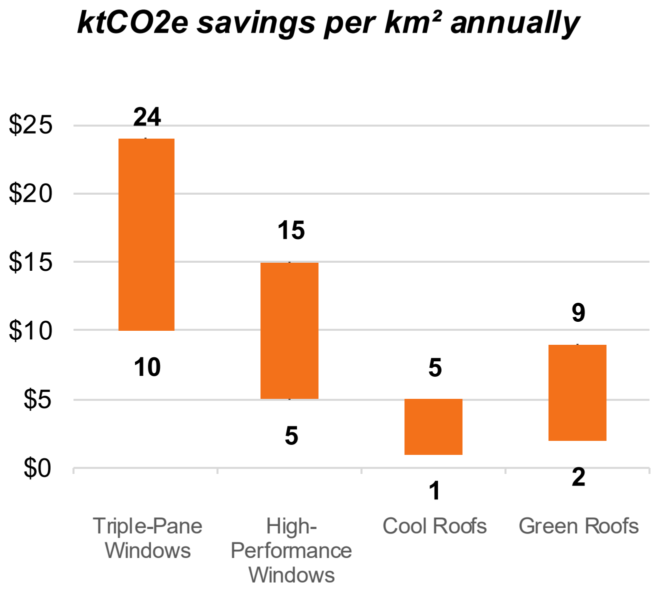
Where to find more information?

- CLASP (Collaborative Labelling and Appliance Standards Program)
- IEA Appliances and Equipment
- United for Efficiency
- Super-Efficient Equipment and Appliance Deployment (SEAD) Initiative

Building Envelopes

Building envelopes refer to the components that make up a building's exterior, including windows and roofs designed for efficiency and cooling.





Lever Details

Industry:

- Buildings and Construction
- Chemicals
- General Manufacturing & Industry
- Energy
- Financial Services
- Information Technology
- Professional Services

Cost Assumptions and Details

- The **cost of installing efficient roof and window options** to lower the heating or cooling burdens of buildings **varies significantly based on the specific context** in which it is applied.
- These include **if the features are part of a new build, a larger renovation, or a standalone project**. The technical specifications of the installations can vary significantly, both in terms of temperature regulation capability and with respect to other design considerations which may be incorporated into building exterior modifications.
- **"Extensive" green roofs**, which may cover a larger surface area and comprise of a basic layer of moss, are significantly cheaper than "**intensive" green roofs**, which include a variety of plants which require continuous dedicated irrigation and maintenance, but provide greater energy savings.
- The **specific sunlight exposure of the building, local energy costs, and the total energy profile of the building** will lead to variations in the effectiveness, and associated payback costs, of these solutions.

Building Envelopes

External Factors, Dependencies, and Systemic Change Opportunities

- **Material innovations,** such as vacuum-insulated panels and aerogels, have **advanced temperature regulation capabilities for roofs and windows** but are currently **prohibitively expensive** for mass-market application; innovation is required to bring costs down. Manufacturing and installation innovations such as pre-assembly and modular roof and window inserts can lower costs across the value chain.
- **Large buyers, such as real estate investors, can influence the market** through bulk purchasing, providing wide-scale consumer benefits, lower unit costs, and ready cash and market support for manufacturers to ramp production and increase investment. This can be facilitated through **clearer understanding of the energy savings** and resulting financial benefits of each energy-efficient installation.
- **Regulations which direct new construction to follow minimum standards** for roofing and windows performance builds **efficiency into new building stock.** For existing building stock, **these upgrades are viewed as luxuries** which are usually not implemented outside of existing large-scale renovation efforts. **Providing incentive schemes including tax credits or low interest loans for these upgrades may assist in their uptake.**

Key Impacts Outward on Nature and People

Upstream

Chemicals and pigments used in manufacturing processes may have harmful effects on workers and local environment. **Manufacturing and transport processes** are energy-intensive and would should use renewable energy.

Operations

Waste can be created during the installation process of doors and windows, such as **coatings or glazing**, that must be properly disposed of. **Worker safety** is crucial when working at high or otherwise dangerous buildings and environments, and **community impacts** of any construction should be considered.

Downstream

Raw materials should be recycled as much as possible across projects and within buildings. High-efficiency renovations are often **skewed toward higher-income communities because of the intrinsic costs**; specific mechanisms may need to be implemented to ensure equity.

Building Envelopes

Vision for net zero: where does the lever fit in a 2050 net zero world?

Building envelopes are a fundamental part of improving the sustainability and efficiency of existing and new building stock. They help replace energy waste in space heating and cooling by tightening air leakage, increasing insulation, mitigating thermal bridges, upgrading glazing and façades, and deploying reflective or green roofs that cut solar gain. Applications span new construction and deep retrofits in residential, commercial, and industrial buildings, including warehouses and cold-chain facilities where envelope performance governs process energy. Their sustainability involves durable assemblies, low-GWP insulation blowing agents, non-toxic sealants and membranes, moisture management, and circularity through repairable, deconstructable systems with verified environmental product declarations.

In the near term, targeted air sealing and insulation upgrades, high-performance windows and doors, cool or reflective roofs, and verified airtightness (e.g., blower-door testing) should be prioritized, paired with "envelope-ready" electrification that right-sizes heat pumps, adds balanced ventilation with heat/energy recovery, and ensures proper commissioning; materials with lower embodied carbon and moisture-robust details should be standard to lock in durable savings. Through the 2030s, delivery should shift toward industrialized solutions: panelized over-cladding and curtain-wall retrofits, dynamic and vacuum glazing, phase-change and high-thermal-mass assemblies, and façade systems that integrate shading, PV, and sensors, interfacing with building management systems so envelopes provide thermal demand response, pre-heating/cooling, and verifiable performance under outcome-based codes and portfolio contracts. By the 2040s, envelopes should function as a reliability product that delivers firm "demand-reduction capacity," flattening seasonal peaks and improving passive survivability, and as a system optimizer that enables 24/7 carbon-free operations by shrinking HVAC and storage requirements, deferring grid reinforcements, and closing the loop via digital passports, reuse, and high-recovery recycling.

The building and construction ecosystem should embed performance-based codes and outcome-guaranteed retrofits, standardize panelized solutions for occupied buildings, and pair envelope work with commissioning and continuous monitoring. Chemicals firms should scale low-GWP blowing agents, aerogels and vacuum panels, low-VOC (volatile organic compounds) adhesives and membranes, and transparent disclosures that phase down PFAS (per- and polyfluoroalkyl) substances and other chemistries of concern. Industry should harden shells at docks and process areas, reduce infiltration in large-volume spaces, and right-size electrified HVAC after envelope upgrades. Energy providers should value energy efficiency and conservation via demand-side contracts, on-bill tariffs, and capacity credits for verified peak reduction, and coordinate interconnection and program design so envelope projects are treated as firm resources. Financial services should expand green mortgages, Property Assessed Clean Energy (PACE) and performance-contracting vehicles, securitize measured-savings cash flows under recognized MRV protocols, and tie rates to embodied-carbon disclosures. Technology firms should develop digital twins and building analytics that verify envelope performance, integrate with Building Automation Systems (BAS) and DERMS for thermal load shifting, and provide audit-grade MRV.

Who to partner with?

- Vendors across the space include ZinCo, Pella, and GAF

Where to find more information?

- IEA
- GRESB
- EPA
- Project Drawdown
- Cool Roof Rating Council

Data Center Cooling

Includes liquid-cooling technologies where server racks are cooled by pumped cold liquid, and other components to optimize the energy environment.

Lever Details

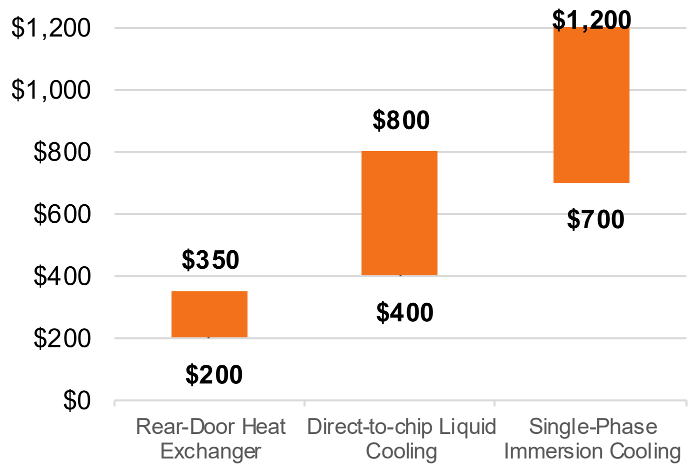
Industry:

- Information Technology
- Communications & Telecom
- Energy
- Buildings and Construction
- Chemicals
- General Manufacturing & Industry
- Financial Services

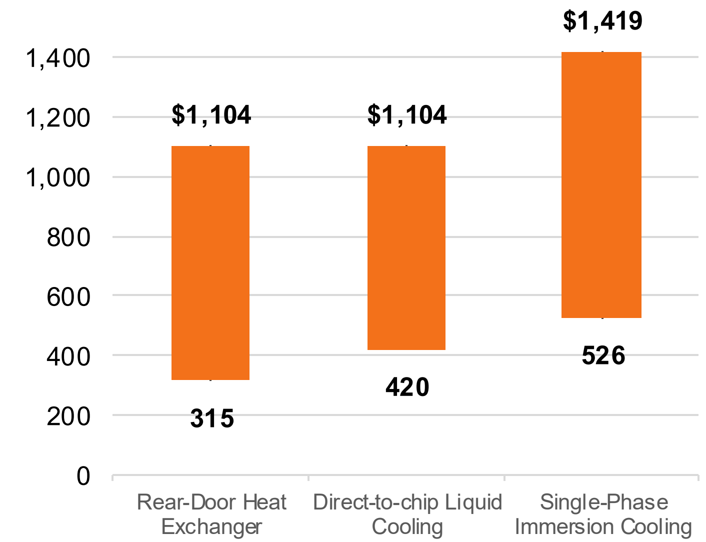
Cost Assumptions and Details

- **Up to 40 percent of data center energy consumption** is dedicated specifically for **cooling the racks of servers**, which heat up as they perform their functions.
- Traditionally**, air-cooling has been more common than liquid-cooling,** due to relative technological maturity, cost, and simplicity. However, **the increased cooling demands of AI datacenters has forced innovation, and liquid cooling solutions**, which have higher upfront costs but are **more power and energy efficient over the long term**, have become **increasingly commonplace** for sophisticated facilities.
- Costs depend on the specific provider used and technology implemented; **cooling systems are often built to be optimized for a particular data center's design specifications,** so the specific technologies used, and corresponding costs vary significantly.
- **Local energy costs, server rack design, water price and availability, and local climate** all impact cooling costs. The higher the energy demand of a facility, the more it makes sense to implement liquid cooling.

Installation Cost per kW



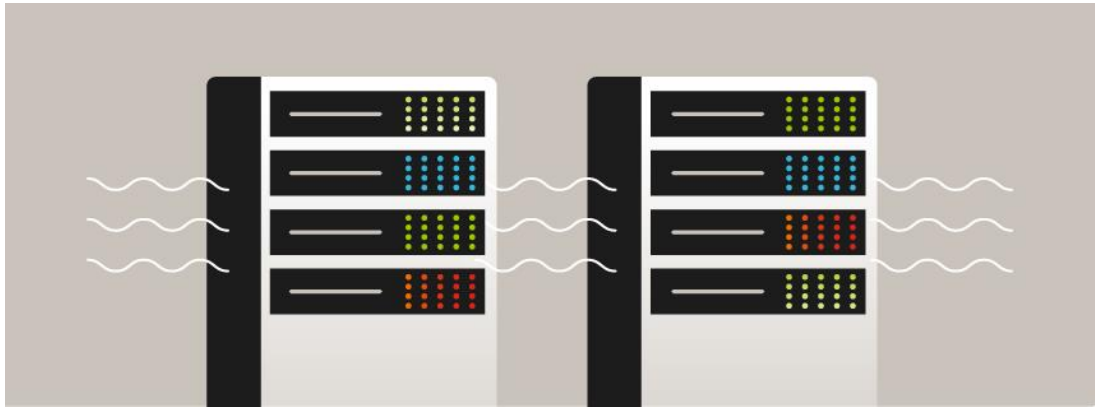
Net avoided CO_2e per kW of IT load, per year



Data Center Cooling

External Factors, Dependencies, and Systemic Change Opportunities

- Liquid cooling has **come under scrutiny** due to the **significant water use intrinsic to their design.** The scale of the water used, mapped against the future potential scale of data center infrastructure**, presents significant localized threats to water scarcity and availability.** This may lead to regulations and public backlash which limit how much water a data center can use, resetting the cost/benefit dynamic of liquid vs alternative cooling solutions. **These adverse effects can potentially be mitigated through circular water-practices.**
- **Energy efficiency solutions do not decarbonize data centers by themselves;** they only reduce total energy demand. The predominant concern for data center decarbonization is **the provision of reliable, cost-competitive renewable energy resources** which can meet energy demand from both cooling and operations.
- **Governments can facilitate data center efficiency through Power Usage Effectiveness (PUE) mandates and standards**. The European Energy Efficiency Directive lays out reporting requirements on efficiency, heat utilization, and renewable energy use specifically for the data center industry.



Key Impacts Outward on Nature and People

Upstream

Fluorinated dielectrics, the dielectric liquid used in data center immersion cooling, **often use PFAS which have high embedded carbon**, and systems may require **copper and rare-earth metals** for pump and valve manufacturing. **Worker safety** at material extraction, processing, and end-product manufacturing stages are all relevant, considering potential chemical exposures and heavy equipment use.

Operations

Water depletion in local areas may result in water stress and price increases. Noise from cooling operations may disturb nearby communities.

Downstream

PFAS fluids require safe handling and disposal. Improper disposal may create groundwater contamination and human health risks

Data Center Cooling

Vision for net zero: where does the lever fit in a 2050 net zero world?

Data center cooling allows the exponential buildout of data center infrastructure to be achieved within a carbon and energy-conscious framework. It includes the replacement if legacy perimeter air and direct expansion computer room air conditioner/air handler (CRAC/CRAH) systems with high-efficiency architectures: hot/cold-aisle containment, rear-door heat exchangers, direct-to-chip liquid cooling, and single-/two-phase immersion, that cut fan energy, raise allowable supply temperatures, and enable heat reuse. Applications span hyperscale halls, colocation suites, telecom central offices and edge sites, and high-performance computing where power density and uptime constraints dominate. Its sustainability involves the use of low-GWP refrigerants and right-sized chillers, free-cooling/economization, water responsibility, circular management of dielectric fluids, and controls that maintain service-level agreements while driving power usage effectiveness (PUE) and water usage effectiveness (WUE) toward best-in-class; modern, certified levels.

In the near term, operators should prioritize containment (hot/cold aisle and cabinet-level), higher supply-air temperatures within recommended envelopes, variable-speed fans and pumps on CRAH/CRAC and chilled-water loops, high-efficiency economization (air- or water-side), and retrofit rear-door heat exchangers or in-row cooling for hotspots; pervasive telemetry and AI-assisted controls should continuously tune setpoints, airflow, and delta-T to cut PUE/WUE while preserving thermal headroom. Through the 2030s, campuses should shift to liquid-first designs: direct-to-chip and immersion systems should become standard for dense racks, paired with heat-recovery loops to buildings or district networks, modular thermal storage (chilled water or phase-change), low-GWP refrigerants, digital twins, and grid-interactive operations that align load shifting and demand response with renewable availability and local network constraints. By the 2040s, cooling should provide dependable thermal capacity for ultra-dense compute without excess overbuild, while acting as a system optimizer that minimizes water use via dry/closed-loop solutions, eliminates high-GWP refrigerants, exports usable heat at scale, and supports 24/7 carbon-free digital operations through automated orchestration with power systems and IT workloads.

Technology operators should commit capex to liquid-ready white space, AI-driven thermal controls, and heat-reuse interconnections, phasing legacy air systems to rear-door, direct-to-chip, or immersion based on density and risk, while enrolling campuses in flexibility markets. Energy providers should integrate data centers as flexible loads with time-coincident tariffs, capacity/flexibility contracts, and on-site thermal storage or chillers operating as grid assets. The construction sector should deliver cooling-plant rooms, heat-recovery exchangers, and district-energy tie-ins, using low-carbon materials and commissioning to verifiably hit PUE/WUE targets. Chemicals firms should scale low-GWP refrigerants, high-stability dielectric fluids for immersion, and advanced thermal interface materials, providing transparent safety and environmental data and take-back programs. Industry should localize supply of high-efficiency chillers, towers/dry coolers, pumps, and plate-and-frame exchangers, with performance warranties and spare-parts logistics that de-risk uptime. Policy engagement across these sectors should back tighter minimum-efficiency and refrigerant standards, water-use disclosure and limits, streamlined district-energy interconnects, and market designs that compensate demand flexibility and verified heat export.

Who to partner with?

- Leading suppliers include CoolIT, Schneider, and Rittal.

Where to find more information?

- IEA
- Data Center Dynamics
- Uptime Institute
- EU Code of Conduct for Data Centers

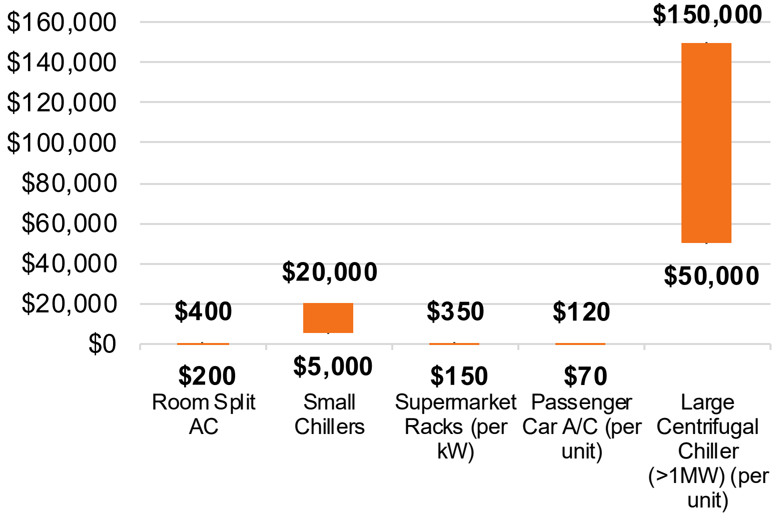
Refrigerants

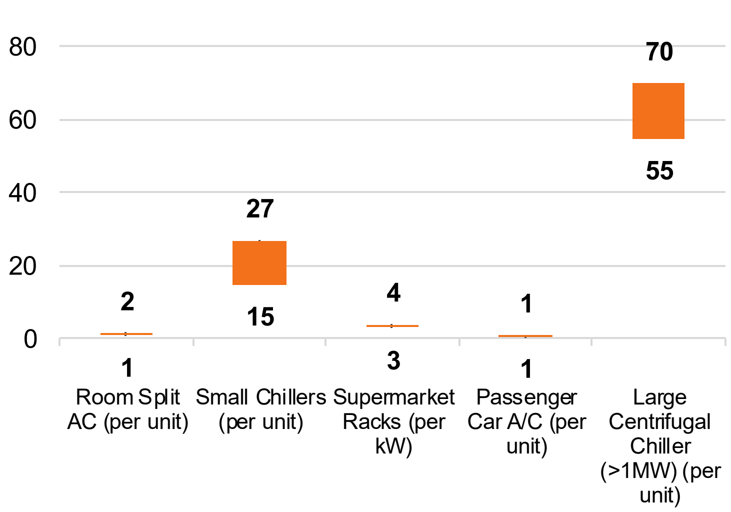
Includes air conditioning, commercial and industrial cooling, and transport cooling

Lever Details

Industry:

- Buildings and Construction
- Consumer Goods
- Chemicals
- Food and Beverage
- Healthcare
- Automotives
- Energy





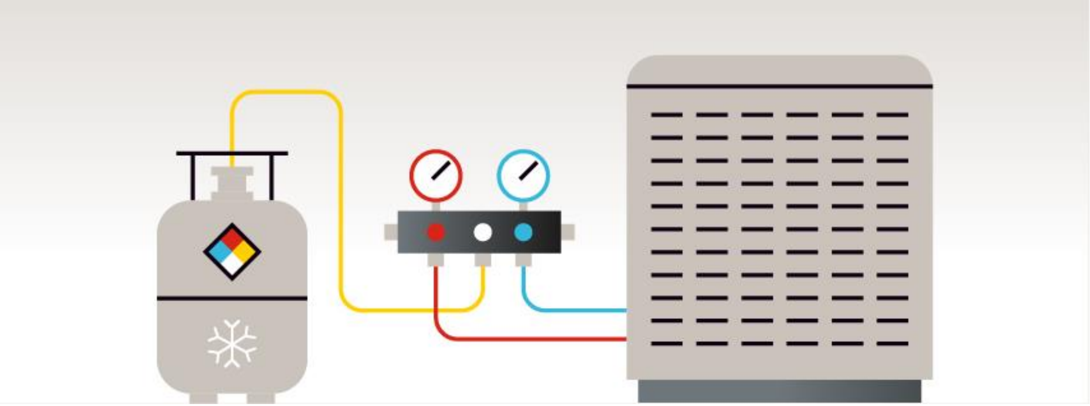
Cost Assumptions and Details

- Replacing existing, **high GWP refrigerants** with greener alternatives faces challenges as the **efficiency impacts are relatively small**. This leads to **long or no payback periods from lower energy gains.**
- The cost of replacing refrigerants depends on the setting: **different refrigerants are used in different places**, and each have their own low-carbon alternative.
- As the world has already sought to move away from high-emissions refrigerants, **relevant taxes and levies such as those in Norway and Sweden** may reduce the incremental expenditure between high and low carbon options.
- **Costs will vary further based on labor costs and modularity;** customized, more complex upgrades or installations will cost more, while cheap labor may reduce total costs in emerging markets.

Refrigerants

External Factors, Dependencies, and Systemic Change Opportunities

- The **Kigali Amendment is an international agreement mandating 80-85 percent phase out of HFCs** (hydrofluorocarbons) globally by 2045.
- **In the EU, policy has already moved** to remove refrigerants high in F-Gases through the EU F-GAS Regulation. The Regulation sets progressively **tougher fluorocarbon supply quotas and outright bans high-GWP fluids in most new equipment by 2032.** Similar regulation should ideally be adopted around the world, with phased pathways, so producers can ramp production and develop relevant technologies over a reasonable period.
- As **the payback potential for refrigerant replacement is low, public policy is required to move private action.** This may come through regulation, tax breaks, and subsidies for updates, while promoting awareness of the societal cost of high-emission refrigerants, such as through stringent labeling programs. At the same time, these systems would need technicians for both mass installation and monitoring who must be trained and employed, particularly around handling flammable materials as propane is increasingly used.
- Utilizing the temperature regulation technologies highlighted elsewhere in this section(green roofs, windows, etc.) may allow a decrease in the volume of refrigerant used, decreasing any total intrinsic emissions.



Key Impacts Outward on Nature and People

Upstream

Compressors and valves require copper, placing pressure on peoples and the environment where it is extracted. **Workers may be exposed to flammable refrigerants** and other harmful chemicals at processing facilities.

Operations

Some **HFCs degrade into a trifluoracetic acid**, a “forever” chemical with significant environmental impacts. **Leaks drive the significant portion of lifetime refrigerant emissions;** managing these and ensuring product quality and maintenance is crucial to successful decarbonization. Technician safety protocols around chemicals and heavy equipment must be implemented.

Downstream

Most refrigerants are currently not recovered post-use, leading to significant emissions and disposal in more unregulated, emerging markets. Developing and enforcing recovery and recycling programs is critical in reducing lifecycle emissions.

Refrigerants

Vision for net zero: where does the lever fit in a 2050 net zero world?

Refrigerants are used where precise thermal control is essential across buildings, cold chains, vehicles, and process cooling. Decarbonization includes the replacement legacy high-GWP ozone-safe HFCs (and remaining ozone-depleting substances, or ODS, in foams/banks) with ultra-low-GWP and natural alternatives: CO_2 (R-744), ammonia (R-717), hydrocarbons (R-290/R-600a), water/air cycles, and select hydrofluoroolefins (HFOs), while cutting indirect emissions through higher system efficiency. Applications span space conditioning and heat-pump water heating, supermarket and warehouse refrigeration, process/chiller loads, transport refrigeration, and mobile A/C. Their sustainability covers three pillars: transition to low-GWP refrigerants, containment and leak reduction (tight installation, monitoring, maintenance), and circular management of the refrigerant bank (recovery, reclamation, destruction).

In the near term, rapid substitutions focus on prioritize low-GWP platforms: hydrocarbons for household and commercial plug-ins; CO_2 transcritical for supermarkets, cold rooms, and distribution centers; R-1234yf (or CO_2 heat-pump loops) in vehicle A/C; and low-GWP chillers plus high-efficiency variable refrigerant flow (VRF)/heat-pump systems in buildings. Mandatory leak detection, tightness testing, certified reclaim at service and end-of-life, and a shift to ultra-low-GWP foam blowing agents should be standardized, supported by contractor training for safe handling of flammable or toxic refrigerants. Through the 2030s, deployment should evolve into integrated thermal systems: natural-refrigerant heat pumps (CO_2, ammonia, hydrocarbons) supplying space and process heat; district-scale heat-recovery networks absorbing data-center and refrigeration waste heat; and professionalized bank management with digital tracking, standardized cylinders, and regional reclaim/destruction capacity. By the 2040s, refrigerant use should deliver high-availability thermal control for electrified buildings, industry, and logistics with near-zero leakage, low-GWP fluids, predictive monitoring, and closed-loop recovery and reuse, minimizing lifecycle climate impact while meeting stringent safety and performance requirements.

Buildings should specify low-GWP heat pumps and chillers, commission to tightness and performance, adopt envelope upgrades that right-size equipment, and align codes to permit safe use of natural/flammable refrigerants with verified ventilation and detection. Chemicals firms should scale supply of natural refrigerants and select HFOs with transparent LCAs (life cycle assessments), invest in reclaim and high-temperature destruction capacity, and manage PFAS-related risks via by-product controls and stewardship. Food and Beverage companies should work to convert supermarkets and cold-chain hubs to CO_2 transcritical systems or secondary loops, electrify transport refrigeration, and contract for leak-rate and energy-intensity guarantees. Healthcare should migrate medical/pharma cold storage to low-GWP platforms with redundancy and monitoring that protect product integrity while minimizing WUE and GWP. Automotives should standardize low-GWP mobile A/C and, for EVs, adopt high-efficiency thermal management (including CO_2 heat pumps in cold climates), provide refrigerant service protocols, and design for end-of-life recovery. Energy providers should fund demand-side programs that accelerate heat-pump adoption on low-GWP refrigerants, integrate cooling loads into flexibility markets, and support district-energy tie-ins for heat reuse. Across sectors, policy engagement should back Kigali-aligned HFC phasedowns, stronger leak-check and recovery mandates, technician certification, updated safety codes for flammable/toxic refrigerants, Mandatory/Minimum Energy Performance Standards (MEPS)/Ecodesign that reward seasonal efficiency and extended-producer-responsibility for refrigerant banks.

Who to partner with?

- Suppliers include Honeywell, Godrej, and Advansor

Where to find more information?

- IEA
- Kigali Cooling Efficiency Programme
- EU F-Gas Observatory & Regulation portal
- Project Drawdown

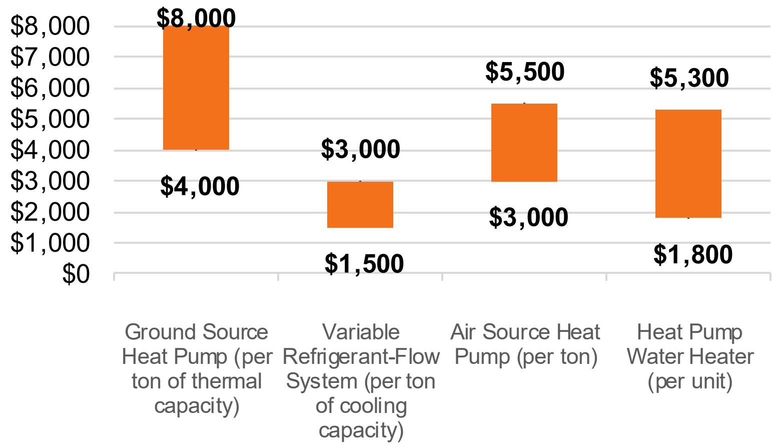
Efficient Heating and Cooling

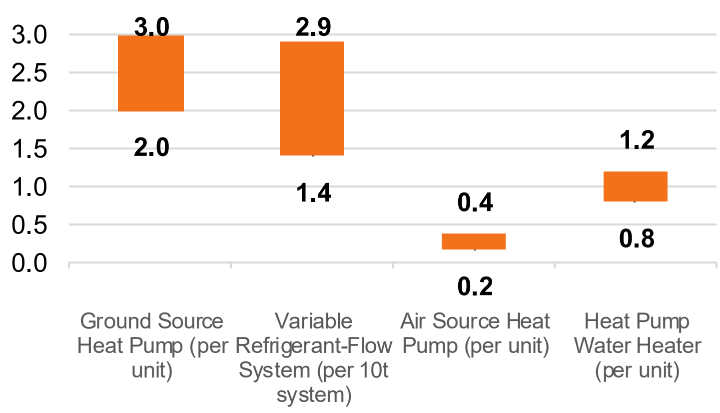
Includes heat pumps and cooling systems for commercial, residential, and industrial settings

Lever Details

Industry:

- Buildings and Construction
- Energy
- Consumer Goods
- Chemicals
- Information Technology
- Healthcare
- Professional Services





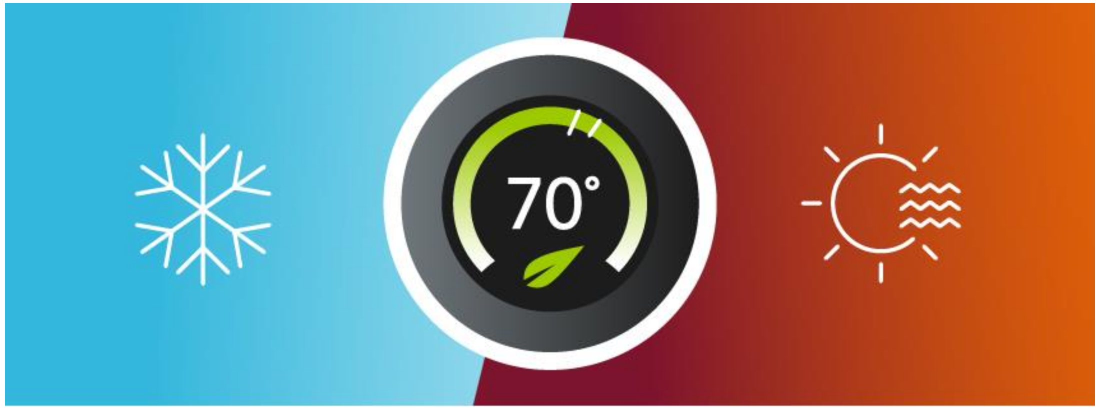
Cost Assumptions and Details

- Efficient heating and cooling systems have **differing payback periods** based on their individual **manufacturing costs, relative efficiencies, and related labor costs.**
- Performance varies further based on local climate: **heating efficiency declines in colder temperatures, and cooling efficiency declines in warmer temperatures.**
- **Other local considerations,** such as the **variations in the difficulty of installing** a ground-source heat pump, the **ability to create centralized sources of district heating, and the price of gas,** determine the cost or payback period.
- Coolant **leakages** also affect cooling efficiency performance; reducing the leakage rate both increases operating efficiency and product life.

Efficient Heating and Cooling

External Factors, Dependencies, and Systemic Change Opportunities

- Cooling has a **unique set of considerations** in a **climate-changed world**; the **hottest countries in the world** will face the **most acute effects** of climate change, and **much of their population will enter middle-income** for the first time in the next 25 years. This underlines an accelerating demand for space cooling and introduces **climate justice considerations** to related costs and burdens with cooling these countries.
- Cooling and heating units can benefit **from stringent policy mechanisms** which mandate **performance standards**, while providing suppliers and consumers with the support needed to invest in these units. Due to the high operating costs of heating and cooling units, **consumers already understand the benefits of energy efficiency** but may face logistical **challenges due to upfront unit costs**. **Financing mechanisms** would help address this.
- The cost of **alternative heating installation**, which has **proved difficult to address,** must decline for these solutions to hit **cost parity with gas**. This must be accompanied by a sizeable number technicians trained worldwide in heat-pump and other temperature regulation technologies.
- The grid itself must be decarbonized for an electrified solutions to curb their emissions.



Key Impacts Outward on Nature and People

Upstream
Risks related to the extraction of **copper and rare earth metals**. Risks **of PFAS chemicals leakages** and **chemical-plant and mine worker safety** during manufacturing.

Operations
Electrification may lead to higher electrical loads on the grid, threatening reliability and renewable generation supply. **Refrigerant leaks** during operation must be monitored, as should safety **managing and working with flammable gases.**

Downstream
Risks related to the **safe disposal and recycling** of equipment, machinery, and component materials.

Efficient Heating and Cooling

Vision for net zero: where does the lever fit in a 2050 net zero world?

Efficient heating and cooling are critical where permanent load reductions and precise thermal comfort are essential. Decarbonization includes the replacement fossil boilers, resistance heating, and oversized, inefficient chillers with heat-pump systems (air-, water-, and ground-source), and the development of variable-speed drives, advanced controls, and heat-recovery architectures that cut both energy use and peak demand. Applications span space conditioning and service hot water in homes, campuses, hospitals, laboratories, data-rich commercial buildings, and light industry, with emerging high-temperature heat pumps extending electrification into low-/medium-temperature process heat. Their sustainability includes right-sizing equipment after envelope improvements, low-GWP refrigerants and tight leak management, durable and repairable components, and circular end-of-life practices.

In the near term, upgrades should include high-efficiency heat pumps (including cold-climate air-source and ground-source), variable-speed chillers with advanced controls, smart thermostats and building automation, rigorous commissioning/retro-commissioning, and modular thermal storage (ice, phase-change, and hot-water tanks); these measures should be paired with low-GWP refrigerant platforms and targeted envelope upgrades so smaller systems deliver the equivalent comfort and process performance. Through the 2030s, delivery should shift toward integrated thermal networks and “liquid-to-liquid” campuses: ambient-temperature district loops with shared geo-exchange borefields, wastewater and data-center heat recovery, and building-level heat pumps and electric boilers, all co-optimized via tariffs, DERMS, and demand-response so heating and cooling act as flexible grid assets; seasonal storage borehole thermal energy storage (BTES)/aquifer thermal energy storage (ATES) and standardized performance warranties should make load shifting bankable. By the 2040s, efficient heating and cooling should provide a dual service: firm ‘demand-reduction capacity’ and dispatchable thermal storage that complement variable renewables across days and seasons, and a system optimizer that enables 24/7 carbon-free operations by flattening peaks, shrinking required grid reinforcements, and monetizing waste heat, backed by digital twins, predictive maintenance, and circular refrigerant and equipment management.

Buildings should adopt performance-based codes and outcome-guaranteed retrofits, pair envelope work with heat-pump conversion and balanced ventilation, design new assets “network-ready” for ambient loops and standardize measurement and verification so savings are financeable. Energy providers should create interconnection fast lanes for electrified heat, structure capacity and flexibility contracts that value duration and availability, and co-invest in geo-exchange fields, thermal networks, and demand-response programs that pay for controllable heating and cooling. Consumer goods manufacturers should scale heat-pump water heaters and room systems with low-GWP refrigerants, design for repairability and parts availability, and embed telemetry for performance guarantees. Technology operators should plan liquid-first cooling and heat reuse into district networks, enroll campuses in flexibility markets, and use AI controls to keep PUE low while shifting thermal loads off-peak.

Who to partner with?

- Suppliers include Honeywell, Godrej, and Advansor

Where to find more information?

- IEA Heating
- IEA Cooling
- U.S. Department of Energy
- European Environmental Agency

Industry

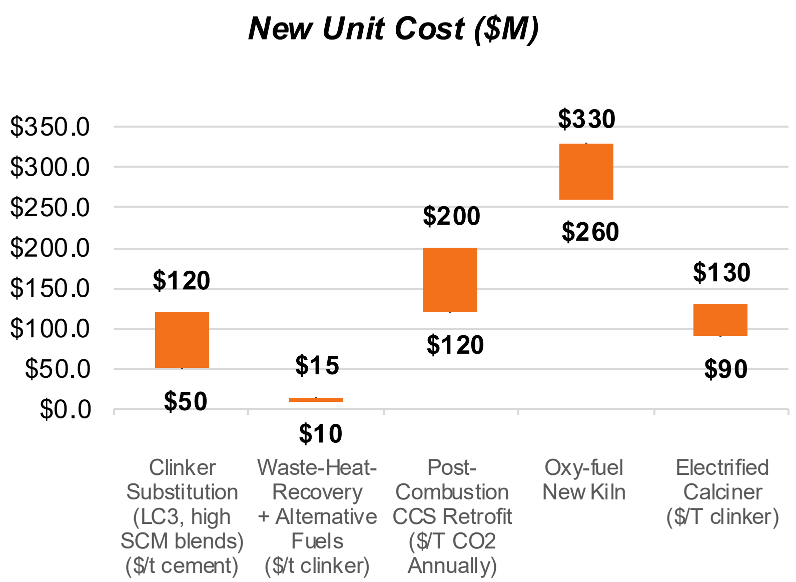
Low-Carbon Cement and Concrete

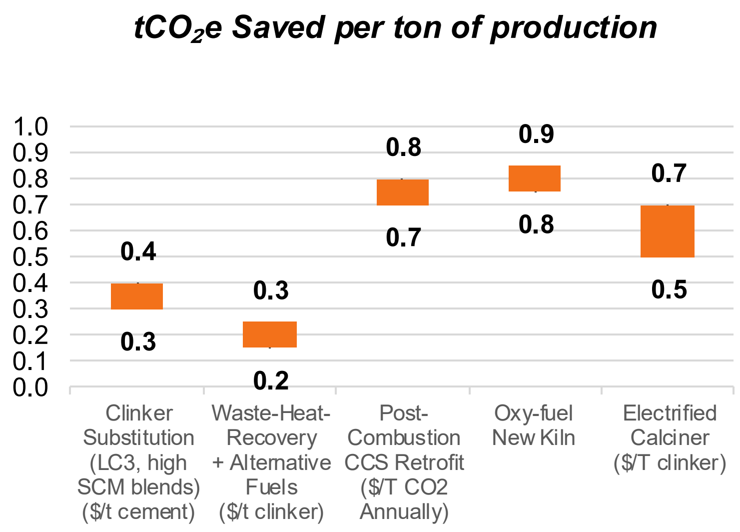
Low-Carbon Cement and Concrete includes clinker substitutions, kiln and calciner electrification, heat waste recovery, and CCS retrofits.

Lever Details

Industry:

- Buildings and Construction
- General Manufacturing & Industry
- Energy
- Mining and Extractives
- Financial Services
- Professional Services
- Chemicals





Cost Assumptions and Details

- Cement produces **most of its CO_2 emissions from clinker**, an intermediary used as a binding agent during the manufacturing process. **Producing lower-carbon clinker, deploying local CCUS, and replacing clinker** all together present a pathway to decarbonization.
- Current lower-carbon cement solutions command a premium due to their **constrained supply and technological complexity.** As industrial capacity scales, costs should fall closer in line with traditional cement.
- CCUS and cement production are energy intensive**. Location and renewable energy availability** is critical for cost and decarbonization effectiveness.
- Other methods of emissions reduction include **admixtures**, which reduce the level of cement needed in concrete, **replacement binding agents** such as limestone and clay, and **recycling cement.**

Low-Carbon Cement and Concrete

External Factors, Dependencies, and Systemic Change Opportunities

- The **vast majority of global cement manufacturing and use is in China.** Recognizing the size of its emissions and positioning its industrial base to capture the low carbon cement market, **China added cement to its carbon trading market** earlier this year.
- **Several levers must come together**, from materials substitution, renewable energy use, alternative fuel use, and efficiency in design and construction, to credibly shift cement to a net zero pathway.
- Even while using **clinker substitutions**, there are **inevitable residual emissions**. These require **on-site CCS facilities to be offset**. As most cement production is in the developing world**, the price and availability of these technologies is crucial to their utilization.** Significant infrastructure for the storage and transport of this CO_2 will also have to be constructed. Developed, importing nations may offset some of these costs.
- **International standards for emissions intensity**, public-private research and funding partnerships, and regulatory measures are all necessary to coerce the industry into decarbonization.

Key Impacts Outward on Nature and People

Upstream

Fly ash, slag, limestone, calcined clay, or other materials used to reduce clinker content can face **resource scarcity and disturb local land and peoples. Informal waste collection for alternative fuels** (e.g., plastic waste) could be linked to **child labor or unsafe working conditions** in certain regions.

Operations

While clinker substitution lowers CO_2 emissions, **other emissions (e.g., NOx, SOx) may fluctuate if alternative fuels or novel chemistries alter combustion profiles. Carbon capture for low-carbon cement can increase energy demand** and create new waste streams if not carefully managed.

Downstream

Alternative fuels or binders could yield cements with trace contaminants, potentially leaching into soils or water if not managed properly at end-of-life. Insufficient education and improper application of low-carbon cement may lead to **physical integrity issues in construction.**

Low-Carbon Cement and Concrete

Vision for net zero: where does the lever fit in a 2050 net zero world?

Low-carbon cement replaces high-clinker, fossil-fired cement, used as a durable, versatile binder for buildings, infrastructure, and industrial facilities. It replaces coal-intensive clinker with lower-carbon alternatives by cutting the clinker factor, switching kiln fuels and heat sources, improving process efficiency, and adopting carbon capture where process CO_2 is unavoidable. Applications span ready-mix, precast, and masonry products that meet structural and durability requirements with lower embodied carbon through supplementary cementitious materials (SCMs) such as calcined clays and limestone, ground granulated slag, natural pozzolans, recycled concrete fines, and emerging alternative binders. Its sustainability includes verified environmental product declarations, performance-based specifications that reward lower life-cycle emissions, and circular practices.

In the near term, substitutions should prioritize clinker-factor reduction: limestone calcinated clay cement (LC3) and other calcined-clay blends, limestone-rich cements, and optimized admixture/aggregate design, paired with high-efficiency grinding, waste-heat recovery, and fuel switching to biomass and refuse-derived fuels; pilots for direct-separation or oxy-fuel calcination and early carbon-cured concretes that permanently mineralize CO_2 should advance alongside performance-based specifications, verification, and contractor training. Through the 2030s, supply chains should scale into low-carbon industrial clusters where SCM production (calcined clay and regionally available alternatives), electrified or hydrogen-assisted calciners, alternative raw materials, and post-combustion or direct-separation CO_2 capture integrate with shared CO_2 transport, storage, or mineralization; while standardized mix designs, code updates, and digital material passports with CO_2 accounting should enable consistent sub-threshold product intensities across plants and regions. By the 2040s, near-zero-carbon cement and concrete should be available at scale for buildings and critical infrastructure: remaining clinker lines may operate with capture and low-carbon heat. LC3 and other blended cements dominate, with widespread carbonation curing and CO_2-bound aggregates capturing additional carbon.

The construction industry should adopt performance-based specs and embodied-carbon budgets, require third-party EPDs, and qualify high-replacement mixes and carbon-cured products so designers can right-size strength and durability without defaulting to high-clinker recipes. Cement and concrete producers should invest in calcined-clay units and SCM logistics, high-efficiency mills, waste-heat recovery, alternative-fuel systems, kiln upgrades compatible with electrification or hydrogen blends, and capture pilots that tie into regional CO_2 networks; digital quality control and admixture optimization should lock in performance at lower clinker. Mining companies should secure kaolinite-rich clays, high-quality limestones, and pozzolans; expand responsible quarrying and beneficiation; and support aggregate recycling streams that unlock SCMs from recovered fines. Financial firms should scale transition finance for calcined-clay lines and capture retrofits, use sustainability-linked loans tied to verified kg-CO_2/t metrics, and back contracts-for-difference or green-public-procurement premiums that de-risk the cost gap to near-zero cement. Insurance for capture performance and long-tenor infrastructure debt will also be critical. Professional services can accelerate permitting, code updates, and independent MRV for plant and product claims, while structuring outcome-based contracts that pay for embodied-carbon reductions. Chemicals firms should supply low-carbon grinding aids and high-performance admixtures that enable higher SCM substitution, deliver capture solvents/sorbents and carbon-cure media with take-back programs, and co-develop alternative binders that meet durability and sustainability codes.

Who to partner with?

- Sustainable cement producers include Brimstone, Fortera, and Prometheus Materials.

Where to find more information?

- GCCA (Global Cement and Concrete Association)
- IEA Cement
- Project Drawdown – Alternative Cement
- First Movers Coalition

Low-Carbon Steel

Includes electric furnaces, Direct Reduced Iron (DRI) furnaces with natural gas and hydrogen, and blast and blast oxygen furnaces with on-site carbon capture

Lever Details

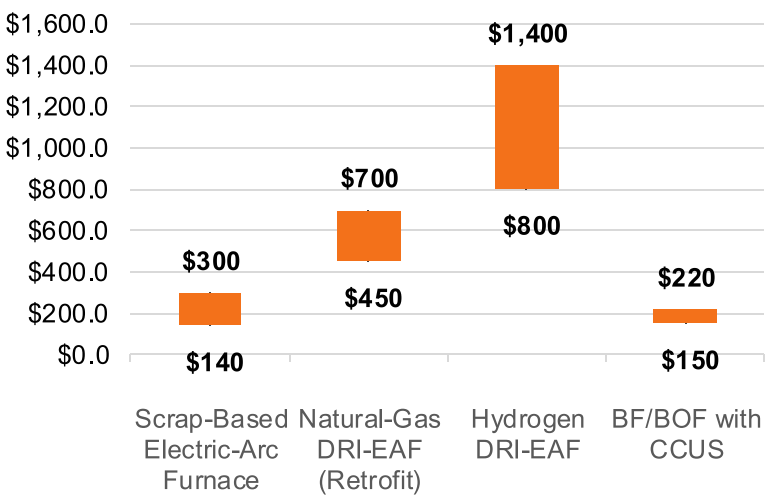
Industry:

- Automotives
- Buildings and Construction
- Mining and Extractives
- Energy
- General Manufacturing & Industry
- Shipping and Logistics
- Financial Services

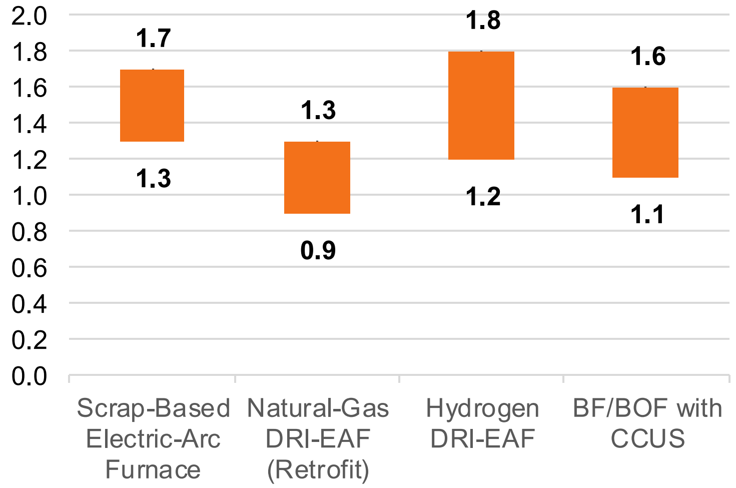
Cost Assumptions and Details

- **Electricity costs** are a **large determinant of operating costs,** and final steel costs **for electrified furnaces.**
- Steel is notable for its **high recycling rate**, and around the world **varying amounts of steel production will come from scrap.** The **price of scrap steel** as an input is then **a large cost determinant** of final steel prices.
- The **price of scrap-based electric-furnaces** are thus cheapest where both **abundant low-carbon power** and clean scrap are available.
- **Electrolyzer costs** are a large determinant of **Hydrogen DRI-EAF (Direct-Reduced Ion – Electric Arc Furnace) costs.** The price and availability of renewable energy to power the electrolyzer further leads to cost variations.
- **CCUS costs** include **power and low-pressure steam** to regenerate solvent, and compression, dehydration, transport, and storage of CO_2.

Cost of Substitution, Abatement, and Capture



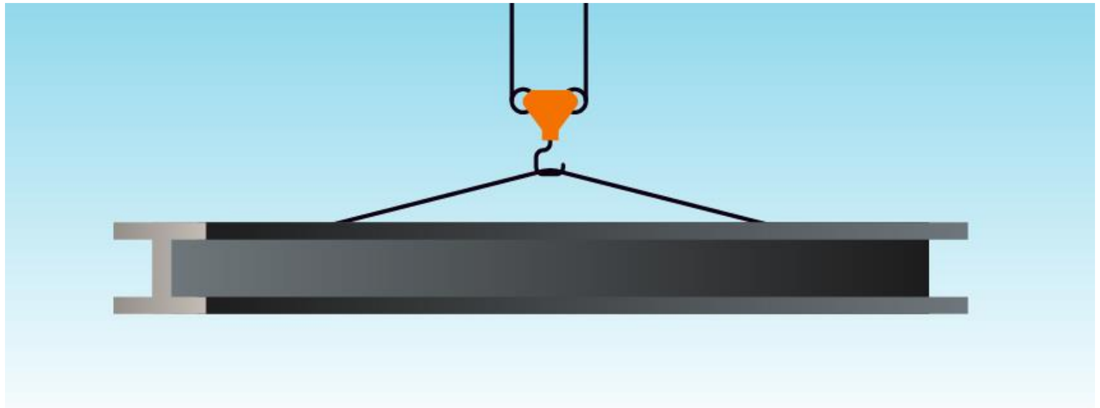
tCO_2e Saved per ton of production



Low-Carbon Steel

External Factors, Dependencies, and Systemic Change Opportunities

- About **70 percent of global steel output is still from coal-based blast or basic-oxygen furnaces, and 29 percent from electric-arc furnaces**, up marginally from 24 percent a decade ago. However, **49 percent of the global development pipeline is EAF,** signaling an **accelerating pivot away from fossil fuels.** These are spread **across hydrogen pilots, natural-gas based retrofits, and demonstrations of CCUS capabilities.**
- **Demand levers**, such as decarbonization plans by **automakers and other steel purchasers,** may guide the industry into more rapid transformation. **Offtake contracts** signed by industry leaders have already given developers bankable revenue floors, which may assist in expanding the development pipeline.
- **China's move to add steel to its emissions-trading system**, and increasing emphasis on circular economy, **likely presents the largest determinant of how steel decarbonizes.** Scrap steel has lower lifecycle emissions than fresh steel, and its increasing use is important in curbing emissions as electrification is built out. India, the world's second largest producer, has also identified increased scrap utilization as a strategic priority to guide reductions to CO_2 intensity within the industry.



Key Impacts Outward on Nature and People

Upstream
Mining for **high-grade DRI pellets** and electrolyzer expansion have **mineral, mining, and land-use impacts in vulnerable geographies.**

Operations
Risks related to **worker health and safety**, at recycling and other manufacturing facilities. Risks related **to hydrogen safety and nitrogen-oxide emissions.**

Downstream
Risks related to **respiratory effects of iron dust, CCUS leakages, and economic effects of potentially higher steel prices** or displacement caused by the retirement of existing facilities.

Low-Carbon Steel

Vision for net zero: where does the lever fit in a 2050 net zero world?

Low-carbon steel involves a replacement of existing coal-based blast-furnace/basic-oxygen-furnace (BF-BOF) routes, supplying an essential input to vehicles, buildings, grids, machines, logistics, and global development without the legacy carbon intensity. It pivots on three technological pillars: scrap-fed electric-arc furnaces (EAFs); direct-reduced iron paired with EAFs (DRI-EAF), shifting from natural gas to hydrogen; and, as a transitional or regional option, carbon capture on residual BF-BOF assets. Emerging processes such as molten-oxide electrolysis could deliver ore-to-iron pathways powered entirely by electricity. Market integrity is underpinned by site and product standards and target-setting frameworks (e.g., ResponsibleSteel certification and SBTi Steel Guidance), while trade and procurement policy, most notably the EU's Carbon Border Adjustment Mechanism (CBAM) and Buy Clean programs, disadvantage high-embodied-carbon steel and reward verified low-carbon supply.

Through the late 2020s, the quickest abatement comes from expanding scrap-based EAF capacity, raising scrap quality via advanced sorting and pre-treatment, installing hydrogen-ready DRI modules, piloting industrial-scale hydrogen-DRI and early electrolysis routes, and applying targeted CCUS to BF-BOF assets slated for later retirement. Parallel upgrades, such as DR-grade ore beneficiation and pelletizing, waste-heat recovery, high-efficiency electrification, and flexible EAF operations synchronized with high-renewables grids, cut energy intensity and enable load-shifting. In the 2030s, integrated "green-iron" hubs co-locate DR-grade ore processing, multi-gigawatt clean power plus firming, hydrogen supply and storage, DRI modules, EAFs, and port- or mine-adjacent logistics, financed by long-term offtakes and product-level certification; harmonized standards for DR-grade quality and low-residual scrap, with digital traceability, derisk bankability at scale as hydrogen displaces coal and electricity becomes the dominant energy input. By the 2040s, scrap-EAF and hydrogen-DRI/EAF dominate global output with residual CCUS only where warranted; commercial electrolytic iron contributes in regions with abundant low-cost clean power; and circularity: higher scrap recovery, design for recycling, and normalized product disclosure delivers cost-competitive near-zero steel by 2050 without adding air-pollution or land-use burdens.

Automakers can codify near-zero steel in platform specifications and sign multi-year offtakes that ramp from scrap-EAF to hydrogen-DRI supply, supported by third-party certification and SBTi-aligned targets. Building owners and public agencies may anchor demand through Buy Clean rules and EPD-based procurement that tighten embodied-carbon thresholds over time. Miners can assure stable flows of DR-grade pellets and invest in beneficiation compatible with hydrogen reduction. Energy providers can plan firmed renewable PPAs and grid interconnections sized for EAF and electrolyzer loads. Manufacturers can maximize scrap recovery and design for high-quality recycling to expand the circular feedstock base. Logistics providers can green critical corridors for ore, hot briquetted iron (HBI) and DRI, coils and finished goods while cutting transport emissions, and financial institutions should structure transition finance for DRI-EAF conversions, renewable and hydrogen supply, and CCUS where relevant, using instruments such as contracts-for-difference, regulated-asset-base or capacity payments, and sustainability-linked loans tied to verified product carbon intensities. Cross-cutting policy engagement should focus on timely CBAM implementation, robust green-public-procurement and product standards, accelerated permitting for renewables, grids and hydrogen infrastructure, and clear MRV rules so low-carbon premiums are defensible and bankable.

Who to partner with?

- Providers include Vattenfall, Arcelor Mittal, and Sortera

Where to find more information?

- Global Iron and Steel Tracker
- IEA Steel
- IEEFA
- Circular Economy Solutions for China's Steel Industry

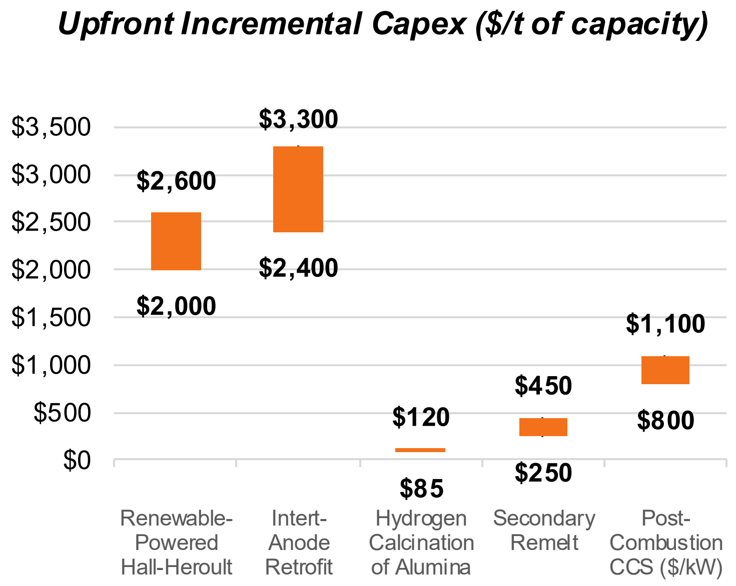
Low-Carbon Aluminum

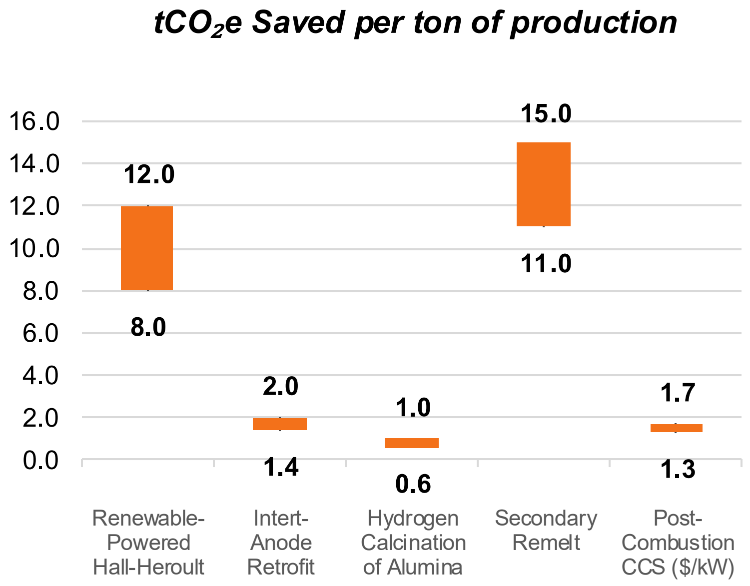
Includes retrofits to existing facilities, new facilities, scrap, and CCS

Lever Details

Industry:

- Automotives
- Aviation
- Consumer Goods
- Buildings and Construction
- Energy
- Information Technology
- General Manufacturing & Industry





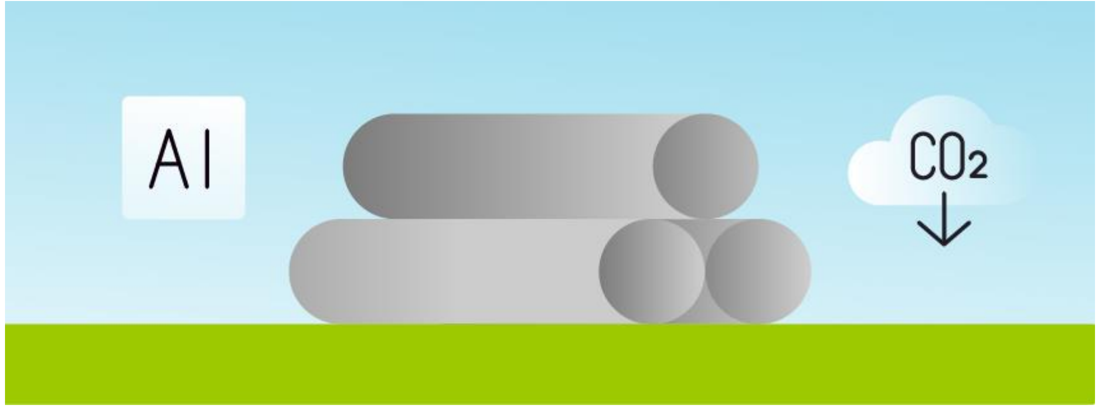
Cost Assumptions and Details

- **Electricity prices**, as with the electrification of other industrial processes, have a **large effect on the cost of decarbonization of aluminum.**
- **Inert anodes reduce or eliminate some process emissions** but are currently more expensive than carbon anodes. However, **inert anodes last longer, so theoretically pay off over time.**
- The price of hydrogen and electrolyzer construction influences costs of **hydrogen calcination of alumina, which serves as the input for finished aluminum.**
- **High-grade scrap purity and availability** contributes to costs; lower grade scrap raises the blended cost of metal.
- **Taxes on non-green aluminum** and subsidies for the purchase of low-carbon alternatives may reduce the premium between the alternatives.

Low-Carbon Aluminum

External Factors, Dependencies, and Systemic Change Opportunities

- **Renewable energy sources currently supply about 39 percent of world smelter electricity.** The continued increase of this number relies on decarbonization in China and other producers. EU's CBAM includes aluminum, developing a price mechanism to incentivize low-carbon aluminum production.
- **Inert anodes** have started being produced in commercial capacities and are being gradually piloted at scale following breakthrough developments.
- **China has moved a significant amount of capacity from coal-powered plants to hydropower basins.** India and Middle Eastern nations are looking to replicate this with solar-plus facilities.
- Rio Tinto, Sumitomo, and ARENA broke ground on **the world's first hydrogen-fired calcination demonstration** at a refinery in Australia, aiming to provide a **70 percent CO_2 emissions reduction at the alumina processing stage**.
- Deposit-return schemes and automotive "closed-loop" scrap contracts have lifted the global recycling share to 36 percent. Despite promising advances, only ~5 percent of committed capacity is truly net zero carbon, leaving significant scope to accelerate ambition .
- **Accelerants to adoption** include firm power for electrified smelters, sustainable bauxite and alumina suppl chains, and developments to the scrap ecosystem, including quality and traceability infrastructure.



Key Impacts Outward on Nature and People

Upstream

Bauxite mining can drive deforestation and red-mud tailings. Hydropower reservoirs can displace communities**; iridium and rare-earth demand** for inert-anode alloys could create **new supply stresses and land and community impacts.**

Operations

Risks related to emissions from CO_2 and PFCs from traditional anodes, air pollutants release, and noise and thermal pollution. Risks related to **worker exposure** to heat and heavy machinery.

Downstream

Leakages of alloying elements may hinder recyclability. Transportation of aluminum may create emissions and coated or mixed material products may have harmful degradation effects where not properly recycled. Risks related to **informal scrap and waste handling** in developing economies.

Low-Carbon Aluminum

Vision for net zero: where does the lever fit in a 2050 net zero world?

Low-carbon aluminum is an eventual replacement for coal- and gas-powered primary aluminum, used as a light, durable, and corrosion-resistant material for vehicles, aircraft, buildings, electronics, and power infrastructure. It replaces high-embodied-carbon metal by maximizing scrap-based production and shifting primary smelting to near-zero electricity and process emissions, so automakers, airframe manufacturers, building owners, consumer-goods brands, grid operators, and industrial original equipment manufacturers (OEMs) can cut Scope 3 with material choice. Applications span auto body sheet and battery enclosures, aerospace plate and extrusions, façade and window systems, beverage cans and appliances, server and device housings, conductors and solar frames, and a wide range of industrial castings. Its sustainability includes low-carbon electricity for smelting and refining, high recycled content enabled by alloy-aware sorting and closed loops, and responsible mining and residue (red-mud) management backed by third-party certification.

From now through the late 2020s, actions should focus on scaling high-recycled-content product lines, locking in long-tenor clean-power contracts for refineries and smelters, tightening potline operations to suppress anode effects and perfluorinated compounds (PFCs), optimizing fluoride capture, and upgrading scrap segregation and alloy design for closed-loop recyclability; in parallel, run first-of-a-kind trials for inert-anode cells and for electrified or hydrogen-assisted alumina calcination. In the 2030s, these discrete efforts scale into coordinated regional systems, including clean, firm power and grid access for smelting and refining, staged replacement of legacy pots with near-zero smelting (inert anode) where advanced sorting and remelt facilities that meet tight specifications, and digital product passports to verify carbon intensity. By the 2040s, standardized near-zero-carbon billet, slab, plate, and extrusions are produced at industrial scale: electricity is the dominant energy and cost driver, inert-anode smelting eliminates process CO_2 and PFCs, calcination is electrified or hydrogen-fired where economical, and circularity, including higher post-consumer scrap capture, alloying compatible with repeated remelt, and transparent product-level disclosure, delivers competitively priced low-carbon aluminum globally.

Automotives should lock in multi-year offtakes for near-zero sheet and extrusions, design platforms for closed-loop press-shop scrap and high-recycled-content alloys and publish environmental product declarations (EPDs) tied to verified kg-CO_2/kg thresholds. Aviation should specify certified low-carbon plate and extrusions for fatigue-critical parts, co-develop alloy chemistries that preserve properties at high recycled content, and contract for plant-level intensity floors with chain-of-custody. Construction should require EPDs and embodied-carbon budgets in procurement, prioritize façade and window systems from near-zero smelters, and enable end-of-life recovery. Energy sector buyers should source low-carbon aluminum for conductors, solar frames, and storage hardware, align delivery with renewable PPAs that firm smelter loads, and support transmission access for green-power smelting. Industry should redesign castings for recyclability, standardize alloy families to reduce down-cycling, and co-invest in sorting, remelt, and near-zero smelting capacity in regional hubs. Across these sectors, policy engagement should back robust product-carbon standards and “Buy Clean” rules, timely implementation of border-carbon adjustments, certification schemes for responsible mining and Aluminum Stewardship Initiative (ASI)/chain-of-custody, and grid and permitting reforms that unlock round-the-clock low-carbon power for smelters.

Who to partner with?

- Providers include Rio Tinto, Almatis, and RUSAL

Where to find more information?

- IEA
- WEF
- ARENA Hydrogen Calcination Project Brief

Chemicals

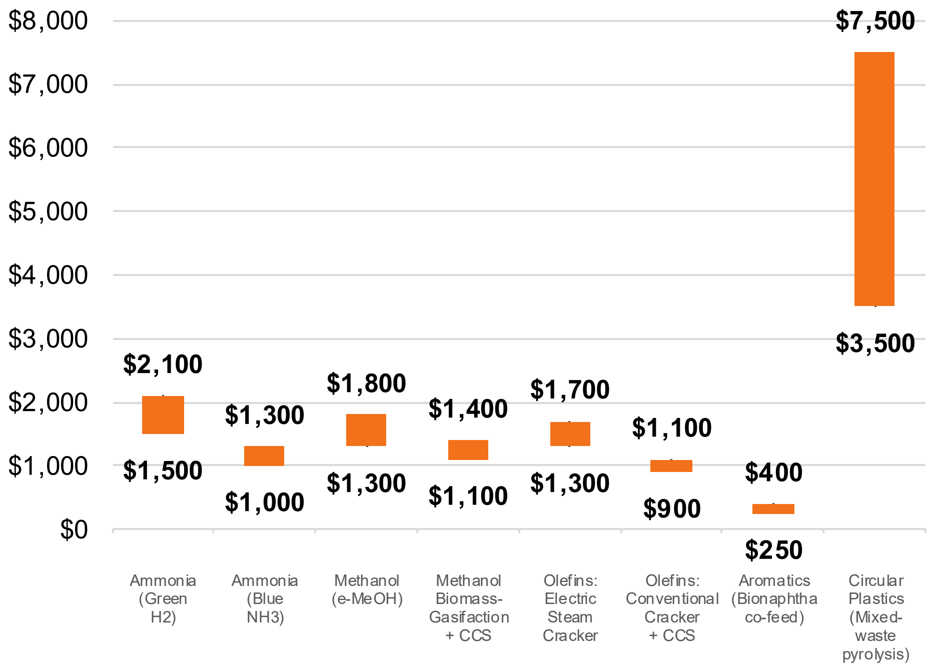
Includes ammonia, methanol, olefins, aromatics, and plastics

Lever Details

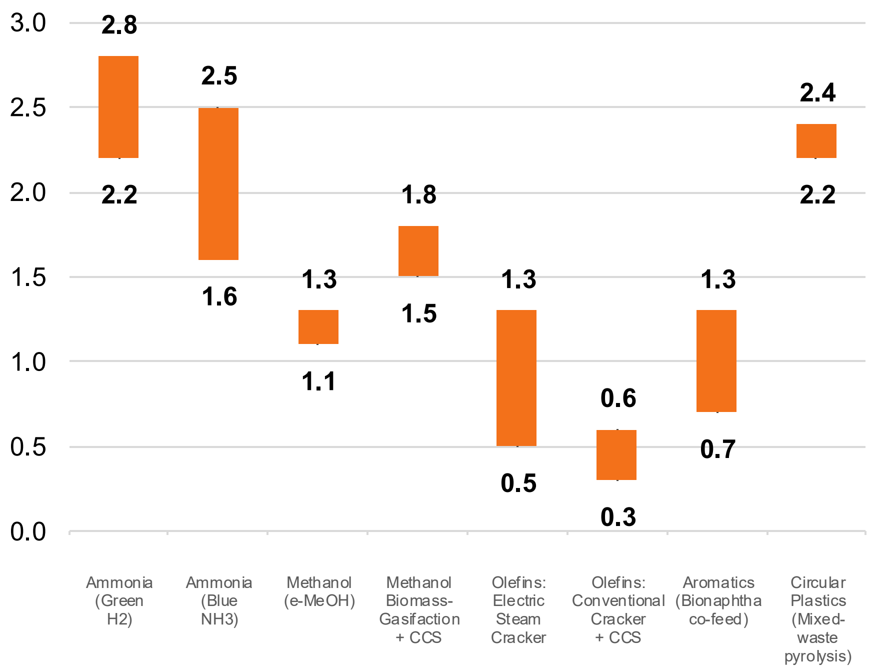
Industry:

- Chemicals
- Consumer Goods
- Food and Beverage
- Energy
- Healthcare
- General Manufacturing and Industry
- Mining and Extractives

Upfront Incremental Capex ($/t of annual)



tCO_2e Saved per ton of production



Cost Assumptions and Details

- **Electricity and effective hydrogen prices** have a significant effect on the price of decarbonizing chemical processes.
- The **price and quality of chemical feedstock**, which provides the basis for finished chemicals, effects final price. Captured and repurposed CO_2, for example, may vary significantly in price across regions. **Lower quality feedstock requires more processing.**
- **Furnace and facility electrification presents upfront costs** but may break even if electricity can be supplied at cheap enough rates.
- **Electrolyzers and pyrolysis** plants both exhibit economies of scale, so **large localized facilities** may become economically feasible before more boutique applications.

Chemicals

External Factors, Dependencies, and Systemic Change Opportunities

- About **half of the chemical sector's energy input is consumed as feedstock,** where **fuel is used as a raw material** rather than as a source of energy. Substituting this fuel with alternate inputs is crucial to decarbonizing the sector beyond simply electrifying industrial processes.
- **Efficiency measures**, particularly in plastics and fertilizer use, can play a large role in reducing new chemicals demand. **Currently, only about 10 percent of plastic is recycled.**
- Roughly **15 GW of announced electrolyzer capacity** is tied to **green ammonia and e-methanol projects**, primarily in Europe. **Electric crackers have started to be piloted at industrial scale.**
- Inert-anode aluminum and low-carbon steel projects are signing offtake agreements that will provide a ready market to green ammonia and methanol as decarbonizing agents.
- **A crucial step will be electrifying heat pumps** and reducing heat loss within complex industrial systems.

Key Impacts Outward on Nature and People

Upstream

Risks related **to bauxite, phosphate, and gas extraction**. Risks related to the **manufacturing and handling of precursor chemicals**, including worker safety, leakages, and fires.

Operations

Risks related to **land-use for biomass, water stress** at green-NH3 hubs, ammonia toxicity, methanol leaks, plastic-pyrolysis dioxins, and worker health and safety.

Downstream

Risks related to **plastic leakage, fertilizer emissions, CO_2 transport and storage, and disposal and reuse of byproducts.**

Chemicals

Vision for net zero: where does the lever fit in a 2050 net zero world?

Chemicals decarbonization is crucial where carbon-based intermediates, solvents, and polymers remain essential to the real economy. Decarbonizing this system replaces grey hydrogen in ammonia and methanol, cut fossil feedstocks in steam cracking, and shrink the footprint of polymers and solvents that flow into packaging, consumer products, construction materials, healthcare devices, and industry. Applications extend from fertilizer and methanol-to-chemicals to ethylene/propylene and benzene, toluene, and xylenes (BTX) aromatics that underpin plastics and advanced materials. Sustainability includes switching to low-emission hydrogen and electricity, cutting process heat emissions, deploying high-quality recycling (mechanical where possible, chemical where needed), substituting bio-naphtha and other advanced bio-intermediates where they meet performance and land-use safeguards, and embedding mass-balance, product-carbon disclosure, and end-of-life responsibility.

Between now and 2030, the focus should involve swapping grey hydrogen for low-emissions hydrogen in ammonia and methanol (via CCUS-equipped reforming with early electrolytic volumes), electrifying sub-200–300°C heat with heat pumps and electric boilers, tightening catalysts and heat-integration, and capturing high-purity process/biogenic CO_2 for storage or for e-fuels. By the mid-2030s, first-of-a-kind units turn mainstream: electrically heated steam-cracker furnaces move from demonstration to commercial deployments, CO_2 compression and transport links connect concentrated sources to storage, pretreatment standards upgrade pyrolysis oils to cracker-grade feeds, and mechanical plus selective chemical recycling scale with auditable chain-of-custody and digital product passports across polymer value chains. In the 2040s, near-zero-carbon ammonia, methanol, olefins, aromatics, and polymer grades are produced at industrial scale, with low-emissions electricity and hydrogen supplying a far larger share of energy, recycling materially displacing virgin fossil feedstocks, and residual process emissions addressed by capture and storage, consistent with credible 1.5 °C-aligned pathways while reflecting real-world build-out rates for hydrogen and electrification.

Chemicals producers need to invest in low-emission hydrogen supply, electrified cracking and heaters, shared CO_2 transport and storage, advanced recycling with strict quality control, and mass-balance certification so product claims survive audit. Consumer goods brands should lock in multi-year offtakes for low-carbon resins and packaging with minimum recycled-content and product-carbon thresholds, redesign for recyclability, and stand up take-back systems that upgrade waste quality. Food and beverage companies should migrate packaging to verifiably low-carbon polymers, lightweight where possible, and pair cold-chain efficiency with natural-refrigerant systems to avoid offsetting chemical gains. Energy actors should provide firmed renewable PPAs for electrolysis and electrified process heat, build hydrogen and CO_2 networks that anchor molecule hubs, and procure low-carbon chemicals for their own assets. Healthcare buyers should specify low-carbon, sterile-grade polymers and solvents with validated supply traceability and end-of-life pathways that meet regulatory standards. General Manufacturing and industry should substitute low-carbon plastics, resins, and solvents in components and coatings, synchronize procurement with recycling streams, and co-site loads near hubs to benefit from waste-heat and oxygen/steam integration. Across these sectors, financial services and professional advisors should standardize long-dated offtakes (ammonia, methanol, low-carbon resins), contracts-for-difference for e-fuels and electrified crackers, and sustainability-linked loans tied to verified KPIs.

Who to partner with?

- Providers include Yara Green Ammonia, ThyssenKrupp, and BASF

Where to find more information?

- IEA
- U.S. Department of Energy
- Decarbonizing the Chemical Industry
- Pyrolysis and Beyond: Sustainable Valorization of Plastic Waste

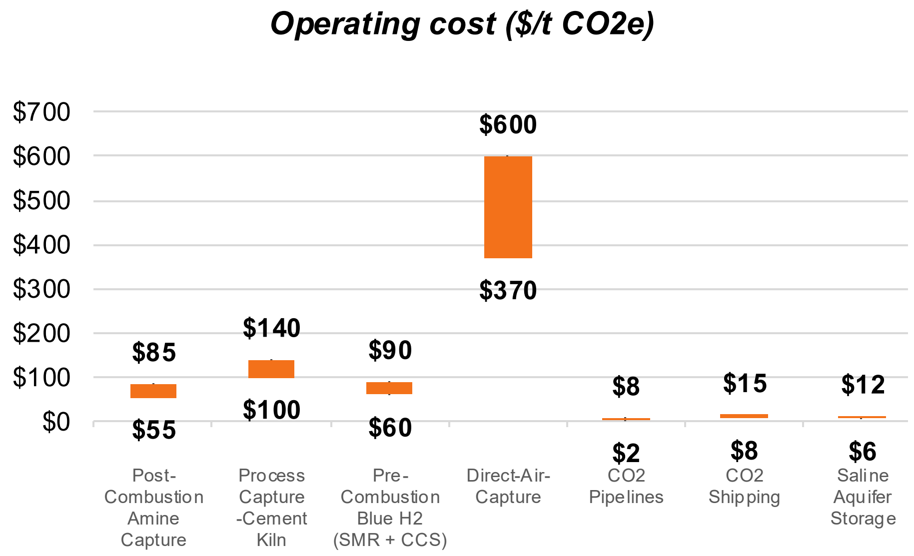
CCUS

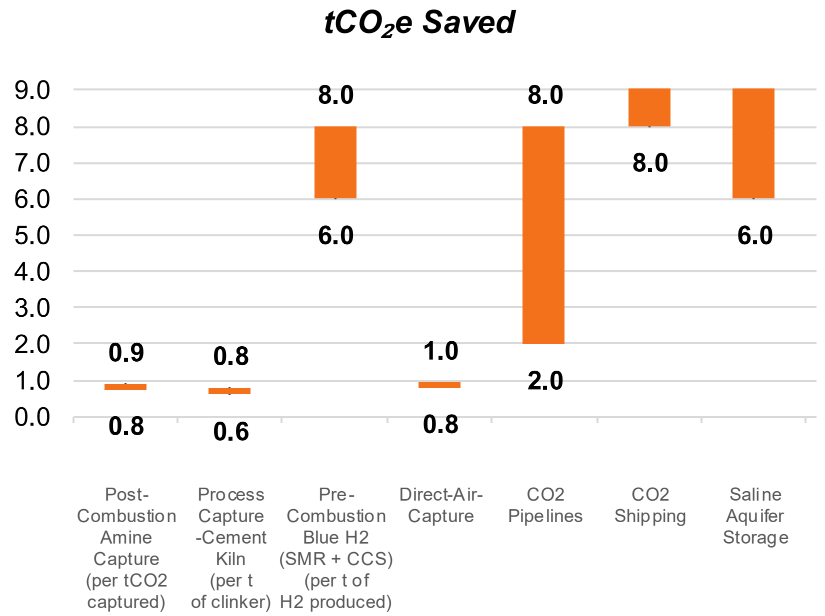
Includes industrial air capture, direct-to-air capture, transport, and storage

Lever Details

Industry:

- Energy
- Chemicals
- Buildings and Construction
- General Manufacturing and Industry
- Mining and Extractives
- Aviation
- Financial Services





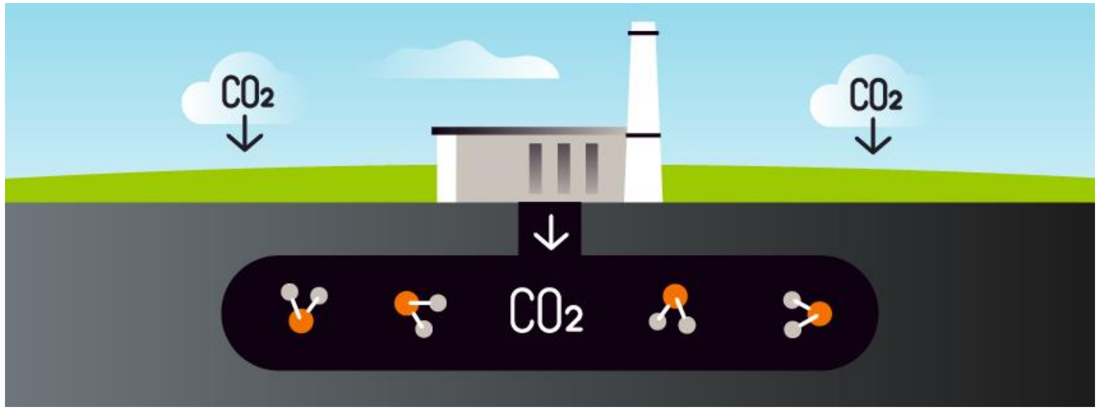
Cost Assumptions and Details

- **Electricity and localized energy prices** have a significant influence on the price of CCUS technology.
- **The availability and specifics of storage and transport technologies** and options affect project capex and operating costs. Co-locating capture facilities to combine storage facilities can realize economies of scale. Additionally, increasing the scale of pipelines and shipping facilities will have significant positive scaling.
- **Local geologic features** determine the ease of storage and transport.
- **Policy credits and subsidy mechanisms** exist in the U.S. and Europe for geologic storage. Their local applicability can determine project feasibility.
- Industries with **more concentrated CO_2 streams have easier-to-capture emissions**, requiring less energy. Others, such as cement or power, require more energy to process diluted gas streams.

CCUS

External Factors, Dependencies, and Systemic Change Opportunities

- About **45 commercial facilities have been installed around the world applying CCUS to industrial processes** and power generation. Following a gradual buildout, momentum has gathered, with technologies such as Direct-to-Air capture and sophisticated industrial applications seeing successful pilots.
- Announced **planned capture capacity for 2030 still significantly lags behind** net-zero pathways. Developing financing schemes, collective initiatives, and supporting infrastructure such as transport and storage facilities are crucial in increasing utilization.
- **Nine commercial blue-hydrogen or blue-ammonia plants have reached FID** in the U.S. Gulf Coast and Middle East. Europe's first three CO_2-shipping-to-saline hubs are under construction with combined storage of 8 Mt yr.
- **Policy accelerators** include IRA green-H_2 credits, facilitating blue-H_2 + CCS projects, UK Track-1/2 Industrial Clusters offering contracts for difference (CfDs) for capture, transportation, and storage fees, and EU CBAM which will raise the implicit CO_2 price on imports, favoring low-carbon fertilizer and plastics made with CCUS. However, **only about one-third of announced capacity has secured offtake or debt finance,** as perceived market risk and slow permitting remain obstructions.



Key Impacts Outward on Nature and People

Upstream

Risks related to **energy and water demand for DAC (direct air capture)**. Risks related **to mining of potassium and amine sorbents** and risk of **blue-H_2 methane leakage.**

Operations

Risks related to **amine degradation waste, solvent emissions, pipeline rupture or ship boil-off.** Risk of subsurface induced seismicity during injection of stored CO_2.

Downstream

Risks related to long-term storage liability, **potential CO_2 re-release** from utilization pathways. Risks related to public acceptance of injection near communities.

CCUS

Vision for net zero: where does the lever fit in a 2050 net zero world?

CCUS is used where process emissions are unavoidable or where retrofits beat alternatives on cost and timing. It provides a pathway to replace unabated stack emissions in cement, lime, ammonia, methanol, refining, waste-to-energy, and some steel routes; to clean up natural-gas processing and other high-purity streams; and to deliver verified removals when paired with durable geologic storage (bioenergy with carbon capture and storage (BECCS), and direct air capture with carbon storage (DACCS). Utilization pathways such as e-fuels and chemicals can be valuable where they demonstrably displace fossil feedstocks, but they recycle CO_2 rather than remove it; only permanent storage or mineralization counts as a removal. Sustainability involves high capture rates, rigorous MRV, leakage and methane-slip control upstream, safe CO_2 transport and storage with long-term liability management, and strong community safeguards.

From now through the late 2020s, the most bankable tons should be emphasized by capturing CO_2 from high-purity sources (ammonia and hydrogen reformers, ethanol fermentation, natural-gas processing), pairing projects with brownfield storage that leverages characterized depleted fields and existing wells where integrity allows; in parallel, first-of-a-kind DAC and BECCS should move from pilot to early commercial, alongside standardization of compression, dehydration, and CO_2 specs for pipeline and shipping, implementation of continuous monitoring, and structuring of storage-as-a-service/offtake contracts. In the 2030s, CCUS should scale into hub-and-spoke systems, including open-access pipelines and ship hubs linking multiple emitters to shared onshore and offshore storage, with co-located capture at cement, lime, chemicals, and waste-to-energy facilities; applying power-sector capture selectively where reliability needs or local constraints limit faster alternatives. By the 2040s, CCUS covers residual, hard-to-abate process and upstream emissions under mature MRV and transfer-of-liability frameworks at site closure, providing durable abatement to heavy industry.

Energy players may develop transport-and-storage networks (saline formations, depleted reservoirs), structure capacity payments and take-or-pay storage agreements, apply capture to gas processing and selected peaking/CHP units only where justified, and integrate methane control across supply. Chemicals producers should retrofit ammonia, methanol, and hydrogen units with capture, co-locate electrolysis where economical, route biogenic or DAC CO_2 to e-fuel synthesis with book-and-claim transparency, and contract for stored tons when removals are required. Buildings and industry should prioritize process electrification first, then apply capture to residual high-temperature and calcination steps, and then aggregate volumes into regional hubs to lower unit costs and secure multi-year storage capacity. Aviation stakeholders can de-risk power-to-liquids by signing e-kerosene offtakes tied to DAC/biogenic CO_2 and additional renewable power, while avoiding “double counting” of recycled fossil CO_2 as removals. Financial services should standardize removal purchase agreements and storage capacity contracts, provide long-tenor project finance for transportation and storage systems, underwrite permanence and performance risk (well integrity, reversal insurance), and back contracts-for-difference or price floors that close the cost gap to captured and stored tons. Policy engagement across these sectors should support clear carbon-accounting rules (storage vs. utilization), robust permitting and monitoring standards for pipelines and wells, timely access to pore space and liability frameworks, product-carbon standards that reward captured cement/chemicals, and market designs that recognize verified removals.

Who to partner with?

- Providers include Mitsubishi Heavy, Aker Carbon Capture, and Climeworks

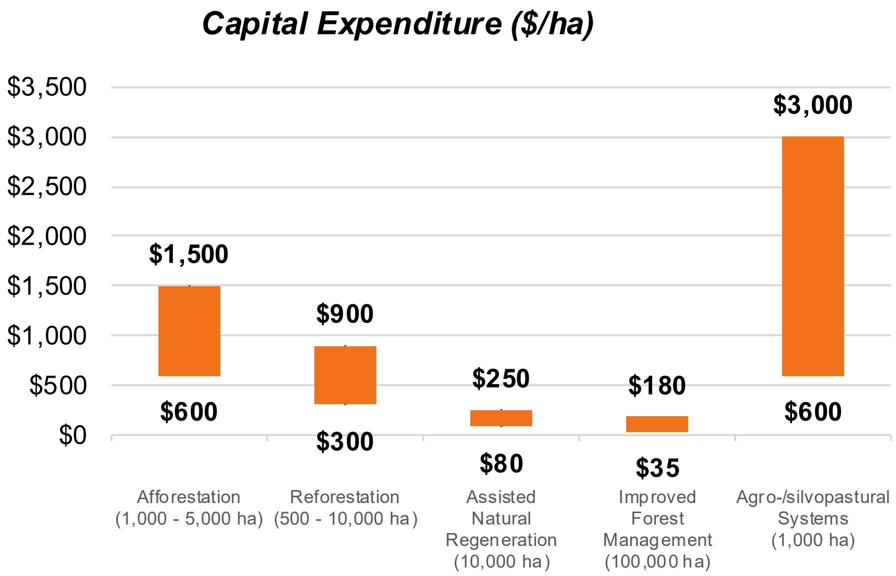
Where to find more information?

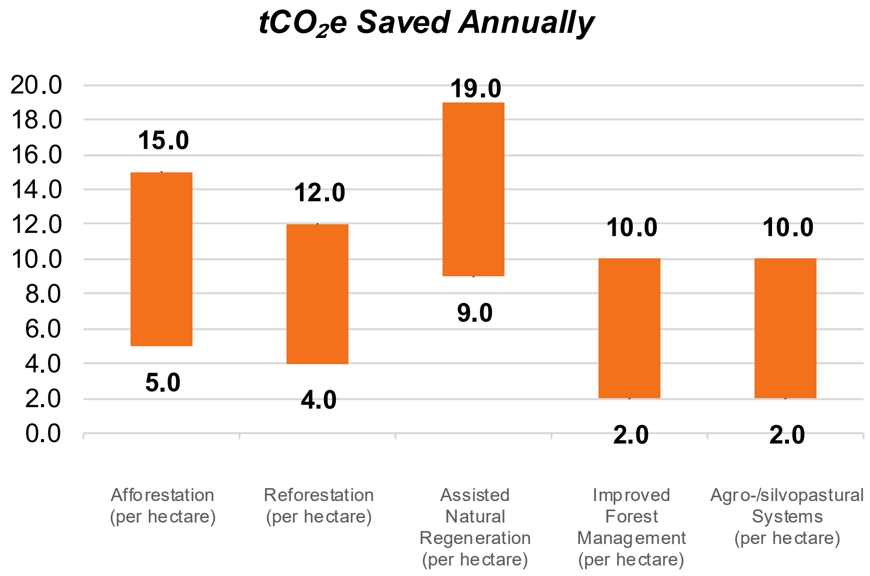
- IEA
- U.S. Department of Energy

FLAG and Water

Afforestation, Reforestation, and Restoration

Includes ammonia, methanol, olefins, aromatics, and plastics





Lever Details

Industry:

- Food and Beverage
- Mining and Extractives
- Energy
- Apparel and Textiles
- Consumer Goods
- Financial Services

Cost Assumptions and Details

- **The price of land for forestry projects** is a major determinant of the cost. In the case that the land may be repurposed for high-value agriculture, industrial, or commercial use, **the purchase price from existing landowners** will be significant.
- The **density and survival rate of seedlings** affects cost and effectiveness of solutions. The local context is crucial; **certain ecosystems may take more easily to anthropogenic interventions** than others, particularly in the case of prior degradation.
- The **labor cost of managing and maintaining forests** can be significant. In some cases, this work can be automated, which may allow for solutions to be scaled over large areas. However, manual evaluation and care is often crucial, and the availability of qualified and willing labor may be restricted.
- The **complexity of projects and implemented systems**, and the human and engineering interventions required, drive differences in costs across project types.

Afforestation, Reforestation, and Restoration

External Factors, Dependencies, and Systemic Change Opportunities

- **Forests absorb about 12 Gt of CO_2 a year,** although this is tempered by about 3-4 Gt CO_2e of annual emissions from deforestation. This translates into a positive sink, but the potential benefits may be even greater as deforestation is mitigated and even reversed. Climate change can slow or change the ability of trees to absorb CO_2, due to higher temperatures and changes to precipitation patterns.
- Corporate and state-backed **tree-restoration commitments now surpass 350 Mha**, but only a third have committed finance or is under implementation. **Developing cohesive strategies** between the public, private, and non-profit sectors to emphasize forestry strategies grounded in local contexts, including as potential adaptation solutions, is crucial in expanding forests as a carbon sink.
- Studies have shown that the **potential application for affordable solutions, under US$20/t of sequestered carbon, is significantly larger than previously assumed,** and assisted natural regeneration has become popular in emerging markets for its low upfront cost. Higher up the cost scale, bespoke silvo-pasture projects have taken hold where high-value fruit trees and other cash crops can offset investments.
- **Sovereign "forest bonds,"** blended-finance vehicles such as the LEAF Coalition, and jurisdictional REDD+ nesting rules that let small projects plug into larger baselines have expanded financing options.

Key Impacts Outward on Nature and People

Upstream
Risks related to **land disputes**. Risks of **seedling supply chain disruption** or dependencies. Risk of **fertilizer runoff** from commercial plantations.

Operations
Risks related to **biodiversity trade-offs of monoculture, wildfire and ecosystem disruption**, and shifting dynamics if local timber demand shifts to neighboring forests.

Downstream
Permanence risk (drought, pests). Risks related to **community, farmland, and industrial displacement**, with potential economic impacts to local communities.

Afforestation, Reforestation, and Restoration

Vision for net zero: where does the lever fit in a 2050 net zero world?

Afforestation, reforestation, and restoration (ARR) is used where durable, nature-based carbon removals and ecosystem services are useful, delivering co-benefits related to natural restoration. ARR replaces degraded, eroded, or deforested land with recovering native ecosystems or well-designed working landscapes (e.g., agroforestry), delivering long-lived carbon storage, water regulation, soil stabilization, and biodiversity gains. Applications include natural regeneration, assisted regeneration, mixed-species plantings, riparian and mangrove restoration, and enrichment planting in degraded forests. High integrity rests on "right tree, right place, right community": additionality and strong baselines; indigenous and local land rights and FPIC (Free, Prior, and Informed Consent); locally adapted species and genetic diversity; leakage control within the broader landscape; transparent MRV; and explicit plans for permanence (fire, pests, drought)

Through the late 2020s, ARR should prioritize restoration of degraded lands and natural regeneration where it outperforms planting; backstopped by nurseries, seed banks, and community stewardship; and fuse plot-based inventories with remote sensing, light detection and ranging (LiDAR), and conservative buffer accounting to manage permanence risk while enforcing additionality, leakage safeguards, and land-tenure/FPIC protections. Through the 2030s, it should consolidate into jurisdictional and watershed-scale programs that mosaic protection, restoration, and sustainable production; integrating agroforestry in supply sheds to displace deforestation pressure; embed climate-resilient species mixes, drought- and fire-aware silviculture, and prescribed-burn or fuel-management plans, and standardize monitoring and crediting so verified removals can support national inventories and high-integrity market claims without double counting. By the 2040s, ARR should maintain stable, verified carbon stocks under insured permanence and adaptive management, including long-term stewardship funds, catastrophe and parametric coverage, and dynamic baselines, so ARR delivers durable climate benefit alongside nature and community outcomes.

The food and beverage sector can finance farmer-led agroforestry and riparian buffers in sourcing landscapes, link payments to verifiable carbon and yield co-benefits, and use restoration programs to de-risk Regulation on Deforestation-free Products (EUDR)-style deforestation compliance. Miners should embed restoration in mine plans, consideringprogressive rehabilitation, native species, and tailings revegetation, and endow long-term stewardship funds with measurable biodiversity and carbon outcomes. Energy actors can restore rights-of-way and watersheds that protect hydro, thermal, and grid assets, and invest in jurisdictional ARR to neutralize hard-to-abate residuals with high-integrity removals. Consumer goods firms should back landscape programs where fiber, pulp, or agricultural inputs are sourced, commit to deforestation-free procurement, and design take-back loops that keep recovered fiber/wood at high value while financing ARR to repair historic sourcing impacts. The financial services industry can scale performance-based vehicles, includinglandscape funds, sustainability-linked loans, and removal purchase agreements that pay on verified, durable tons of removal and abatement, while underwriting permanence with reversal buffers and parametric fire/drought insurance; diligence should align with Integrity Council for the Voluntary Carbon Market (ICVCM)/ Voluntary Carbon Markets Integrity Initiative (VCMI)-quality criteria and robust social safeguards.

Who to partner with?

- Potential partners include Conservation International, Rainforest Alliance, and Terraformation

Where to find more information?

- IPCC
- LEAF Coalition
- Trillion Trees Project
- World Resources Institute
- Food and Agriculture Organization

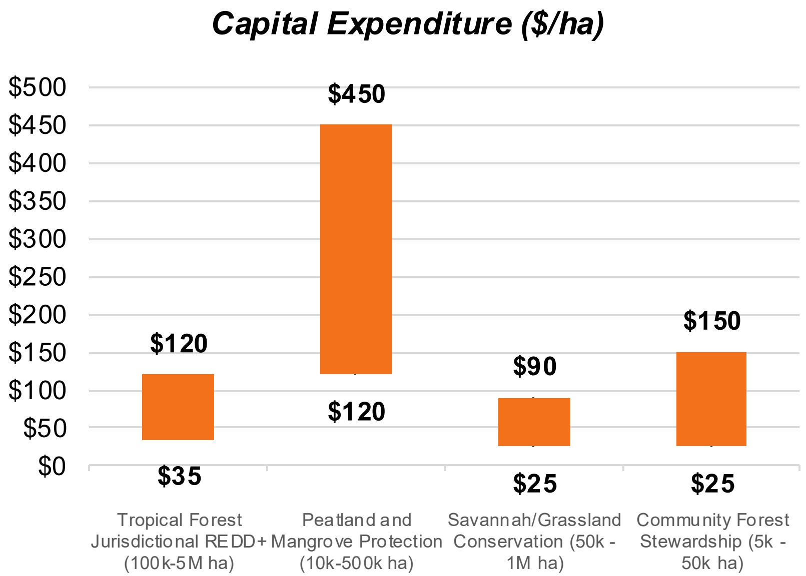
Ecosystem Protection and Conservation

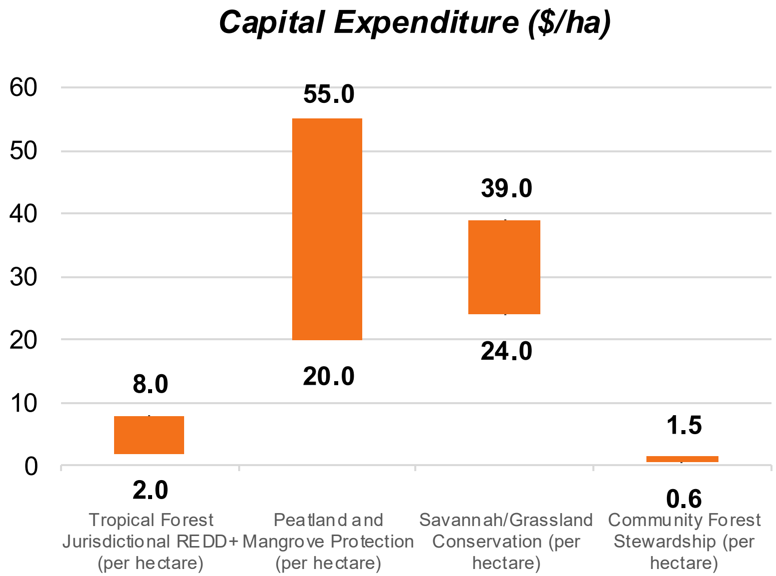
Includes the protection and conservation of ecosystems

Lever Details

Industry:

- Mining and Extractives
- Energy
- Food and Beverage
- Apparel and Textiles
- Consumer Goods
- Shipping and Logistics
- Financial Services





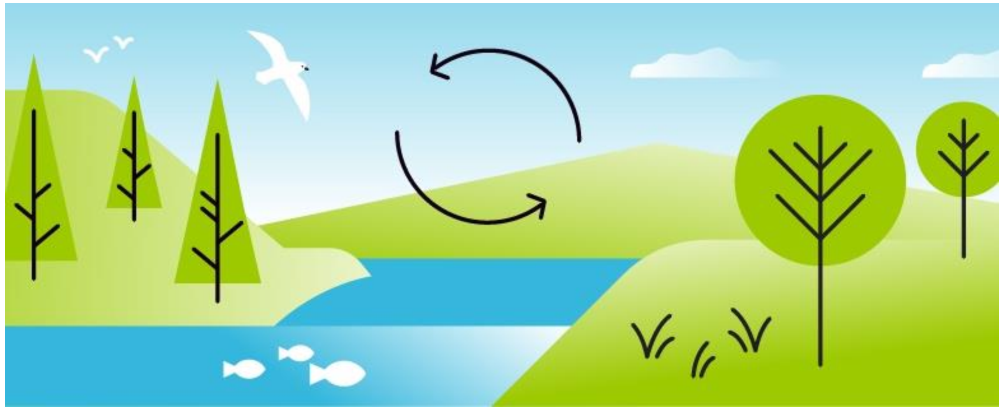
Cost Assumptions and Details

- The cost of conservation is largely through the **opportunity cost of not developing the land** for industrial, commercial, or agricultural uses. Financing mechanisms may be deployed wherein **global actors pay for conservation** to offset this opportunity cost, particularly **in developing countries or those with unique biomes.**
- The **baseline and forward deforestation or destruction rate affects** the efficiency of investments in conservation.
- Added costs include **labor and monitoring**, including satellite and local sensor technologies.
- Other costs could include **community engagement and involvement expenditures**, particularly if conservation is combined with other programs to deliver investment to rural or indigenous populations.

Ecosystem Protection and Conservation

External Factors, Dependencies, and Systemic Change Opportunities

- Roughly **15 percent of net emissions come from deforestation, fires, and agricultural clearing.** As the effects of climate change intensify, fires are expected to become more common, and without due management may both emit considerable emissions and destroy natural habitats. Even as deforestation slowed fires led to record tropical primary forest loss in 2024.
- The **new Brazilian government has strengthened protections in the Amazon**, slowing the rate of logging and agricultural encroachment. However, to achieve net growth would require financing and economic incentives and programs, alongside strong enforcement, which successfully dissuade both large and small economic actors from further degradation.
- Scale further depends on **improved attribution accuracy and trust in measuring the net benefit and absorption of GHGs** to projects and their archetypes
- The **LEAF Coalition** has successfully **executed carbon credits of ~ 0.9Gt CO_2 at floor prices of US$10-15/t**. The state of Para in Brazil, for example, raised US$180m in September 2024 to hire patrols, manage fires, and invest in local livelihoods.
- The **EU's Deforestation-Free Products Regulation (EUDR) will begin enforcement in December 2025**, pushing importers of key ingredients to invest in traceability. China protects a significant amount of the country's land from conversion, with the central government enforcing policy at the local level through satellite monitoring.



Key Impacts Outward on Nature and People

Upstream
Risks related to **land disputes;** correct identification of land-use change and **development of equitable legislature.**

Operations
Risks related to **worker safety, administrative corruption and bribery, and added wildfire risk** from increased tree cover.

Downstream
Risks of **economic displacement or lower prosperity to local populations**. Risks related to the **legitimacy and certification of credits** on carbon and related markets.

Ecosystem Protection and Conservation

Vision for net zero: where does the lever fit in a 2050 net zero world?

Ecosystem protection and conservation prevents conversion and degradation and provides climate and resilience gains. Protecting intact forests, peatlands, savannas, mangroves, seagrasses, and coral and river systems avoids immediate, often irreversible emissions, preserves biodiversity and genetic resources, stabilizes soils and watersheds, and buffers communities and infrastructure from heat, flood, and storm risk. Applications include expanding and effectively managing protected areas and Other Effective area-based Conservation Measures (OECMs), securing Indigenous and community tenure with free, prior, and informed consent, enforcing zero-conversion and zero-degradation in high-carbon and high-biodiversity areas, and creating ecological corridors that maintain connectivity under climate change. Credibility rests on strong baselines and leakage accounting, transparent geospatial MRV, durable governance and financing for stewardship, and alignment with nationally determined contributions (NDCs) and biodiversity strategies.

Through the late 2020s, efforts should halt conversion on priority fronts while recognizing Indigenous and community tenure, enforcing moratoriums in critical habitats (intact forests, peatlands, mangroves), mandating concession- and farm-level traceability for high-risk commodities, and deploying real-time satellite alerts linked to rapid-response enforcement and community co-management; bridge finance should back local guardianship and prosecution capacity. Through the 2030s, initiatives should scale into jurisdictional and basin compacts that layer strict protection with Indigenous-led stewardship, sustainable-use production zones, and nature-based coastal buffers; agricultural policy should shift toward yield gains on existing lands and rehabilitation of degraded areas, while finance blends public budgets, conservation trust funds, debt-for-nature or tax incentives, results-based payments, and only high-integrity avoided-conversion credits with conservative buffers, long-term management plans, and clear benefit-sharing. By the 2040s, countries should manage an ecologically connected network covering ~30 percent or more of land and sea with verified management effectiveness; climate-smart corridors should preserve refuge and hydrological regulation, protection should be embedded in adaptation and disaster-risk strategies, and transparent MRV should evidence durable avoided emissions alongside biodiversity and community outcomes.

Mining firms should make ”no-go” commitments in critical habitats and stringent application of the mitigation hierarchy with biodiversity. Food and Beverage companies should meet and exceed deforestation- and conversion-free sourcing with farm-level traceability, jurisdictional procurement from regions with verified low deforestation, and long-term contracts that reward producers for conserving high-carbon and high-biodiversity areas; apparel and textiles firms should extend the same logic to forest-derived fibers and grazing, enforcing pulp and leather no-conversion standards and fiber traceability. Consumer goods retailers and brands should hard-wire zero-conversion into supplier scorecards, finance community guardianship and restoration around key supply sheds, and shift packaging toward certified, low-impact fiber with end-of-life recovery that reduces pressure on natural forests. Financial services should price conversion risk, adopt exclusion lists for high-risk frontiers, require geospatial due diligence and grievance redress, and scale conservation finance via sustainability-linked loans and bonds, debt-for-nature swaps, jurisdictional REDD+ and blue-carbon transactions under high-integrity standards, with parametric insurance for fire, drought, and cyclone risk. Policy engagement across all sectors should support Indigenous land tenure, durable funding for protected-area agencies, interoperable traceability and customs enforcement, and recognition of high-integrity avoided-emissions credits in compliance.

Who to partner with?

- Potential partners include Emergent, CTrees, and Green Climate Fund

Where to find more information?

- IPCC
- LEAF Coalition
- ICVCM Core Principles
- GCF
- UN FAO

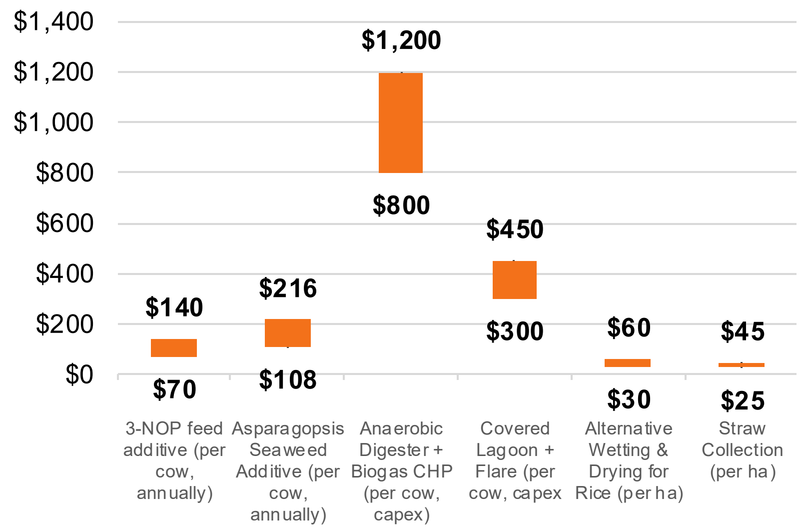
Agricultural Methane Solutions

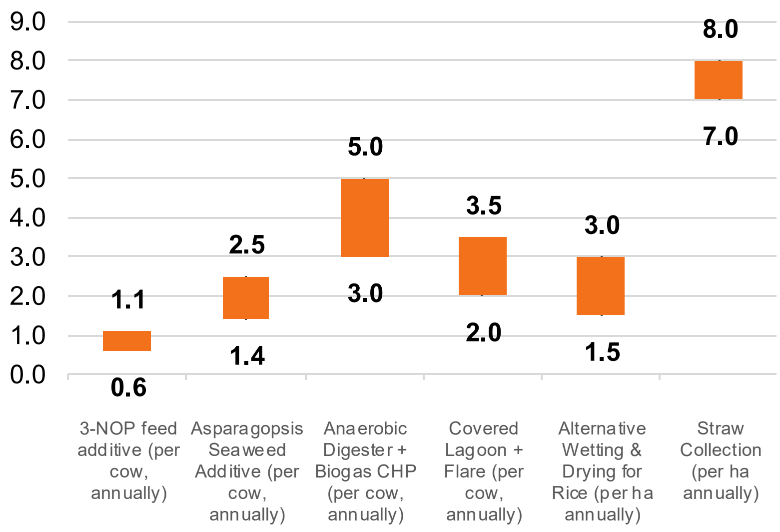
Includes alternative feed, feed additive, waste treatment, anaerobic digestion, and straw burning

Lever Details

Industry:

- Food and Beverage
- Consumer Goods
- Chemicals
- Energy
- Financial Services





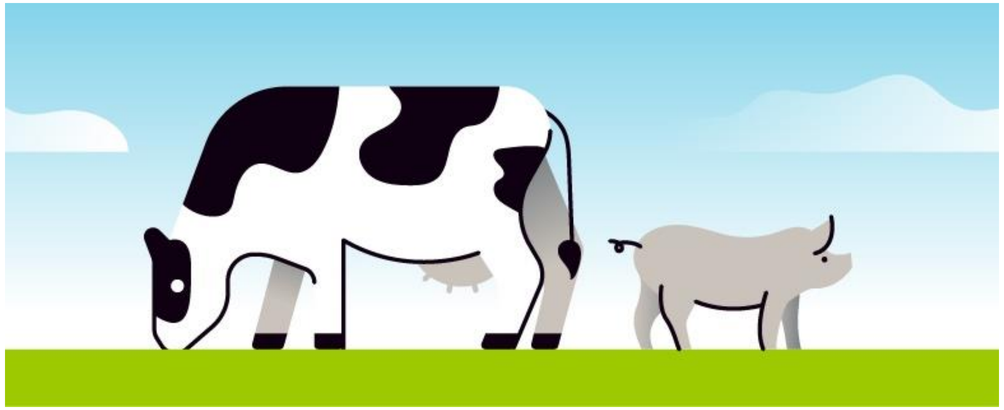
Cost Assumptions and Details

- Costs for **alternative feeds and feed additive** (3-NOP feed, seaweed additive, etc.) depend on the **underlying specifics of their respective supply chains.**
- Livestock emissions have **a significantly greater intensity in poorer nations**; while the cost difference between high and low-quality feed may appear intrinsic, systematic improvements such as **breeding more productive animals, improved pasture management, and managed slaughter and breeding cycles** can provide greater long-term financial stability and reward to small-hold farmers in developing nations.
- **Offtake contracts** for biogas help offset the installment costs. Covered lagoons avoid the complexity and added cost of developing energy production systems but then forfeit their accompanying revenues.
- **Agricultural subsidies**, whether supporting low-carbon or legacy solutions, have a large role in switching and expenditure decisions.

Agricultural Methane Solutions

External Factors, Dependencies, and Systemic Change Opportunities

- **Agriculture emits 145 Mt CH_4 (4 Gt CO_2e)** a year. **70 percent of this is from enteric fermentation** (digestive processes), 10 percent from manure, 9 percent from rice paddies, and 4 percent from residue burning. An important dynamic to monitor is the **higher emissions intensity of cattle in the developing world**. Significant progress can be made by **incorporating practices common in the developed world elsewhere.**
- **Bovaer, a commercial methane inhibitor**, is authorized for use across major markets, but penetration is still limited.
- **Digesters** which convert manure to biogas have received the most investment for their **ability to supply clean natural gas**. However, these **digesters are expensive** and make sense at larger farms. Developing solutions for developing countries requires alternative approaches, such as **solid-liquid separation and storage.**
- **Low-methane rice**, bred specifically to avoid the specific methane emissions produced during rice cultivation, is finding steady traction. The Vietnamese government maintains a low-emission rice program, with the intension of scaling it across the country. Uptake relies on financing or subsidies which can offset the increased labor cost to farmers.
- **Agriculture has received a small portion of financing activated under the Global Methane Pledge**, and most agriculture remains outside of organized methane reduction policy or strategies. Dedicated coordination to increase the scope of existing solutions is critical in decarbonizing the sector.



Key Impacts Outward on Nature and People

Upstream
Risks related to **seaweed farming displacing marine habitat. Worker and chemical risks** related to **the production for additives and alternative feeds.**

Operations
Air and odor impacts from digesters, taste changes due to alternative feed, ammonia leakages from lagoons, water-table depletion from alternative rice drying.

Downstream
Risks of leakages from biogas pipelines, economic damages to smaller farmers due to **higher costs of alternative feed.**

Agricultural Methane Solutions

Vision for net zero: where does the lever fit in a 2050 net zero world?

Agricultural methane solutions replace uncontrolled methane from enteric fermentation, manure management, and rice cultivation with targeted interventions: feed additives and precision nutrition that suppress methanogenesis; improved genetics, animal health, and pasture quality that lift productivity per unit of protein; covered lagoons, solids separation, and anaerobic digestion that capture biogas for heat, power, or biomethane; and paddy practices such as alternate wetting and drying, direct-seeding, and residue management that cut CH_4 formation. Sustainability includes animal welfare and farmer economics; airtight MRV that quantifies intensity per kg of milk/meat/rice and detects leaks; and co-impact control (ammonia/odor, water use in rice, nutrient management of digestate, and safe deployment of feed additives).

Through the late 2020s, deployment should emphasize covered lagoons and digesters at high-emitting dairies and feedlots, alternative wetting and drying (AWD) in rice landscapes (with direct-seeded rice where agronomy and water control allow), silage quality and herd-management upgrades, manure solids separation, and early commercial roll-out of proven feed additives in housed systems, paired with tight leak detection and reparid (LDAR) and methane-slip controls at upgraders, engines, and flares, plus digestate acidification, covered storage, and rapid soil incorporation to curb ammonia and secondary N_2O. In the 2030s, supply chains should scale via cooperative aggregation and shared services: multi-site co-digestion of manure, food waste, and crop residues; biomethane grid injection where practical (or high-utilization CHP where interconnection lags); agronomic return of stabilized digestate with ammonia controls, under digital MRV that blends on-farm sensors, satellite data, and milk/meat/rice intensity metering. Contracts, agronomy, and logistics should be integrated so cooperatives, mills, and processors manage methane as a portfolio, expanding large-scale rice water management, deploying next-gen additives and vaccines as they mature, improving forage systems, and maintaining tight LDAR across biogas assets. By the 2040s, the sector should supply predictable, lower-intensity commodities to global markets, with durable, verified reductions supported by standardized MRV, nutrient recycling, and prudent biomethane use.

Food and beverage companies can sign multi-year offtakes for low-methane commodities with emissions intensity standards, co-finance on-farm digesters and AWD via advance purchase agreements and build aggregation for biomethane to decarbonize plants and fleets. Consumer goods retailers and brands can create private-label standards and premiums for methane-reduced dairy and proteins, cut food loss (which drives upstream methane), and fund farmer services for feed, veterinary care, and water management. Chemicals firms can scale feed additives (e.g., methanogenesis inhibitors, lipids, tannins), silage inoculants, and paddy biostimulants; supply gas-clean-up media and membranes for renewable natural gas (RNG); and develop enteric vaccines with robust safety and efficacy data. Energy providers can interconnect RNG to pipelines, build farm and mill microgrids using biogas, structure take-or-pay offtakes, and offer tariffs that reward flexible generation; where geology allows, they can pair large digesters with CO_2 handling from upgrading. Financial Services can stand up blended-finance vehicles and pay-for-performance facilities tied to verified CH_4-intensity reductions; offer performance insurance for digesters and additive programs; securitize long-dated supply contracts; and standardize crediting under high-integrity methodologies to avoid double counting. Cross-cutting policy engagement should back methane-specific incentives and standards (e.g., AWD programs, manure management credits, high-integrity RNG), on-farm interconnection and intertie upgrades, food-loss reduction policies, and rigorous MRV and labeling.

Who to partner with?

- Potential partners include DSM-Firmenich, CH4 Global, and BrightMark

Where to find more information?

- UN FAO
- IRRI AWD Implementation Guide
- Global Methane Hub
- California Digester Program
- Biogas in Denmark

Regenerative Farming and Nitrogen Management

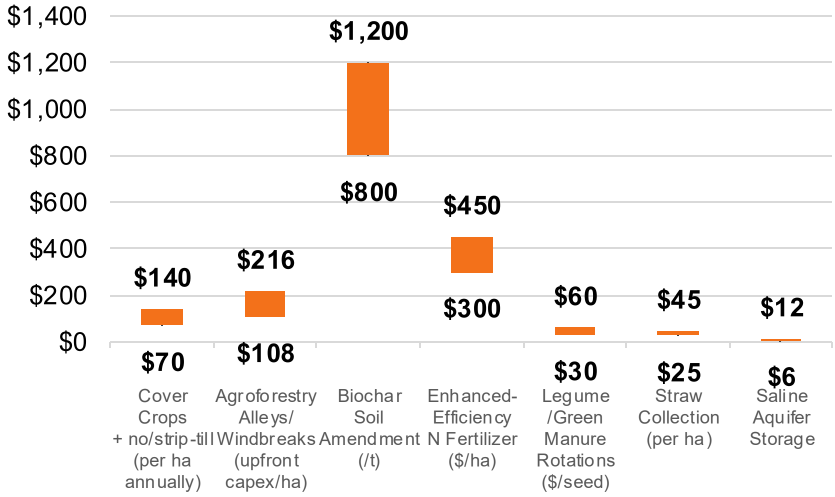
Includes cover crops, soil regeneration, agroforestry, and nitrogen management

Lever Details

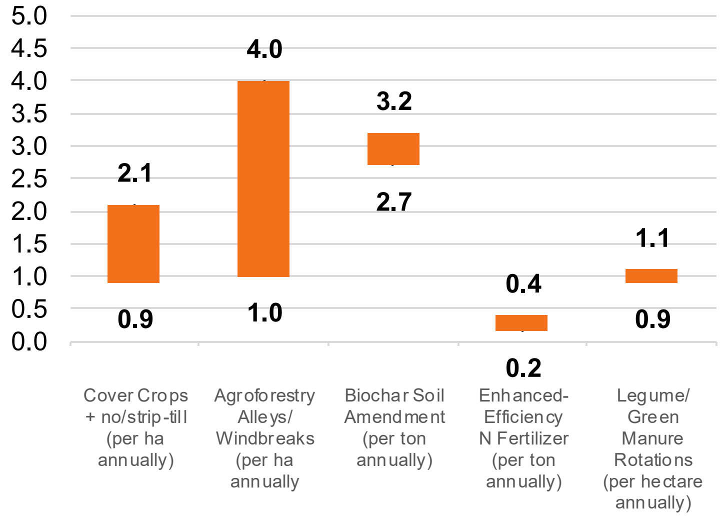
Industry:

- Food and Beverage
- Chemicals
- Consumer Goods
- Apparel and Textiles
- Energy
- Financial Services

Capital Expenditure ($/ha)



tCO_2e Saved Annually



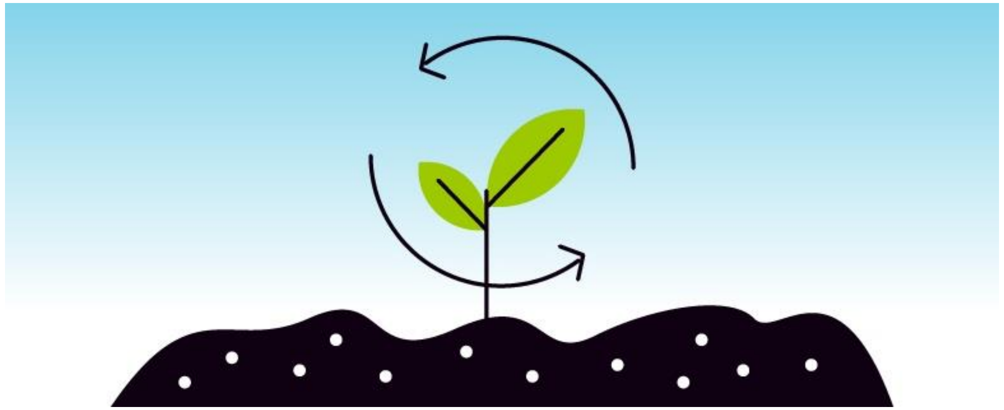
Cost Assumptions and Details

- **Seed mixes, the resources needed** to make them grow, and their **commercial potential** vary the prices of cover crops. **Opportunity costs** may be considered by the **commercial benefits** posed by **alternative uses of the land.**
- Biochar price varies **by feedstock prices** and the **cost of pyrolysis.**
- Nitrogen-based fertilizers **vary** in price **in response to global nitrogen prices.**
- The **price of labor** and **monitoring equipment** varies, with certain initiatives not economic due to high embedded costs.
- The **premium** of nitrification-inhibitors is **expected to fall alongside the build-out of bulk production**.

Regenerative Farming and Nitrogen Management

External Factors, Dependencies, and Systemic Change Opportunities

- **Regenerative farming and nitrogen management** has emerged as a proven lever to both **restore carbon capture** within the soil and **cut nitrogen emissions.**
- The scope of **SOC (soil-organic carbon)** projects has steadily grown, with studies indicating a **potential benefit of 0.8-1.4 Gt annually by 2050** if they scale. Fertilizers have centered around the **"4R" approach to nutrient stewardship: right source, rate, time, and place.**
- Innovative solutions are **accelerating but still patchy. Roughly 15 percent of global cropland is under some form of conservation tillage and 7 percent uses full cover-crop rotations;** uptake is **fastest in the U.S. Corn Belt, France and parts of Brazil,** helped by **carbon-credit prices** that now clear at **US$20–35/t.**
- Only **3–4% of nitrogen applied worldwide** is currently **stabilized with inhibitors or smart-release coatings**, largely because **price spreads remain unattractive** where fertilizer subsidies persist.
- The **EU's Soil Monitoring Law** will make **SOC reporting mandatory by 2028**, and the **U.S. Inflation Reduction Act allocates US$19 billion to climate-smart-ag payments** that reward **lower N_2O intensity and higher SOC bases.**



Key Impacts Outward on Nature and People

Upstream
Seed multiplication may replace diverse rotations; **biochar feedstock** could drive **land-use change if sourced unsustainably.**

Operations
Risks of **improper implementation, management, and monitoring**, leading to unintended and uncontrolled outcomes. **Poorly planned no-till can raise** herbicide load. **Biochar dust is a worker hazard.**

Downstream
Permanence of SOC is reversible under drought or tillage reversion, and **nitrification inhibitors may elevate ammonia volatilization** if mis-timed. Risk of economic harm to farmers.

Regenerative Farming and Nitrogen Management

Vision for net zero: where does the lever fit in a 2050 net zero world?

Regenerative farming and nitrogen management replace conventional, loss-prone fertilizer use and carbon-depleting practices with diversified rotations, cover crops, reduced tillage, residue retention, agroforestry where appropriate, and “4R” nutrient stewardship (right source, rate, time, place). Applications span row and specialty crops as well as cotton and pasture systems that supply food, feed, and fiber; they cut nitrous oxide from soils, reduce ammonia losses and nitrate leaching, and rebuild soil organic matter that buffers drought and flood. Sustainability includes agronomy that raises nutrient-use efficiency, on enhanced-efficiency and lower-emission fertilizers (including urease/nitrification inhibitors and, over time, green-ammonia–based products), and on high-integrity MRV.

Through the end of the decade, deployment should emphasize cover crops on suitable acreage; reduced/strip tillage and controlled traffic; split nitrogen and variable-rate dosing guided by soil testing, optical sensors, and weather-informed models; adoption of nitrification and urease inhibitors where responsive; and targeted edge-of-field practices (buffers, wetlands, denitrifying bioreactors). Where manure or digestate is used, stabilization (e.g., acidification) and injection or rapid incorporation should minimize volatilization, runoff, and secondary N_2O. In the 2030s, efforts should scale through landscape- and supply-shed programs that pair agronomy with procurement and finance: growers adopt diversified rotations and agroforestry where viable; fertilizer producers decarbonize ammonia and nitric acid and expand enhanced-efficiency products; and cooperatives, mills, and processors synchronize water and nitrogen management (including drainage-water and irrigation scheduling) with pay-for-performance contracts and interoperable data to lock in commodity-level intensity gains. By the 2040s, regenerative farming and nitrogen management should deliver predictable, lower-intensity grain, oilseed, cotton, and feed with resilient yields, closed nutrient loops (manure, digestate, crop residues, and recovered nutrients such as struvite), and verified reductions in N_2O and nitrate loss through standardized MRV.

Food and beverage companies can shift from practice lists to outcomes by contracting for low-carbon, water-secure commodities with guaranteed agronomy services, floor-price protection, and data-sharing that ties payments to verified nitrogen-intensity and soil-carbon metrics; mills and processors should co-invest in grain segregation and storage to monetize premiums. Chemicals producers should scale green-ammonia–based fertilizers as grids clean, expand enhanced-efficiency products and biologicals with transparent performance data, and offer “fertilizer-as-a-service” bundles that include variable-rate prescriptions and telemetry. Consumer goods brands should fund supplier transition plans and traceability so regenerative claims on food and personal-care ingredients survive audit, while Apparel and Textiles buyers support regenerative cotton through multi-year offtakes, ginner/spinner traceability, and payments for verified nitrogen- and water-outcomes at farm level. Energy providers should supply firmed renewable power and water-smart electrification for pumping and drying, anchor green-ammonia hubs near demand, and integrate farm biogas where available, aligning tariffs with flexible load from irrigation and cold-chain assets. Financial services should deploy blended facilities and sustainability-linked loans tied to N_2O-intensity and soil-health KPIs, stand up pay-for-performance vehicles that purchase verified abatement in the supply shed without double counting, and offer weather and performance insurance that protects growers during transition years.

Who to partner with?

- Potential partners include Pivot Bio, Indigo Ag, and Yara

Where to find more information?

- One Earth
- WRI
- Nitrogen Management During Decarbonization
- IPCC
- The Nature Conservancy

04
References

Sources: Electricity and Energy

Bioenergy:

1. IEA
2. World Bioenergy Association
3. IEA
4. IEA
5. IPCC
6. Project Drawdown
7. US Department of Energy

Energy and Electricity Storage:

1. IEA
2. Project Drawdown
3. IEA
4. US Department of Energy
5. Solar Thermal World
6. NREL
7. Batteries: From China's 13th to 14th Five-Year Plan

Geothermal:

1. NREL
2. IEA
3. Wall Street Journal
4. NREL
5. Project Drawdown
6. US Department of Energy
7. Enhanced Geothermal Systems for Clean Firm Energy Generation, Nature

Low Emission Hydrogen:

1. Agora Energiewende
2. Hydrogen Insight
3. IEA
4. EU Rules for Renewable Hydrogen
5. IRENA
6. IRENA
7. IEA
8. SBI Capital Markets
9. European Hydrogen Observatory
10. On the Cost Competitiveness of Green and Blue Hydrogen
11. NREL Hydrogen
12. Hydrogen Council
13. China Hydrogen Alliance
14. Hydrogen Financing for Development

Grid Technologies and Modernization:

1. IEA
2. IEA
3. ENTSO-e TYNDP
4. US Department of Energy Grid Deployment Office
5. IEA
6. CIGRE
7. Federal Energy Regulatory Commission
8. US Department of Energy Grid Modernization Initiative
9. EU Ten-Year Network Development Plan

Hydropower:

1. IRENA
2. IEA
3. Life cycle and economic assessment of tidal energy farms in early design phases: Application to a second-generation tidal device
4. Catapult
5. Marine Energy Council
6. Ocean Energy Europe
7. NREL

Nuclear:

1. World Nuclear Association
2. IEA
3. IEA
4. OECD
5. Nuclear Energy Agency
6. US Department of Energy
7. World Nuclear Association
8. International Atomic Energy Agency
9. China Atomic Energy Authority

Wind:

1. NREL
2. IEA
3. NREL
4. Electricity Generation Costs – Gov.UK
5. Global Wind Energy Council
6. EU Status Report
7. Department of Energy
8. Evolution of floating offshore wind platforms: A review of at-sea devices

Solar:

1. NREL
2. Levelized Cost of Electricity – Renewable Energy
3. PV Magazine
4. IEA
5. Assessing Floating PV Costs Across Europe
6. SEIA
7. IEA
8. Project Drawdown

Sources: Transport

Light-Duty and Micromobility:

1. IEA – Batteries
2. Electric Scooter Market Size
3. Bike Dekho
4. Marketwatch
5. IEA
6. BloombergNEF
7. UNEP
8. NREL

Maritime Decarbonization:

1. Sustainable Ships
2. Ammonia Energy
3. Lloyd List
4. Nordic Energy
5. European Union
6. CSL Ships
7. IEA
8. FuelEU Maritime
9. Poseidon Principles
10. Maersk Mc-Kinney Mooler Center for Zero Carbon Shipping

Aviation Decarbonization:

1. UK Government
2. Aviation for Aviators
3. Wall Street Journal
4. NASA
5. IEA
6. ReFuelEU Aviation
7. International Council on Clean Transportation
8. Airbus ZEROe
9. NASA Transformational Tools and Technologies

Freight Decarbonization:

1. PwC
2. Hydrogen.energy.gov
3. Siemens
4. Electrification Cost Challenge Report
5. Hydrogen Insights
6. IEA – Trucks and Buses
7. IEA - Rail
8. ICCT – Trucks
9. ICCT – Rail
10. Siemens eHighway White Paper

Public Transport:

1. GMI
2. Fuels UK
3. Texas A&M Transportation Institute
4. Electrification Cost Challenge Report
5. Future of Southeast Asia
6. International Association of Public Transport
7. World Resources Institute
8. International Transport Forum
9. Hitachi

Sources: Industry

Low Carbon Cement:

1. RMI
2. Waste Heat Recovery Power Plants in Cement Industry
3. Financial Times
4. CO Processing Unit for Oxy-Fuel Fired Rotary Cement Kilm
5. Leilac
6. Cemnet
7. GCCA (Global Cement and Concrete Association)
8. IEA Cement
9. Project Drawdown – Alternative Cement
10. First Movers Coalition

Low Carbon Steel:

1. Steel on the Net
2. HYBRIT
3. Global Iron and Steel Tracker
4. IEA Steel
5. IEEFA
6. Circular Economy Solutions for China's Steel Industry
7. Reuters

Low Carbon Aluminum:

1. Wood Mac
2. ELYSIS
3. ARENA
4. Lifecycle Emissions of Primary vs Secondary Aluminum
5. IEA
6. WEF
7. ARENA Hydrogen Calcination Project Brief

Chemicals:

1. Ammonia Energy
2. Energy Forum
3. Scaling Up Hydrogen: The Case for Low Carbon Methanol
4. BASF
5. Optimization of Electric Ethylene Production
6. CAPEX of Chemical Recycling
7. IEA
8. US Department of Energy
9. McKinsey – Decarbonizing the Chemical Industry
10. Decarbonizing the Chemical Industry
11. Pyrolysis and Beyond: Sustainable Valorization of Plastic Waste

CCUS:

1. Technoeconomic Analysis of Amine Based CO2 Capture Technology
2. Cleantechnica
3. The Cost of CO2 Transport and Storage in Global Integrated Assessment Modeling
4. CO2 Saline Storage Cost Model
5. IEA
6. US Department of Energy
7. McKinsey – Decarbonizing the Chemical Industry
8. Decarbonizing the Chemical Industry
9. Pyrolysis and Beyond: Sustainable Valorization of Plastic Waste

Sources: Buildings

Efficient Fixtures:

1. CLASP (Collaborative Labelling and Appliance Standards Program)
2. IEA Appliances and Equipment
3. IIF IIR
4. Analyzing interventions for energy-efficient appliances and heating & cooling systems adoption: An agent-based model
5. United for Efficiency
6. Super-Efficient Equipment and Appliance Deployment (SEAD) Initiative

Building Envelopes:

1. Renewable Energy Hub
2. Climate Sort
3. National Tax Reports
4. IEA
5. GRESB
6. EPA
7. Project Drawdown
8. Cool Roof Rating Council

Data Center Cooling:

1. Vertive
2. Ashrae
3. KPMG
4. IEA
5. Data Center Dynamics
6. Uptime Institute
7. EU Code of Conduct for Data Centers

Refrigerants:

1. AC Unit for Less
2. Residential Heat Pump and Air Conditioning Systems with Propane
3. Thermodynamic and economic analysis of a supermarket transcritical CO2 refrigeration system
4. Market Research Intellect
5. EU
6. IEA
7. Kigali Cooling Efficiency Programme
8. EU F-Gas Observatory & Regulation portal
9. Project Drawdown

Efficient Heating and Cooling:

1. IEA Heating
2. IEA Cooling
3. IEA Space Cooling
4. Financial Times
5. Checkatrade
6. Eco Experts
7. Department of Energy
8. European Environmental Agency

Sources: FLAG and Water

Afforestation, Reforestation, and Restoration:

1. Climate Adaptation Platform
2. Conservation.org
3. Trillion Trees Project
4. IPCC
5. OECD
6. One Earth
7. LEAF Coalition
8. Trillion Trees Project
9. World Resources Institute
10. Food and Agriculture Organization

Ecosystem Protection and Conservation:

1. Environmental Defense Fund
2. IPCC
3. LEAF Coalition
4. Operational Flexibility in Forest Fire Prevention and Suppression.
5. ICVCM Core Principles
6. VERRA
7. GCF
8. UN FAO

Agricultural Methane Solutions:

1. Effects of feeding 3-nitrooxypropanol for methane emissions reduction on income over feed costs in the United States
2. CH4 Global
3. Anaerobic-Digestion
4. Live Science
5. International Rice Research Institute
6. VERRA
7. UN FAO
8. IRRI AWD Implementation Guide
9. Global Methane Hub
10. California Digester Program
11. Biogas in Denmark

Regenerative Farming & Nitrogen Management:

1. IPCC
2. Project Drawdown
3. Project Drawdown
4. Purdue Agriculture
5. One Earth
6. WRI
7. Nitrogen Management During Decarbonization
8. IPCC
9. The Nature Conservancy

Thank You

BSR® is a sustainable business network that provides global insights, strategic advisory services, and collaborations to more than 300 member companies in Asia, Europe, and North America. BSR® helps its members to see a changing world more clearly, create long-term value, and scale impact.

www.bsr.org

Disclaimer

BSR publishes occasional papers as a contribution to the understanding of the role of business in society and the trends related to corporate social responsibility and responsible business practices. BSR maintains a policy of not acting as a representative of its membership, nor does it endorse specific policies or standards. The views expressed in this publication are those of its authors and do not reflect those of BSR members.

The conclusions presented in this document represent BSR's best professional judgment, based upon the information available and conditions existing as of the date reviewed or delivered. In performing its assignment, BSR relies upon publicly available information, information provided as approved within the scope of work, and information provided by third parties. Accordingly, the conclusions in this document are valid only to the extent that the information provided or available to BSR was accurate and complete, and the strength and accuracy of the conclusions may be impacted by facts, data, and context to which BSR was not privy. As such, the facts or conclusions referenced in this document should not be considered an audit, certification, or any form of qualification. This document does not constitute and cannot be relied upon as legal or investment advice of any sort and cannot be considered an exhaustive review of legal, investment, or regulatory compliance. BSR makes no representations or warranties, express or implied, about the business or its operations. BSR maintains a policy of not acting as a representative of its membership, nor does it endorse specific policies or standards. The views expressed in this document do not reflect those of BSR member companies.