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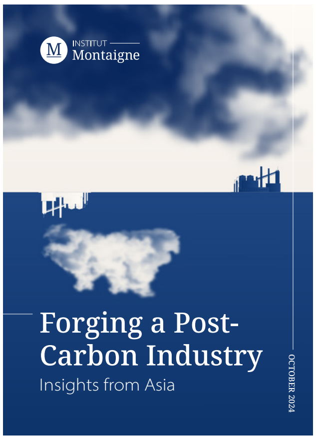
Forging a Post-Carbon Industry

Insights from Asia

Part 1

Shaping a Clean Industrial Strategy for Europe



Europe stands at a critical juncture as it strives to reconcile its ambitious decarbonization goals with the need to sustain and improve its competitiveness. The new European Commission aims to implement the Green Deal into a *Clean Industrial Deal*. In this quest, Europe faces significant challenges, including high energy costs, the need for new infrastructure to support its energy-intensive industries, the need for better support, and intensifying international competition from rivals employing different industrial policy tools to gain market share.

To succeed, Europe must decarbonize while maintaining competitiveness, preserving and transforming its strategic industrial base, and fostering the growth of green industrial jobs. The shift to a post-carbon industrial world will significantly affect the geographical distribution of industry throughout the world, including within the EU. **Some regions are better positioned than others to manufacture net-zero industrial goods**. To address these challenges, Europe must strengthen its industrial strategy—both internally and with trade partners (regional and global)—to enable industry to transition effectively and remain competitive in the green economy.

This report analyzes how several major industrial powers **– China, the European Union, South Korea, and Japan –** are managing the transition from carbon-intensive industries to carbon neutrality. Starting from a comparative analysis of the policy tools they each use in support of their green industries, the analysis examines the cases of four industrial sectors: steel, aluminum, cement, and chemicals. It underscores **the need for Europe to draw lessons from the industrial policies of China, Japan, and South Korea**. The comparative analysis provides valuable insights into how different regions are navigating the complex transition to a post-carbon industrial landscape and highlights the importance of Europe adopting cohesive, well-funded policies.

In contrast to China's directive-based approach and Japan's increasingly organized strategies, Europe faces significant challenges due to its fragmented governance and **lack of large-scale common financing**. The *Net-Zero Industry Act* (NZIA) and the Strategic Technologies for Europe Platform (STEP) represent progress toward addressing these issues, but **disparities among EU Member States remain a critical concern**. Despite its constitutional and political limitations, **Europe needs to devise a governance model for its industrial strategy** that can coordinate efforts and make clear, decisive choices.

The paper recommends a **comprehensive and coordinated "verticalization" of industrial policy in support of Europe's industrial decarbonization**. It advocates the **creation of a Clean Industrial Bond strategy, anticipating future carbon revenues of up to €100 billion per year** to invest in the clean transition of industries, supporting both supply and demand. Europe needs a **sector-focused approach** that **integrates financial support, innovation**, and **streamlined regulatory measures** to facilitate the deployment and scaling up of the clean technologies necessary for industries to decarbonize and remain competitive. Additionally, **Europe needs to address significant technological uncertainties in industry decarbonization**. This necessitates a **more technology-agnostic approach** that supports newcomers and enables a broad spectrum of innovative solutions. Finally, Europe will need to merge existing instruments and **create a transversal Clean Industrial Agency in charge of coordinating European industrial strategy under the Executive Vice-President for Industrial Strategy and the Executive Vice-President for Clean, Just, and Competitive Transition**.

Methodology

This report builds on research interviews and consultations with about 500 European, Japanese, South Korean, and Chinese policymakers and stakeholders held between June 2023 and July 2024. These semi-structured interviews were conducted to gather expert insights and firsthand perspectives relevant to the topics discussed. They were conducted online or during research trips in Europe, Japan, South Korea, and the UAE (COP28). This report also builds on a policy dialogue held in January 2024 with 40 policymakers and stakeholders from industrial sectors in Europe, Japan, and South Korea.

1 What is a "Clean" Industrial Policy?

Chapter 1 of this report provides a comparative analysis of the industrial policies adopted by Europe, China, Japan, and South Korea, highlighting the diverse strategies these regions are employing to decarbonize their industrial sectors. Although the issue is still emerging as a policy priority, each region's approach reflects its unique economic structure, energy resources, and political context, resulting in significant variations in how industrial decarbonization is pursued.

1.1. AN EMBRYONIC EUROPEAN CLEAN INDUSTRIAL POLICY

Europe's clean industrial policy seeks to align achieving decarbonization goals with maintaining industrial competitiveness. Global competition, particularly from the US and China, places immense pressure on Europe's industries, and the need to invest in green technologies against an uncertain technological background – in many cases, it is not possible to know in advance which technology will be suitable to decarbonize an industrial sector – creates the risk of European products potentially being left behind if the wrong choices are made.

At the same time, Europe's energy-intensive sectors require substantial investment due to aging infrastructure, and without affordable decarbonized energy, key industries may relocate to regions with greener, cheaper energy supplies. European industries currently face energy costs that are up to twice those of their counterparts in China or the US, with electricity prices ranging from €110 to €150 per MWh in Europe, compared to just €65–70 per MWh in the US and China. This disparity stems largely from Europe's limited access to domestic energy resources, particularly natural gas, and China's dominant position in renewable energy production.

The EU's fragmented decision-making process, characterized by insufficiently coordinated efforts among Member States, exacerbates the challenge. The *Net-Zero Industry Act* represents a step forward, as it directs greater state support toward strategic industries, but it is still at an early stage of development. Limited EU-wide funding constrains the scaling up of clean technologies beyond early-stage prototypes, creating a critical gap in financing. Moreover, Europe's current industrial strategy lacks the flexibility necessary to quickly adopt new technologies, leaving it lagging behind global competitors. Moving forward, Europe must strike a balance between innovation and protection to ensure that its industries do not fall victim to external pressures while fostering a robust environment for green industrial growth.

1.2. CHINA'S INDUSTRIAL POLICY AND DECARBONIZATION

On the one hand, China's clean industrial policy is driven by its massive industrial base, making it the world's largest net exporter of embodied carbon. On the other hand, the government's "dual carbon" goals, targeting a carbon peak by 2030 and carbon neutrality by 2060, reflect the critical role that China plays in global decarbonization efforts. However, the implementation of these goals is complex due to the country's decentralized governance structure. While the central government sets overarching objectives, the provincial and municipal governments are responsible for their execution, leading to disparities in ambition and effectiveness across regions. This creates a competitive economic landscape as local governments prioritize growth while navigating decarbonization policies.

Strategic planning plays a significant role in China's industrial affairs, with the government investing at least 5 percent of GDP to support industries in general. Initiatives such as "Made in China 2025" and the "dual carbon" strategy are designed to enhance China's technological self-sufficiency while promoting greener industrial practices. The 14th Five-Year Plan has further emphasized restructuring industries to reduce overcapacity and improve energy efficiency, but China's decarbonization efforts remain in their infancy.

Aggressive market behaviors such as oversupply and market dumping highlight the tension between sustaining industrial growth and achieving sustainability. How China balances these priorities will shape the trajectory of its decarbonization agenda. However, clean technology is a major commercial opportunity for China and is seen by its leaders as a key driver of future economic growth. China currently dominates the global cleantech market, particularly in solar panels, wind turbines, and electric vehicle production. This dominance, paired with its control over critical raw materials such as lithium and rare earths, solidifies China's leadership in the clean energy transition and also underscores that other industries in China are likely to follow in adopting clean energy.

China's approach to decarbonization is characterized by:

- **State-driven innovation:** The government plays a dominant role in guiding industrial policy, with significant guidance provided to encourage the development of green technologies.
- **Importance of the provincial level:** Local governments have varying levels of commitment to decarbonization, leading to uneven progress across the country.

- **Massive industrial capacity:** China's sheer size makes rapid decarbonization challenging, as (most) industries continue to expand, aiming to gain international market share.
- **State-owned enterprises creating green clusters:** SOEs play a key role in decarbonization, with private companies clustering around megaprojects that create demand for cleantech and green goods.
- **Dominance in cleantech:** China's dominance in global cleantech supply chains provides the country with a strong economic incentive to accelerate industrial decarbonization. Its leadership in renewable energy installations will soon create surplus energy, pushing industries to absorb this supply.

1.3. JAPAN'S APPROACH

Japan's industrial policy is characterized by close coordination between the government and the private sector, with guidelines often being co-constructed and voluntarily adopted by industries. This collaborative approach is also shaping Japan's gradual shift toward decarbonization. The country aims to adopt policies to make low-carbon products competitive against carbon-intensive alternatives, with significant funding—JPY 2.9 trillion (€18 billion)—dedicated to R&D projects in industry decarbonization through the Green Innovation Fund.

The GX Strategy further bolsters Japan's decarbonization efforts by integrating "growth-oriented" carbon pricing with industrial support. Central to this strategy is the issuance of GX Transition Bonds, aiming to raise JPY 150 trillion (€995 billion) over the next decade, with initial bonds issued in 2024 to fund industrial R&D. Japan also plans to implement a mandatory national emissions trading scheme by 2026–2028, aligning with the implementation of the EU CBAM.

Japan's decarbonization strategy is tightly linked to its energy policy, which prioritizes the "3 E's": energy security, economic security, and environmental sustainability. The government's technology-agnostic approach seeks flexibility in achieving carbon neutrality by 2050, though this may slow the transition as it attempts to balance decarbonization against maintaining economic and energy security. As a result of the significant geographic and resource challenges that Japan faces, the country is planning for the deployment of most industrial decarbonization technologies from the 2040s, which is much later than Europe.

Key points of Japan's strategy:

- **Hydrogen leadership:** Japan has positioned itself as a leader in hydrogen technology R&D, with a strategy aimed at increasing hydrogen usage in industrial processes. Without succeeding in supplying clean hydrogen, Japan's industrial decarbonization will be delayed and will face significant structural changes.
- **Energy security:** Given its dependence on imported energy, Japan's industrial decarbonization strategy tries to reconcile its decarbonization goals with energy security. Nevertheless, if the country succeeds in breaking its dependency on imported fossil fuels, it could gain significant energy security.
- **Collaboration with industry:** Japanese policymakers work closely with industries, aiming to create a cooperative environment for implementing decarbonization initiatives. Technology guidance and planning are at the core of the Japanese strategy under the NEDO agency.

1.4. SOUTH KOREA'S INDUSTRIAL STRATEGY

South Korea's industrial policy is heavily influenced by its conglomerates, or chaebols, which have deep connections with the government and hold significant power in shaping industrial strategies. The country's economy is export driven, particularly in sectors such as steel, where international demand—especially from Europe, the US, and Southeast Asia—plays a crucial role. As the global market for decarbonized products grows, South Korea faces increasing pressure to transition its industries to align with international decarbonization standards, with the EU's Carbon Border Adjustment Mechanism being a key driver of policy change. However, the nature of international demand for Korean exports mitigates against the country taking a more aggressive stance on decarbonizing its industrial sector.

South Korea's shift toward decarbonization is therefore slow. Most efforts have focused on private research and development rather than on comprehensive, mandatory policies. Although South Korea introduced an emissions trading system (SK ETS), its effectiveness has been limited. South Korea pledged to achieve carbon neutrality by 2050 and enacted the Carbon Neutrality Act in 2022, aiming for a 35 percent reduction in emissions by 2030. However, recent revisions to the national carbon plan reduced this target to 11.4 percent.

Overall, South Korea's decarbonization trajectory is cautious, especially given its energy-intensive industries. While policy initiatives such as the Korean Green New Deal and green finance incentives hold promise, the country's reliance on developing markets and internal industrial dynamics complicate the transition to a low-carbon economy in the short term. The government is now considering a more robust clean industrial strategy, which would combine a more stringent ETS with financial support and incentives to help energy-intensive industries decarbonize.

Challenges for industrial decarbonization in South Korea include the following:

- **Dependence on fossil fuels:** South Korea's reliance on coal for electricity and industrial processes remains a barrier to decarbonization.
- **Export-driven economy:** South Korea's industrial policy is heavily influenced by global demand, particularly in the steel sector, which makes rapid changes more difficult.
- **The hydrogen economy:** South Korea is banking on hydrogen as a key component of its industrial decarbonization efforts, but the infrastructure and supply chain are still under development and will rely heavily on imports, with technical challenges to be resolved.

Table Summarizing Key Industrial Strategies in Europe, China, Japan, and South Korea

Region	Main Industrial Policy Framework	Description	Challenges
Europe	*European Green Deal, Fit for 55, Net-Zero Industry Act*	Regulatory mechanisms (ETS, CBAM, etc.), support for clean tech (hydrogen, renewables), demonstration projects.	High energy costs, fragmentation between EU and national policies and industrial strategies, complex EU funding
China	*Dual Carbon Goals, Made in China 2025*	State-led industrial planning, massive scaling of renewables and green tech, moving to R&D strategy, no industry decarbonization targets.	Overcapacity in high-carbon sectors, uneven regional implementation, massive reliance on coal
Japan	*Green Growth Strategy, GX League*	Technology-agnostic approach (with a focus on hydrogen), voluntary emissions reductions, new carbon pricing, green bonds (debt), centralized industrial agency to support R&D.	Fossil fuel dependence, slow policy deployment, energy security issues
South Korea	*National Hydrogen Strategy, Korean Green New Deal*	Research-focused, carbon pricing (SK ETS), no industry decarbonization targets, focus on hydrogen.	Slow policy integration, reliance on action by *chaebols*, lack of a coherent industrial decarbonization framework

2 How to Decarbonize Industry?

Chapter 2 of the report addresses the critical challenge of decarbonizing global industries. It highlights the uneven geographic distribution of carbon-intensive industries and the technological and economic challenges that must be overcome. Key decarbonization technologies and processes—such as electrification, clean hydrogen, raw material substitution, and carbon capture, utilization, and storage (CCUS)—and the support they receive in Europe, China, Japan, and South Korea are thoroughly explored.

Electrification

Electrification offers an efficient way to decarbonize many industrial sectors, especially for low-to-mid temperature heat processes. By replacing fossil-fuel-based systems with clean electricity-powered alternatives, industries can significantly lower their emissions.

- **China:** Although heavily reliant on coal for industrial processes, China is rapidly scaling up renewable energy with the aim of electrifying certain industrial sectors and introducing policies to drive some industrial sectors (such as aluminum) toward regions with large amounts of clean electricity. However, its industrial electrification progress remains slow compared to other regions, and incentives for sectors such as steel remain relatively low.
- **Japan:** Japan's strategy includes the use of electric arc furnaces in steel production and industrial heat pumps for lower-temperature applications, although progress is hampered by high electricity costs and the lack of sufficient electricity in the country to meet the growing need for industrial electricity. The government is taking measures to promote and test applications from energy storage to nuclear energy. Clusterization also plays a role in Japan's industrial electrification.
- **South Korea:** South Korea is making early investments in electrification but remains focused on coal for many applications. The lack of widespread electrification projects has slowed its decarbonization efforts.
- **European Union:** Europe is still slow in promoting industrial electrification. Europe also lacks an electricity strategy for industrial sectors that can match clean electricity supply and availability of infrastructure with the growing demand from the industrial sector.

Clean Hydrogen

Hydrogen is anticipated to play a vital role in decarbonizing heavy industries. Green hydrogen, produced through electrolysis using renewable energy, is central to most decarbonization plans in Europe, although high costs and infrastructure development remain significant challenges. The wider use of clean hydrogen is also central to most industrial strategies in Asia.

- **China:** China has large hydrogen production capabilities but primarily produces gray hydrogen (carbon-intensive). However, it is investing in scaling up green hydrogen projects in line with its decarbonization goals and is increasingly targeting clean hydrogen for industrial processes, at least at the demonstration scale. The promotion of green hydrogen for industrial applications such as steel still falls into the guidance realm, and Chinese industrial strategy aims to both develop industrial demand and scale up hydrogen supply.
- **Japan:** As a global leader in hydrogen technology, Japan's hydrogen strategy aims to boost hydrogen use in its industrial processes and support hydrogen imports to compensate for domestic production shortfalls. Still, a massive shift toward clean hydrogen in industry is not foreseen before the 2040s and will rely on the development of hydrogen and ammonia import infrastructure (i.e., shipping).
- **South Korea:** South Korea has launched a roadmap to become a hydrogen leader, with substantial investments in hydrogen production and infrastructure, including plans to import hydrogen from Australia and the Middle East.
- **European Union:** The EU is advancing very ambitious hydrogen development plans through its "European Clean Hydrogen Alliance" and the "EU Hydrogen Bank," focusing on green hydrogen projects and infrastructure investments to support industrial decarbonization. There is, however, a genuine risk of not matching hydrogen supply with demand quickly enough, especially in the steel and chemicals sectors.

Carbon Capture

CCUS technology is critical for industries where direct electrification or hydrogen use is not viable in the short term. It enables the capture and storage of CO_2 emissions, allowing industries to continue operations while transitioning to cleaner processes. Most industrial countries are developing their carbon management policies.

- **China:** China is advancing CCUS technology through pilot projects, primarily focusing on its heavy industries, such as petrochemicals, steel, and cement, although large-scale deployment is still limited. The role of big SOEs such as SINOPEC is central in clustering CCUS R&D and demonstration projects in the country.
- **Japan:** Japan has included CCUS as part of its "Green Innovation Strategy" and aims to deploy carbon capture technologies across its energy-intensive industries, particularly in chemicals and cement. The strategy also involves creating a global market to ship CO_2 to regions with greater storage capacity.
- **South Korea:** CCUS is gradually gaining traction in South Korea, especially in its steel and cement sectors, as the government recognizes the technology's potential to help meet its carbon neutrality targets. Similar to Japan, South Korea's strategy involves shipping CO_2 to locations with sufficient storage capacity.
- **European Union:** Since the NZIA, the EU has been trying to promote CCUS implementation, with a great deal still to be done to genuinely scale up this technology and create a European CO_2 market. Several demonstration projects across the continent are emerging, and technology is now a central pillar of the EU's decarbonization strategy for some industrial sectors.

Raw Material Substitution

Replacing carbon-intensive raw materials with low-carbon or recycled alternatives is essential for most energy-intensive industries. This strategy is aimed at reducing emissions associated with the production and processing of raw materials.

- **China:** The central government is establishing guidelines to promote circular economy principles and encouraging the use of recycled materials in industries such as steel and cement. The development of EAF in the steel sector and the aluminum sector are the two main targets of this strategy, although they have seen only medium success due to the current lack of scrap in the country. This is still a very new approach and does not come with binding or serious incentives in most sectors. The strategy is to consider scrap as carbon assets.
- **Japan:** Japan is advancing research into raw material substitution, particularly in its cement and steel sectors, with a focus on boosting recycling rates and integrating sustainable alternatives. Implementing policies to keep scrap in the country is becoming an increasingly important topic, given that a large quantity of metal scrap is exported to be melted abroad.
- **South Korea:** South Korea's approach to raw material substitution is still in its early stages, although there are initiatives underway in sectors such as cement to increase the use of alternative materials. The country is a major importer of scrap metal and is trying to gain an even bigger share of global market share.
- **European Union:** The EU has developed stringent regulations promoting raw material substitution, particularly under its Circular Economy Action Plan. Still, the export of scrap is growing in Europe, and the EU has yet to implement a policy that considers scrap as carbon assets. Additionally, the technology history paradigm, especially in standards, sometimes plays against raw material substitution, as in the case of the cement sector.

3 Clean Industrial Strategy Seen from a Comparative Perspective

Chapter 3 of this report compares the emerging clean industrial strategies of the EU, China, Japan, and South Korea. It highlights how each region navigates risk-taking and uncertainties in decarbonizing its industries, promotes innovation, and adapts to the geopolitical and economic shifts emerging in the post-carbon economy. This comparative analysis lays the groundwork for key recommendations regarding the future trajectory of the European *Clean Industrial Deal*.

3.1. TECHNOLOGY CHOICES: STRATEGIC INVESTMENT, PRIORITIES, AND THE NEED TO REMAIN TECHNOLOGY AGNOSTIC

All the industrial decarbonization strategies analyzed in this report emphasize the need to mobilize decarbonization tools that enable the **simultaneous deployment** of a **multiplicity of vectors**. This includes access to **affordable clean electricity**, the massive commercialization of **clean hydrogen**, and the production and use of **liquid hydrocarbon biofuels**, both for energy supply and stocks for industrial use.

While some industrial strategies in China, Japan, South Korea, and Europe emphasize specific decarbonization vectors, **maintaining technological openness is crucial across the board due to uncertainties, varying access to clean alternatives across regions, and the diverse contexts in which industries operate**. This means that support should not favor one technology over another, as long as it achieves the goal of decarbonizing a sector. However, this does not preclude a clean industrial strategy from being consistent in heavily supporting a particular technology, such as clean hydrogen or electrification, especially for processes in which it proves particularly effective.

Adapting high-emissions industries to decarbonization processes will demand **strengthened partnerships between the private sector and governments to streamline and expedite technological advancements**. It is vital for all stakeholders involved to accelerate progress in technology, policy-making, and investment strategies and implement them swiftly to meet environmental targets. **Governments have a critical role to play in this transition by providing clear guidelines and establishing definitive financial support mechanisms to aid industries in their decarbonization efforts**.

Therefore, to move toward carbon neutrality and ensure access to CO_2-free energy, significant investment in clean hydrogen and electrification needs to be prioritized as a key strategy to drive industrial decarbonization. Additionally, CCUS technologies will play a role, particularly in the transition period, and should help preserve some industrial assets necessary for European sovereignty until fully clean alternatives are available. Despite efforts to reduce fossil fuel consumption by 2050, the challenge of completely eliminating its use underscores the necessity for carbon-intensive sectors such as steel, cement, chemicals, and aluminum to intensify **collaborative efforts in developing low-carbon technologies**.

3.2. THE ROLE OF INDUSTRIAL CLUSTERS

Cooperation across industries is essential in order to decarbonize **carbon-intensive sectors, as carbon emissions are embedded in the interconnectivity of the different sectors**. This "clusterization strategy" is becoming central in pilot and demonstration projects in Europe and Asia. For example, products generated by the chemicals industry are deeply embedded in the world's largest value chains, such as manufacturing and construction. As a result, **the level of deployment of low-carbon technologies will be dependent on cross-industrial collaboration**.

Europe and Asia need to anticipate future demand and foster synergies across sectors. For example, CO_2 captured from steel production could be repurposed for nearby chemical applications. This **clustering**

approach is gaining traction in China, particularly around SOEs, with significant backing from the central and provincial authorities. The strategy leverages SOEs' capacity to drive substantial demand and provide financial support to private actors.

The need to anticipate new challenges and cooperate across sectors will arise from multiple fronts. For example, electrification will bring additional electricity demand, and changes of processes will also affect industries, meaning that they will need to find new synergies to comprehensively anticipate new challenges. This includes anticipating challenges such as the following:

- The **loss of the excess heat generated by fossil-fuel-based industrial processes**, which was traditionally **redistributed toward other sectors**
- The **increase in peak loads that heat pumps impose on the grid**
- Finding **funding sources for the construction of electrification-related infrastructure**

3.3. FIRST-MOVER RISK VS. SECOND-MOVER ADVANTAGE

In Europe, the Green Deal and the Fit for 55 package provides significant clarity for European actors and international suppliers, signaling a carbon-neutral future. Nonetheless, investing in new decarbonization technologies still requires substantial support. **Risk-taking remains culturally complicated for some actors unless it is significantly backed by financial and nonfinancial support from the state**.

The main challenge facing many European industries is the risk that **a first-mover advantage may not materialize in the realm of industrial decarbonization**. Countries such as **Japan, South Korea, and especially China are positioning themselves to capture a probable second-mover advantage**. In contrast to the approach taken with emerging sectors such as batteries, their main strategy for traditional industries involves closely monitoring and testing what works in first-mover regions – particularly Europe, with its more stringent policies – and scaling up once the leading technology becomes evident. As a result, the European strategy must tackle both fronts: supporting first movers who are willing to take risks and quickly anticipating competition from regions that are not bound by the same regulatory constraints.

Europe's strategy toward achieving industry decarbonization hinges on three key policy mechanisms:

- The use of an **emissions trading system and Carbon Border Adjustment Mechanism that are generating revenues**
- **National subsidies**
- A long list of EU-level support mechanisms for R&D, demonstration, and deployment such as the **Innovation Fund, the IPCEI, STEP, and legislative packages such as the *Net-Zero Industry Act* and Net-Zero Europe Platform**

This is a starting point, but it is insufficient to both achieve decarbonization and address the emerging uneven playing field created by national industrial policies and diverging decarbonization priorities. **Europe must recognize the need for pragmatic trade measures during the transition period**, which will intensify around 2028 with the gradual phasing-out of free allocations in the EU ETS.

There is, therefore, a need to **coordinate industrial policy with trade policy, not only politically but also organically. If an emissions-intensive trade-exposed sector is under strict decarbonization regulations in Europe, this should be considered in EU trade policy**.

To safeguard its industries, Europe should therefore **expand the Carbon Border Adjustment Mechanism, implement green procurement policies that favor European-made green goods, and provide financial support to lead markets**. If the industry decarbonization agenda aligns with that of other global actors, green trade will become feasible. However, there is a significant risk that industrial decarbonization efforts may not proceed at the same pace across trade partners, necessitating protective measures. This dilemma is also abundantly clear in the cases of Japan and South Korea.

3.4. COMBINE REGULATION WITH INDUSTRIAL STRATEGIES

a. A Clean Industrial Strategy Requires a Demand-Side Approach

Given the high costs of investment and the significant risks that industrials face due to technological uncertainty, it is **crucial that green industrial policies supporting the decarbonization of the most polluting industries address risk-taking**.

- Europe addresses risk mitigation through a mix of financial and nonfinancial instruments, including regulations.
- China is establishing a support network with technology guidance and is enabling large industrial players to test new technologies before full-scale implementation has been achieved and any stringent measures have been implemented.
- Japan focuses on R&D and demonstration projects and is implementing sectoral agendas for deployment but has yet to promote widespread implementation across most industrial sectors.

A critical question that remains across all jurisdictions is **how to generate sufficient demand for green goods to justify the significant investments required for carbon-neutral processes**. Europe has primarily relied on rising carbon pricing to stimulate this demand – a strategy increasingly being adopted by other nations, including Japan, South Korea, and, to some extent, China.

There is a growing **need to implement demand-side measures, such as green public procurement and mandatory green purchasing requirements, as part of a broader industrial strategy**. These approaches are already being explored in Japan and South Korea, while public procurement and purchasing mandates have long been integral components of China's industrial policy framework. Demand-side measures should be part of the European industrial strategic playbook, and the *Clean Industrial Deal* must have a demand-side dimension.

b. A Strategic Selection of the Right Clean Technology

A key challenge in designing an effective industrial strategy is determining which technologies to support, as governments cannot operate as typical market participants. This issue remains one of the most contentious among stakeholders and policymakers in both Europe and Asia. **While industries should ideally have the freedom to select their own best technologies, governments inevitably play a role in shaping those choices**.

In China, the government's consistent support for massive deployment of renewable energy is effectively influencing some industries' decisions. Governmental intervention is particularly the case in some heavily industrialized provinces that intervene more directly in industry than others, or in sector specialists provinces. Despite this, the Chinese authorities maintain sectoral open lists of technologies that are eligible for support through green industrial funds. These lists (sometimes provincial-based) are updated regularly due to industry demand (notably through industry associations—which are actually public governmental agencies) and eventually enable many technologies or approaches to be supported.

In Japan, technology selection is approached with caution, as the government strives to remain as technology-neutral as possible, although the availability of clean energy vectors imposes certain limitations. NEDO plays a central role in technology selection, in co-construction with industries. South Korea, although still in the early stages, appears to be following a similar path.

Europe, on the other hand, needs a system that **combines** vertical interventionist measures **– guiding and promoting decarbonizing technologies –** and horizontal market-based regulations (e.g., carbon pricing) to ensure competition among companies and technologies to identify the best options for each geographical area.

Moreover, a critical element of a successful green industrial policy is its **ability to adapt quickly to the changes and technological advancements** that inevitably arise in the market. **China, in this respect, is adept at being technologically flexible until it becomes clearer which technology will dominate the market**. In practice, this means that **the policy should not only focus on market leaders but also promote the emergence of new, often smaller, players** who have developed technologies closer to market needs for decarbonization.

Public–private partnerships are also essential in this context. Government agencies, industries, and even civil society should collaborate to select projects supported by the community to decarbonize industries. This collaborative approach ensures that the projects selected are aligned with broader societal goals and contribute effectively to decarbonization efforts while also being open to newcomers.

The European strategy should therefore offer technological guidance on decarbonization, particularly for the most hard-to-abate sectors, **without limiting support to any single type of technology**. This requires **regularly reviewing the basis for technology guidance, with the primary criterion being carbon abatement in the most cost-efficient manner while upholding the sovereignty objectives of the *Net-Zero Industry Act***.

c. Easy Financing of OPEX Becomes Essential

The need for operational expenditure (OPEX) financing during the transition period has become evident for most industrial sectors. This will be a critical element in establishing lead markets. **Financing OPEX can be justifiable under certain conditions**. Primarily, it should be **considered for bridging temporary gaps**. However, if these gaps become persistent, continuing to finance them is not justifiable and becomes a waste of resources. It is crucial to assess the sustainability and long-term impact of such financing to ensure it contributes to economic stability rather than perpetuating inefficiencies.

Carbon contracts for difference are a promising tool that could indeed be extended to support industry decarbonization in more sectors, such as steel or cement. European countries, Japan, and South Korea are considering adopting them. However, in Europe, **CCfDs face significant limitations due to a lack of visibility regarding the long-term cost of carbon on the EU ETS**, making them challenging to implement. To function effectively, CCfDs require a perfect Carbon Border Adjustment Mechanism and a predictable carbon price. In the current situation, this instrument is complex and risks being restricted to a specific sector, such as hydrogen or CCUS, if no better predictability of carbon price is established. That said, using European CCfDs for green goods such as steel or green aluminum may be the best option available in the toolbox.

Direct OPEX subsidies should also be included in the playbook. China is using OPEX subsidies as a way to reshape its industrial apparatus and may well continue to do so for decarbonization when the time comes. In Europe, state aid for **financing operational expenditures presents significant challenges, particularly within the framework of EU market competition rules**. These rules make the implementation of such aid complex and often restrictive. To overcome these challenges, **a shift toward a European-level approach is essential**.

One critical question arising in Europe and Japan is whether state aid should cover expected or actual OPEX. Understanding the necessary conditions to trigger investment decisions is key to effectively addressing this issue. **A sector-based approach employing a production-based discriminatory factor could provide the necessary framework for this evaluation**. This approach would ensure that aid is distributed fairly and effectively, targeting the sectors where it is most needed and likely to stimulate growth.

In Europe, this also means **perennializing exemptions to competition law – like the IPCEI – for industry decarbonization, allowing industries to receive the necessary support to establish green lead markets**. This is especially crucial during the transition period, which will involve numerous tests, failures, and attempts by external market actors to capture market share.

d. The Importance of Green Industrial Standards

Establishing international standards for green industrial goods is crucial, especially during the transition period. Regional and national conditions will differ significantly, and technological uncertainty will be influenced by specific geographical factors.

The first mover on standard setting could well be the one that defines the global standard—this should encourage the EU to move fast. China is actively positioning itself to shape global industrial standards, as it recognizes that standardization can promote certain technologies on the global market. If a country succeeds in embedding technologies that it dominates into global standards, it can gain a considerable competitive advantage over other nations.

To develop effective green standards, a period of experimentation is essential to determine which approaches work best. However, such experiments must be thoroughly evaluated, with the goal of eventually consolidating standards to avoid fragmentation.

Considering the great political difficulties and diverse national tactics on standard setting, interoperability could well be the best obtainable version of an agreement on low-carbon industrial standards. Each country or bloc could thus develop its own standards based on local conditions, considering other instruments implemented globally, particularly among trade partners. This approach can be used to initiate discussions on making these standards interoperable, using science-based criteria such as **carbon intensity, processes, tailored emission calculation methods**, and **carbon pricing**.

However, this should not sidestep difficult political decisions that are crucial for resolving power dynamics and achieving true progress. In the context of industrial decarbonization, China presents a key challenge due to its dominance across many sectors. While dialogue with China on standards is necessary, it will always be influenced by geopolitical considerations, given the country's industrial dominance and policy support. **This underscores the need for Europe to lead in developing its own standards – ideally in cooperation with like-minded partners and countries engaged in the *Clean Industrial Deal* – before pursuing a truly global set of clean industrial standards**. A clear, consolidated set of European green standards will ensure stronger alignment and commitment across the industry and Member States, fostering more decisive action toward sustainability.

e. Preparing for the Coming of Age of an Uneven Playing Field

Despite Europe's significant strides toward decarbonization through stringent regulatory policies such as carbon pricing, it is not the only region advancing in this area. **Governments worldwide are encouraging industries to accelerate their transition to better position themselves in the emerging post-carbon economy**. This effort is particularly evident in the evolving interactions and policy frameworks within and among major industrial and trade blocs, including the EU, China, the US, South Korea, and Japan.

However, these **governments are adopting very different approaches and timelines**, and this trend is likely to continue. These varied strategies **can lead to issues such as market distortions**, where goods are priced differently across borders, causing competitive imbalances.

Without international coordination, such discrepancies can result in "carbon leakage," where industries relocate to countries with less stringent regulations, thus undermining global decarbonization efforts. This is why the EU has implemented the Carbon Border Adjustment Mechanism as it phases out free allocations in the EU ETS. However, **the CBAM may not be sufficient to shield these sectors due to various ramifications of the value chain**, and the complexity of transitioning these sectors **may lead to the simultaneous existence of "green" and "brown" economies during this transformative phase**. As nations develop their transition timelines and policies, effectively managing this coexistence becomes crucial.

Beyond the Carbon Border Adjustment Mechanism, a significant challenge is the **relative absence of a cohesive political trade policy at the European level**, which hinders the use of industrial policy to support European sectors. For example, cooperation on carbon pricing has been a key aspect of China–EU relations, but it is evident that further progress in this area will not lead to significant convergence, particularly regarding ETS linkage. Access to relevant data for CBAM from China, and even from the Chinese ETS itself, also remains doubtful. Additionally, the US Inflation Reduction Act has changed the landscape by providing financial support for both CAPEX and OPEX to a level unseen in Europe. China's continental scale and relatively opaque industrial policy further exacerbate the absence of a unified political approach to trade policy in Europe.

Coordinating industrial strategies at an international level is, therefore, imperative to ensure a level playing field and foster a global market for green goods that is both fair and competitive. Support for initiatives such as the Climate Club and a demonstrated European willingness to share knowledge with potential partners is also crucial. In this context, Europe's neighborhood becomes critical, particularly for industries such as steel and chemicals, which require access to substantial amounts of clean energy and hydrogen. **There is a need to make the EU *Clean Industrial Deal* an international instrument, not only for Europe's decarbonization and competitiveness but also for international partners exchanging industrial goods with Europe** (e.g., Mozambique and aluminum).

If this collaborative approach does not emerge quickly, green markets for industrial goods could become more localized, with trade limited to countries that transparently share the same practices. This would result in higher costs for industrial goods and could ultimately hinder the clean transition's popularity among populations already facing inflationary pressures.

4 Recommendations for a Streamlined Sectoral Clean Industrial Strategy

Currently, there is no perfect industrial policy or strategic management framework globally. However, certain practices from other jurisdictions could significantly enhance Europe's approach.

Europe has implemented various instruments such as the IPCEI, SET Plan, and STEP to coordinate a nascent common industrial policy. Despite these efforts, they are insufficient.

Unlike Japan, which has the Green Innovation Fund under NEDO **coordinating investment, technology guidance, and policy support across different levels of power**, Europe still lacks a similar agency. Additionally, unlike China, **Europe does not have a centralized approach to technology guidance and cannot efficiently promote the allocation of resources where it makes the most sense** – for instance, where renewable or low-carbon energy resources are abundant or where clean hydrogen will be cheapest to obtain.

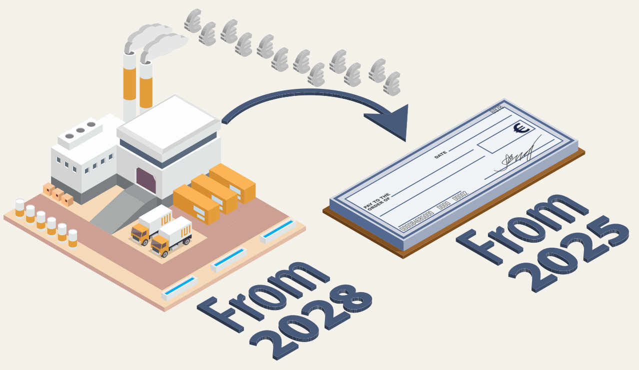
Moreover, **securing long-term support for OPEX remains challenging due to overly complex procedures** that need to be streamlined to meet objectives. Consequently, Europe's industrial policy related to innovation, demonstration, and scaling up faces numerous obstacles.

Beyond the lack of funding in the EU for developing a green industrial policy, one critical aspect is that the European **funding landscape is highly fragmented**, posing significant challenges for companies seeking financial support. Obtaining the necessary funds often requires about a year's worth of resources, a burden many find excessive. To address this, there is a **pressing need for a streamlined Clean Industrial Fund tailored to each sector, complete with a more open list of supported technologies** and **objectives at both the EU and Member State levels where appropriate**.

The EU should adopt a *Clean Industrial Deal* incorporating the following elements:

Recommendation 1

Establish EU-level common funding through a European Green Bond – or a Clean Industry Investment Debt of €100 billion per year, repaid by anticipating portions of future carbon revenues starting in 2028 and through the removal of free allocations in the ETS.



Recommendation 2

Use the base of the European Climate, Infrastructure, and Environment Executive Agency CINEA Platform and STEP to <u>create an EU Clean Industrial Strategy Agency</u> under the Executive Vice-President for Industrial Strategy and the Executive Vice-President for Clean, Just, and Competitive Transition. A dedicated European agency should not be an end in itself, but rather a strategic tool to structure and accelerate the green transition, provided it operates with clear priorities and objectives. The agency should be responsible for the following areas:

a. **Providing technology guidance** with direct and organic cooperation of industrial stakeholders and the participation of civil society. It should **regularly review the basis for technology guidance**, using carbon abatement in the most cost-efficient manner as the primary criterion while upholding the sovereignty objectives of the *Net-Zero Industry Act*.

b. **Analyzing existing projects**, identifying key success factors, and determining how these can be replicated while avoiding loopholes, redundancies, and inefficiencies.

c. **Coordinating EU-level funds** and support mechanisms with Member State–level funds.

d. **<u>Merging existing instruments</u>** such as the EU **IPCEI**, **STEP**, and **SET Plan**, and **<u>perennializing</u> them**.

e. **This agency should function as a <u>one-stop European financing hub</u>, centralizing funds and streamlining access for clean industrial projects.** Its role would be to facilitate the implementation of the objectives of the NZIA, ensuring that financial support is directly tied to the achievement of decarbonization targets and other NZIA objectives.

f. Implementing **<u>a cluster-based distribution of funds</u>** that promotes competition among Member States when beneficial and fosters cooperation when possible. This approach will enable local and regional authorities to be involved in projects at the earliest stages of the process.

Recommendation 3

Embrace a demand-side approach with instruments such as a **Made-in-Europe Green Public Procurement Policy** for clean industrial goods.

Recommendation 4

Use trade policy as an instrument of industrial strategy based on two elements:

a. **Trade policy should consider scrap as a carbon asset**, and its status as such should be preserved within the European market during the transition period. This would avoid many circumvention issues in the Carbon Border Adjustment Mechanism.

b. **Favor trade with regions and countries adopting similar industrial decarbonization agendas and/or cooperating under the Clean Industrial Deal or member countries of the Climate Club.**

Recommendation 5

Beyond further electricity market integration, **there is a need to support and anticipate the demand for industry electrification**. The European Commission should **establish a comprehensive monitoring framework to track electrification progress in industry**:

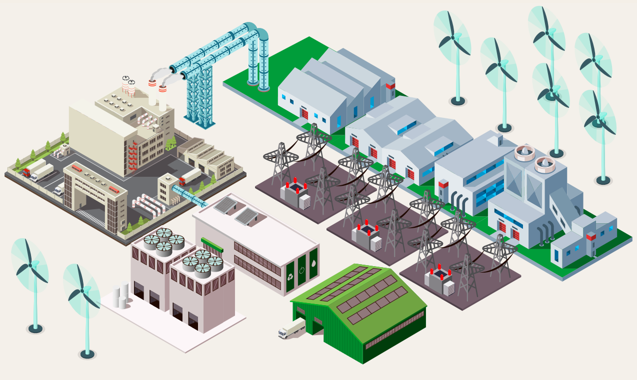
a. Ensuring **coordination among Member States** and **enforcing electrification targets.**

b. **Closely monitoring technological and industrial advancements in this field** to ensure that the electrical infrastructure can support the transition.

c. **Proactively anticipating future needs and the potential impacts of increased demand resulting from electrification.**

Recommendation 6

Adopt a **Cross-Sectoral Technology-Hub Strategy**:



a. Cross-sectoral and within-sector collaborations are crucial for fostering technological innovation, essential for the mass production and market introduction of carbon-neutral technologies and processes such as green hydrogen, as well as for advancing CCS and CCUS technologies to **practical application levels**.

b. Promoting mutualization of clean electricity generation in locations where this is easily achievable.

Recommendation 7

Follow two principles to **establish clean industrial standards**:

a. Break technology path dependency – Standards often evolve from earlier technologies and practices, meaning that the history of prior standards heavily influences the design and adoption of new ones. Once a standard becomes widely accepted, it can lead to inertia, making it difficult for newer technologies to break through, even if they are more efficient or innovative.

i. In the case of industry decarbonization, there is a need to **enable emerging technologies to enter the market**. This requires **reviewing standards on a rolling basis**, preventing the lock-in of old technologies, and allowing newcomers to compete. This approach is relevant for most industrial products.

b. Adopt and promote a product-based approach and accelerate the implementation of ecodesign regulations:

i. The European Union should promote a product-based approach to standardizing green industrial goods to **ensure a uniform, high standard of environmental sustainability across the market**. This approach would facilitate the creation of products that are not only carbon neutral but also competitive on a global scale, reinforcing the EU's position as a leader in green technology and sustainability. By **focusing on the end products**, the EU can more effectively regulate the environmental impact of goods, ensuring they meet strict sustainability criteria **regardless of the manufacturing processes used**. This also enables avoidance of technological lock-in.

ii. This method would also drive innovation as manufacturers seek cost-effective ways to meet these standards, ultimately benefiting the economy and the environment. Additionally, it would **accelerate the implementation of ecodesign requirements and the promotion of sustainable products through standards set by the Ecodesign for Sustainable Products Regulation**, fostering a greener market and driving the shift toward a circular economy.

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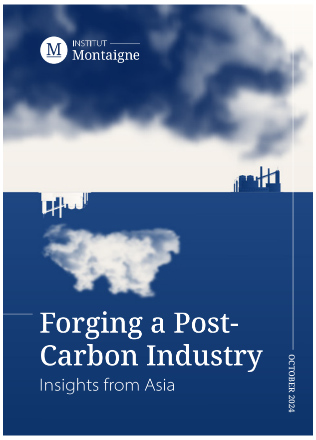
REPORT Executive Summary - October 2024

Forging a Post-Carbon Industry

Insights from Asia

Part 2
Strategies to Decarbonize the Steel and Aluminum Sectors



In the face of the climate crisis, with the world moving rapidly toward a dangerous threshold of +2°C warming, decarbonizing industries has become an urgent priority. As the second part of the Institut Montaigne's research report on industrial decarbonization policies and strategies in Europe and Asia, this paper delves into the critical issues surrounding the decarbonization of two carbon-intensive sectors: steel and aluminum. These industries are central to global economic activity but also contribute significantly to greenhouse gas emissions. For nations seeking to lead in industrial decarbonization, the challenge lies in reducing emissions while maintaining industrial competitiveness. This analysis focuses on how to navigate that delicate balance.

In this second part, the emphasis shifts to a more granular examination of the steel and aluminum sectors. Both sectors are indispensable for the post-carbon economy, with steel required for infrastructure and aluminum crucial for lightweight transportation solutions and electrification infrastructures. The report undertakes a comparative analysis of the strategies pursued by Europe, China, Japan, and South Korea to decarbonize these sectors, highlighting not only the policy and technological choices but also the economic environment shaping each region's approach. This section specifically evaluates the technological pathways for decarbonization and assesses the financial and policy support mechanisms that will enable their deployment.

In this context, it is vital to understand the competitive dynamics between green and carbon-intensive goods and their impact on decision-making for decarbonization. In particular, for many industrial sectors such as steel and aluminum, decarbonization may have a significant impact on location, economic model, and current supply chains. Through its comparative approach, this report looks at international best practices and provides recommendations tailored to the European context with a view to ensuring that the steel and aluminum industries can decarbonize without compromising their role in future economic prosperity.

Methodology

This report builds on research interviews and consultations with about 500 European, Japanese, South Korean, and Chinese policymakers and stakeholders held between June 2023 and July 2024. These semi-structured interviews were conducted to gather expert insights and firsthand perspectives relevant to the topics discussed. They were conducted online or in person during research trips to Europe, Japan, South Korea, and the UAE (COP28). This report also builds on a policy dialogue held in January 2024 with 40 policymakers and stakeholders from industrial sectors in Europe, Japan, and South Korea.

1 Strategies for Decarbonizing the Steel Sector

Steel production is responsible for approximately 8 percent of global carbon emissions. This is due to the energy-intensive nature of the traditional blast furnace-basic oxygen furnace (BF–BOF) method, which uses coal both as a heat source and as a reducing agent for iron ore. The key technologies driving decarbonization include hydrogen-based direct reduced iron (H2-DRI), electrification through electric arc furnaces (EAFs), and carbon capture utilization and storage (CCUS) for existing carbon-intensive processes.

Decarbonizing the steel sector differs significantly across industrialized regions and will have a profound impact on the industry's current geographical distribution and economic models. China, Europe, Japan, and South Korea are each pursuing distinct strategies to decarbonize a sector that, in many cases, forms a critical pillar of their economic foundation.

China overwhelmingly dominates global primary steel production, generating approximately 1.019 billion tons annually, which accounts for 57 percent of global output. In contrast, other major producers play a much smaller role: Europe produces around 126 million tons, Japan 87 million tons, and India 67 million tons. Given China's significant share of global steel production, decarbonizing its steel sector is essential for achieving carbon neutrality in the industry by 2050.

SUMMARY OF THE FUNDAMENTAL CHALLENGES

The decarbonization of the steel industry faces fundamental challenges for every steel-producing region that require adaptive and open policies to ensure that carbon-neutral steel production becomes a viable commercial reality. This is a reality faced by industrials and policymakers in Asia and Europe. **The key obstacle lies in demonstrating the commercial feasibility of carbon-neutral steel, especially given the variability in regional access to clean hydrogen, high-grade iron ore, sufficient clean electricity, and the necessary infrastructure**. Policymakers are trying to address these challenges while accommodating technological uncertainties that could change the industry's dynamics.

The transition from blast furnaces (BFs) to hydrogen-based direct-reduction iron (H2-DRI) is currently seen as the most practical pathway for manufacturing carbon-neutral primary steel. However, it requires significant investment in hydrogen production and infrastructure, as well as high-grade iron ore, which is geographically concentrated. This is one of the core issues for Europe, Japan, and South Korea highlighted in the report. In contrast, China sees this as a future problem for its transition to hydrogen steelmaking.

A consequence of these limitations for hydrogen steelmaking is that **some regions may find it more economically viable to import intermediary steel products or carbon-neutral iron than to continue local primary steel production**. Meanwhile, other regions are preparing to attract primary steelmaking or gain market share. The flexibility of the **DRI-EAF process**, which can dissociate iron-making and steelmaking, **opens up opportunities for regions with abundant renewable energy to lead in green iron production, reshaping global steel supply chains**.

Carbon capture technologies, including carbon capture utilization (CCU) and carbon capture and storage (CCS), are also part of steel decarbonization strategies in Europe and Asia, although they remain underdeveloped compared to alternative solutions. For CCU, the focus is on integrating captured CO_2 into industrial processes, whereas CCS needs to be utilized in regions with suitable geological formations. The development of carbon capture, utilization, and storage (CCUS) presents an appealing option for industrialists to preserve traditional fossil-fuel-based steelmaking processes. However, this approach relies on costly carbon capture technologies, which are only economically viable under a significantly high carbon price. In most regions analyzed, CCUS is seen more as a means of preventing asset stranding than as a long-term solution for decarbonization.

A further **critical challenge for policymakers is determining the right strategic approach for different regions and jurisdictions**. The same question arises in "old" industrialized regions, such as Europe, Japan, and even South Korea: What is the right strategy given this economic and technical equation? Indeed, regions with limited access to clean hydrogen and high-grade iron ore may benefit from importing intermediary products, while others may leverage abundant renewable energy to produce green iron for export.

Technological uncertainty also plays a key role, as emerging technologies such as molten oxide electrolysis (MOE) may represent viable alternatives to H2-DRI for primary steelmaking. This level of technological uncertainty tends to slow down deployment investment in many traditional steelmaking regions – this is particularly the case in Japan and South Korea, which are facing difficult prospects for future primary steelmaking and are currently not deciding how much support they want to give to each strategy beyond simply supporting R&D.

Ultimately, **successful decarbonization policies must balance cost competitiveness, capital investment needs, and government support while remaining open to technological advances**. They must also foster and promote secondary steel recycling and the development of EAFs in key locations where clean electricity is readily available. The steel industry's decarbonization requires not only current solutions but also future-proofing through open-technology policies to allow for potential breakthroughs.

CHINA

China's long-term goal is to fully decarbonize its steel sector by 2060 or sooner while maintaining its position as the world's largest steel producer (accounting for up to 57 percent of global production in 2024). It has recently included the steel sector in its intensity-based Emissions Trading Scheme (ETS), which indicates that the country could eventually implement a stringent cap on the sector's emissions by the end of the decade. Unlike other major steel-producing regions, China is determined to retain its entire steel value chain and expand its market share in the future carbon-neutral steel market by leveraging its renewable energy capacity and strategic partnerships for iron ore access.

China's strategy for decarbonizing its steel sector follows a pragmatic, phased approach that is **technology-opportunistic** and balances immediate emissions reductions against long-term breakthroughs in innovation. A key element of this strategy is **reducing steel production capacity**, driven primarily by falling domestic demand rather than a direct goal of lowering emissions. Even if the country implements carbon intensity targets, capacity reduction is still the main decarbonization policy in China. This **gradual reduction**

buys China time to develop alternative steelmaking technologies without massively disrupting key steel-producing regions.

China's approach focuses on expanding EAF capacity and eventually utilizing surplus renewable energy to power these furnaces, which provides a more sustainable and efficient way to reduce emissions. However, the country faces challenges in building a comprehensive steel scrap strategy and ensuring a reliable clean electricity supply for EAFs during periods when renewable energy is unavailable.

Leading companies – mostly state-owned enterprises (SOEs) such as BAOWU – are already demonstrating H2-DRI processes (using European technology), aiming to leverage China's growing renewable energy infrastructure for long-term clean primary steel production. Mixing hydrogen in traditional blast furnaces is also part of the solutions tested, even if this solution is not carbon neutral.

CCUS is part of the Chinese primary steelmaking decarbonization strategy. SOEs play a central role in this CCUS strategy, clustering industries around the chemicals and steel sectors. This reflects the temptation to continue using domestic resources such as China's still vast coal reserves, in an effort to maintain the competitiveness of its steel industry. This is also a solution to avoid stranded assets as much as possible. However, to make these options economically viable, China will need to establish a robust carbon pricing mechanism and stimulate demand for low-carbon steel, both domestically and internationally.

International demand, particularly from policies such as the EU's Carbon Border Adjustment Mechanism (CBAM), could incentivize China's low-carbon steel initiatives. However, recent investments in "efficient blast furnace capacity," despite their lack of carbon neutrality, pose a risk of stranded assets. In this respect, **China's phased, technology-opportunistic approach allows it to adopt and adapt successful technologies from other countries before scaling them domestically**.

JAPAN

Japan's steel industry faces significant challenges in its path to decarbonization, primarily due to the slow pace of development of low-carbon technology and the difficulty of securing sufficient green hydrogen, given the country's limited production capacity. To achieve carbon neutrality by 2050, Japan must address several critical issues, including securing large-scale investments from both the private and public sectors to fund low-carbon steel production and compensate for the societal costs of this transition.

Key priorities include the development of green infrastructure to support the use of low-carbon ammonia and hydrogen, along with intersectoral cooperation to advance CCUS. Japan's hydrogen strategy must be adaptable, relying on both small-scale domestic production and imports due to local limitations. Political decisions will play a crucial role in determining the future of Japan's primary steelmaking operations, particularly with respect to subsidies needed to maintain domestic production and the willingness to preserve this activity to the same extent in the country.

The upcoming replacement of many Japanese BFs by the 2040s creates a critical decision point: If clean hydrogen remains expensive or inaccessible, Japan may shift toward EAFs instead of betting too much on direct reduced iron (DRI) systems. This shift could lead to the relocation of primary steel production to regions with more favorable economic conditions, potentially impacting Japan's ability to balance the promotion of decarbonization against continued primary steel manufacturing in the country. In this respect, the Japanese government is still evaluating how the technology is evolving and aims to create a global hydrogen market to ensure that the Japanese steel sector remains competitive and sustainable during this transition.

SOUTH KOREA

South Korea faces substantial challenges in decarbonizing its steel sector, one of its key economic pillars. The policy framework, including the Korean ETS, has yet to provide a strong enough carbon pricing signal to drive significant investment in green technologies. The need to balance industry competitiveness against decarbonization remains a key issue in South Korea, and without a higher carbon price, the widespread adoption of decarbonization technologies appears unlikely in the near future.

Decarbonizing industry is not a current priority in South Korean policy, despite the country's pledge for carbon neutrality by 2050. While there is no comprehensive industrial strategy for decarbonization, South Korea supports industrial R&D, with POSCO advancing hydrogen steelmaking to address challenges such as access to high-grade iron ore. Still, the broader industrial strategy lacks a near-term focus on the transition. South Korea remains closely tied to international demand for green steel and is likely to delay stringent decarbonization measures until this demand solidifies.

A potential turning point for South Korea's strategy is the EU's CBAM, which affects up to 10 percent of South Korea's steel exports. This has pushed the South Korean government and steel producers to reform the SK ETS to align with the CBAM, signaling a shift in domestic climate policies. South Korea's steel sector is vital to its economy, producing 70 million tons of steel annually, with 30 million tons exported. However, 80 percent of South Korea's steel trade is with regions that may not tolerate price increases due to higher CO_2 costs, such as the ASEAN countries and China. This trade dependence complicates the transition to low-carbon steel, suggesting that the shift will be slow despite global pressure to decarbonize.

South Korea also faces challenges in accessing the clean electricity and hydrogen needed to decarbonize its steel sector. The high costs of hydrogen imports are driving South Korea to explore alternative strategies like sourcing reduced iron from regions such as the Middle East and Australia for further processing in EAFs domestically. Such a shift would fundamentally change South Korea's steel sector and its global market position. Despite these challenges, South Korea aims to become the world's third-largest steel producer by 2030, reflecting its commitment to remaining competitive while navigating the complex transition to a low-carbon future.

EUROPE MUST MAKE THE RIGHT CHOICE

Europe's transition to a decarbonized steel sector hinges on overcoming regulatory and infrastructure barriers, ensuring access to clean hydrogen, and managing energy demand. The implementation of the CBAM and strategic decisions about the future of steel production will shape the continent's ability to maintain its competitiveness while meeting net-zero goals. The steel industry's decarbonization will require coordinated efforts from public authorities, industry leaders, and policymakers to ensure a sustainable long-term solution.

Europe faces critical choices in decarbonizing its steel sector as it moves toward a net-zero future. The path forward requires the adoption of hydrogen-based steelmaking, wider electrification, the deployment of carbon capture technologies (to some extent), and substantial infrastructure investments. However, several challenges must be addressed, including access to clean hydrogen, energy reliability, and regulatory obstacles.

Hydrogen Regulation and Infrastructure Challenges

A key component of Europe's strategy involves hydrogen-reduction steelmaking, which is expected to play a central role in decarbonization. However, although **most H2-DRI projects will be "hydrogen-ready," they will still need to rely on natural gas due to insufficient access to clean hydrogen on the Continent**. This issue was exacerbated by disruptions in energy markets following Russia's invasion of Ukraine. To ensure the transition is sustainable, significant investment in clean energy sources to provide the electricity required for clean hydrogen production is needed.

The current EU regulatory framework for hydrogen, particularly the strict definition of Renewable Fuels of Non-Biological Origin, complicates progress. Key barriers include the prohibition on state aid for electricity production and the limitations on subsidies for non-renewable hydrogen sources (such as nuclear hydrogen). A shift toward a carbon-intensity approach, allowing flexibility in hydrogen production methods, is essential for scaling up decarbonization efforts in the steel sector.

Additionally, Europe's steel industry faces substantial energy challenges, as **the demand for electricity to power green steel projects is expected to more than double by 2030**. This includes 90 TW/h required to produce green hydrogen via electrolysis. The sector currently generates only 35 TW/h, leaving a significant gap to fill if Europe wants to maintain its current production level, given that the continent is already a net importer of steel.

The **deployment of CCUS technologies also faces infrastructure and energy-use hurdles**. The **availability of scrap steel must be improved equally**, as Europe currently exports a substantial amount of scrap that could be used domestically to meet decarbonization targets.

Public authorities will need to balance regulatory frameworks to support CCUS and hydrogen projects, as well as encourage electrification, ease administrative delays, and address infrastructure gaps. Maintaining constant updates on rules and addressing potential barriers will be critical as the EU implements the Net-Zero Industry Act.

The Impact of the Carbon Border Adjustment Mechanism

The introduction of the CBAM is set to reshape the European steel sector by imposing carbon costs on imports, aligning them with EU carbon prices. While the CBAM presents opportunities for promoting decarbonization measures in industrial sectors around the world, it also brings significant challenges. The CBAM is designed to prevent carbon leakage by imposing equivalent carbon costs on imports, ensuring that European producers are not undercut by cheaper, high-carbon steel from non-EU countries. However, risks such as resource shuffling – where exporters send their cleanest products to the EU while continuing to produce carbon-intensive steel elsewhere – could undermine its effectiveness. **A country- and sector-based average calculation method for carbon intensity within the CBAM could mitigate this risk by incentivizing decarbonization across entire industries in exporting countries**.

Strategic Dependence and the Future of Europe's Steel Industry

Europe must also decide how to manage its dependence on the global steel supply chain. The high costs of producing or importing green hydrogen and the need for extensive infrastructure development present challenges for keeping iron-making in Europe. One potential solution is a shift toward a secondary steel production model based on EAFs, which melt recycled steel and imported DRI. This approach, while requiring regulatory support for scrap use and clean energy mandates, offers an easier pathway for regions lacking access to cheap clean energy.

If it does not succeed in securing sufficient quantities of clean hydrogen in due time, Europe's future steel strategy will depend on whether it chooses to continue to rely on iron ore or to shift to dependence on hot briquetted iron (HBI) post-DRI. While the latter carries greater risk due to there being fewer suppliers, it offers a potential way forward for decarbonizing the steel sector in a post-carbon world.

SUMMARY OF RECOMMENDATIONS FOR AN INDUSTRIAL STRATEGY TO DECARBONIZE THE STEEL SECTOR IN EUROPE

Recommendation A

Implement a country-and sector-based average calculation method for carbon intensity within the CBAM. Even as a temporary measure, this approach would streamline verification and mitigate the risk of circumvention. Applying a standardized average methodology would prevent exporters from selectively sending only their cleanest products to Europe while failing to decarbonize the rest of the sector at large.

Recommendation B

The Renewable Fuels of Non-Biological Origin Directive (RFNBO) poses significant challenges to scaling up hydrogen-based steelmaking in the EU. Key regulatory hurdles include:

- **The prohibition on state aid in electricity production for clean hydrogen:** Projects receiving state aid for electricity production are not considered green.
- **Subsidies and carbon intensity:** A shift toward a carbon-intensity approach is needed to enable the use of all types of clean hydrogen in the transition phase, including nuclear-based hydrogen.

Recommendation C

Prioritize clean hydrogen for industrial sectors such as steel:

- The development and prioritization of hydrogen as a decarbonization vector for the industry are vital. The EU's hydrogen strategy aims to facilitate hydrogen pilot projects. However, high hydrogen pricing and access difficulties necessitate a strong regulatory framework to support this transition.
- **At this stage, priority must be given to the steel sector – and (petro)chemicals – in clean hydrogen supply**. This will enable it to launch market demand and decarbonize this sector faster than other sectors could.

Recommendation D

Enhancing energy efficiency and circular economy practices: Adapting to the post-carbon economy will require the steel industry to enhance its energy efficiency and shift toward circular economy practices. These include:

- **Electric arc furnaces:** Transitioning to secondary steel production models that focus on EAFs, which melt recycled steel and imported DRI, rather than relying heavily on hydrogen to reduce iron domestically.
- In the era of the CBAM, **steel scrap is a carbon asset**, and **Europe must adopt more stringent regulations to keep steel scrap in Europe** and recycle it on the Continent.

2 Strategies for Decarbonizing the Aluminum Sector

Aluminum production is responsible for around 2 percent of global greenhouse gas (GHG) emissions, particularly due to its reliance on energy-intensive processes such as electrolysis, which accounts for two-thirds of the sector's emissions. The global aluminum sector is highly dependent on electricity, and regions with access to clean energy sources have a competitive advantage in terms of decarbonizing production.

While aluminum is critical for sectors such as transportation, construction, and packaging, the carbon footprint of aluminum production is largely shaped by the electricity grid's carbon intensity, meaning that primary aluminum production tends to be located in regions with a lot of cheap electricity and with direct or easy access to bauxite (aluminum ore).

China, the world's largest aluminum producer, accounts for 60 percent of global production, with significant carbon emissions due to its reliance on coal-fired power. The country dominates global primary aluminum production, manufacturing around 41 million metric tons in 2023. In comparison, India produces about 4.1 million metric tons, followed by Russia with 3.8 million tons, and Canada with 3 million tons. Europe's contribution remains modest in comparison, with 1.22 million metric tons, South Korea produces 1.04 million metric tons, and Japan's output is negligible, producing only secondary aluminum.

KEY DECARBONIZATION METHODS

1. **Clean electrification:** Transitioning to clean electricity for the electrolysis process can greatly reduce the carbon footprint of aluminum production. Regions with access to clean energy sources such as hydropower are particularly well positioned to lead in low-carbon aluminum production.
2. **Inert anodes:** Replacing carbon anodes with inert anodes in the electrolysis process can eliminate direct CO_2 emissions. Although this technology is still in the early development stage, it holds significant potential for decarbonizing primary aluminum production. Several countries are banking on future technological breakthroughs to fully decarbonize the sector and gain a competitive edge in the emerging clean aluminum market.
3. **Carbon capture and storage (CCS):** While CCS is less suited for aluminum compared to other industrial sectors, some countries—including China—are exploring this option for reducing emissions in primary aluminum production.
4. **Enhanced recycling (secondary aluminum production):** Aluminum recycling requires only a fraction of the energy needed for primary production, making it a key strategy for decarbonizing the sector. Governments and companies are focusing on increasing recycling rates through better collection and sorting technologies and designing products that can be easily recycled at the end of their life cycles. Given aluminum's importance for future clean technologies, the ease of recycling, and the rise of carbon pricing and trade levies such as the CBAM, aluminum scrap is increasingly becoming a valuable carbon asset.

CHINA

China's dominance in aluminum production presents both an opportunity and a significant challenge for global decarbonization efforts. Aluminum production in China is heavily reliant on coal-powered electricity, accounting for 4.5 percent of the country's total GHG emissions. Decarbonizing this sector will require a significant overhaul, primarily shifting toward clean electricity and expanding recycling efforts. Despite the sector's carbon intensity, China is committed to maintaining its leadership in global aluminum production while reducing emissions.

China has implemented policies to curb blind expansion in aluminum smelting and incentivize the use of aluminum scrap, rather than relying on primary aluminum production. By limiting primary aluminum exports and encouraging the use of secondary aluminum, the country also aims to support its growing cleantech industries. Central to decarbonization efforts is the relocation of aluminum production to regions rich in clean electricity, particularly hydropower (such as Yunnan), which could substantially lower the carbon footprint of its aluminum production.

Key elements of China's strategy include the following:

- **Transition to renewable energy sources:** China aims to shift smelting operations from coal-reliant provinces to those powered by renewable energy, such as hydropower. The country is aiming for more than 25 percent of the energy used in aluminum electrolysis to come from renewable sources by 2025, rising to 30 percent by 2030.
- **Regulatory and financial incentives:** China's regulatory measures focus on phasing out inefficient smelting operations, controlling the expansion of aluminum production, and incentivizing recycling efforts. Furthermore, financial support from institutions such as the Bank of China is helping to finance projects aimed at reducing emissions and energy consumption, although these programs do not necessarily require carbon neutrality, which could limit their impact.
- **Technological advancements:** Technological innovation plays a crucial role in China's aluminum sector decarbonization strategy. The "14th Five-Year Plan" promotes the adoption of advanced aluminum electrolysis techniques and low-emission technologies. Efforts to develop more energy-efficient processes, as well as innovations in carbon anode technology, are part of the sector's future emissions reduction strategy.
- **Recycling initiatives:** China aims to increase the use of recycled aluminum, with a target of producing 11.5 million tons of recycled aluminum by 2025. Provincial governments are actively supporting the expansion of aluminum recycling initiatives, with provinces such as Henan setting strict capacity controls and production targets for scrap-based aluminum.
- **The Chinese Emissions Trading Scheme (ETS)** is slated to expand by 2025 to include aluminum production. This extension is vital for capturing indirect emissions from electricity consumption in aluminum smelting. The shift from an intensity-based system to an auction-based cap-and-trade model would effectively drive decarbonization in the sector, but probably not before 2030.
- **Impact of the EU Carbon Border Adjustment Mechanism (CBAM):** The CBAM's coverage of semifinished and finished products provides an opportunity for China to increase its exports of value-added aluminum products, which are currently exempt from the EU's carbon tariffs.

JAPAN

Japan's aluminum sector presents unique challenges and opportunities for decarbonization, primarily due to its reliance on imported primary aluminum. Domestically, Japan processes imported aluminum by melting and recycling it into finished products. Japan's decarbonization efforts are focused on increasing recycling rates and transitioning to clean energy for melting processes while trying to preserve scrap aluminum on the domestic market.

As aluminum plays an increasingly critical role in electric vehicles and renewable energy infrastructure, Japan must navigate a global market in which competition for low-carbon materials will intensify. Recycling and standardization are considered pivotal to creating a sustainable aluminum sector in the country.

The aluminum sector is supported by Japan's Green Innovation Fund, which promotes R&D in recycling, electrification, and CCUS. Stakeholders emphasize the need for further policy support through green procurement initiatives and ecodesign mandates to stimulate demand for low-carbon aluminum. A market for green aluminum has yet to be legislated, but efforts are underway to create benchmarks for low-carbon aluminum products.

Key elements of Japan's strategy include the following:

- **Energy transition for aluminum melting:** Japan is exploring electrification, hydrogen, ammonia, and CCUS technologies for the aluminum melting process. However, the feasibility of these strategies is hindered by Japan's limited clean energy resources and current technological advancements.
- **Carbon intensity of imports:** Japan imports primary aluminum, making decarbonization dependent on the carbon policies of exporting countries. A CBAM to mitigate emissions from imports is being considered. However, the implementation of such a policy is uncertain due to concerns about trade retaliation. The complexity of disclosing full life-cycle emissions from current primary aluminum imports adds further challenges.
- **Recycling rates and scrap management:** Japan boasts a high aluminum recycling rate, with 76 percent of waste aluminum recycled domestically, accounting for 48 percent of inputs. However, the recycling rate for wrought products remains low (10 percent), and 20 percent of aluminum scrap is exported, reducing domestic recycling resources. Increasing the recycling rate to 75 percent by 2050 is critical to reducing dependence on imported aluminum. The government is considering policies to preserve aluminum scrap for domestic use, although export restrictions are not yet in place.

SOUTH KOREA

South Korea's aluminum sector seeks to balance rising demand against decarbonization goals. Driven by growth in the automotive, electronics, and construction industries, aluminum demand is increasing, but domestic production remains limited, leading to heavy reliance on imports. The decarbonization of this sector is complicated by its high energy intensity and dependence on fossil-fuel-based electricity, making it difficult to reduce emissions without substantial investments in clean electrification, which are failing to materialize quickly.

The aluminum production process in South Korea is highly energy-intensive, and the sector relies on an outdated coal-intensive electricity grid. This creates high carbon emissions and necessitates costly investments in clean technologies that the sector is currently not making. South Korea imports a significant portion of its aluminum from countries with environmental regulations of varying strength, further complicating efforts to manage the carbon footprint of its supply chain.

The implementation of the EU CBAM poses an additional challenge for South Korean aluminum exports, as producers will face extra costs due to the carbon intensity of their products, potentially impacting the competitiveness of South Korean products in the European market.

While the government supports public–private partnerships and R&D, the aluminum sector has not been prioritized in South Korea's broader decarbonization agenda. The Carbon Neutral Green Growth Technology Innovation Strategy emphasizes decarbonizing steel, cement, and chemicals, with aluminum receiving limited attention. Furthermore, the sector's reliance on imports suggests that **future strategies may focus more on recycling and importing aluminum than on transforming domestic production processes**.

Key elements of South Korea's strategy include the following:

- **Hydrogen and clean electrification:** The government has focused on clean hydrogen and clean electrification to decarbonize aluminum production. However, the current carbon-intensive grid and lack of clean hydrogen access make it difficult to implement these strategies at scale.
- **Circular economy and aluminum recycling:** The government is promoting aluminum recycling as a low-carbon alternative to primary production, and South Korea is already a major importer of aluminum scrap. However, recycling infrastructure and technology still require further investment if they want to really be labeled as green, and the use of

plastic waste in recycling also poses environmental concerns.
- **Support for CCUS:** Investments are being made in R&D for CCUS technologies, with the aluminum sector positioned as a key beneficiary. However, CCUS is viewed as a long-term solution, with full implementation not expected before the 2040s.

EUROPE

Despite having a robust downstream value chain with over 600 plants across 30 countries, primary aluminum production has been in decline in Europe, with a 30 percent reduction in capacity since 2008, due mainly to high energy costs. Therefore, the EU relies heavily on imports, bringing in around 9.4 million tons of aluminum annually while producing just 2.2 million tons domestically. Europe is also a leading exporter of aluminum scrap, sending over 1.5 million tons abroad annually.

Although European aluminum production is relatively carbon-efficient, with emissions at 6.8 kg of CO_2 per kg of aluminum compared to the global average of 16.1 kg, there is substantial variation in emissions intensity across European countries due to differences in their energy mixes. Countries such as France and Norway, which use nuclear and hydropower, achieve much lower carbon intensities than others such as Germany and Italy, which rely on fossil fuels. This disparity highlights the importance of decarbonizing electricity grids as a key step in reducing the sector's overall carbon footprint.

Key elements of Europe's strategy include the following:

Clean Electricity Use and Electrification

The European Union has embedded decarbonization targets within its broader energy transition policies, particularly through the Renewable Energy Directive (RED III) and the Energy Efficiency Directive. These mandates aim to ensure that a larger portion of electricity used in aluminum production comes from renewable sources, with an annual increase of 1.6 percent until 2030 and a target of 42.5 percent renewable energy by 2030.

Energy efficiency is another key focus, with new rules requiring energy audits and management systems for high-consumption industries such as aluminum. These measures aim to reduce final energy consumption by 11.7 percent and increase annual energy savings by 1.9 percent by 2030.

Inert Anode Technology

Inert anode technology presents a frontier solution for decarbonizing aluminum production by replacing carbon anodes with inert materials, thus eliminating CO_2 emissions during the electrolysis process. While there is R&D support at both the EU and Member State levels, this technology remains in the developmental stage, with no large-scale demonstration projects yet operational.

Recycling and the Circular Economy

Europe has made significant strides in aluminum recycling, with a 51 percent recycling rate and a target of full circularity by 2030. The EU's Circular Economy Action Plan supports this goal by enhancing collection systems, ecodesign standards, and advanced recycling technologies. However, a considerable challenge is the export of aluminum scrap, which undermines the carbon-saving potential of recycling within Europe. The EU's Waste Shipment Regulation aims to address this by encouraging the retention of aluminum scrap for domestic recycling, but it has still to prove its effectiveness.

Key Challenges of the EU CBAM for the Aluminum Sector

The introduction of the CBAM is set to reshape the aluminum sector by imposing carbon costs on imports to the EU. Key suppliers will face higher carbon costs due to their carbon-intensive production processes. However, the CBAM will only cover direct emissions during its transitional phase, ignoring the significant indirect emissions from electricity use, which account for 62 percent of the sector's carbon footprint. This exclusion could result in partial decarbonization efforts and competitive disadvantages for European producers reliant on grid electricity.

Additionally, the focus on primary aluminum risks carbon leakage downstream in the value chain, as producers of semifinished aluminum products face increased costs. This could lead to production shifting outside the EU, where carbon regulations are less stringent. Resource shuffling and circumvention further complicate the CBAM's effectiveness, with non-EU countries potentially bypassing the mechanism by exporting "carbon-neutral" scrap or modifying production processes to avoid paying the carbon levy.

Europe's aluminum sector is on a complex decarbonization journey, shaped by a mix of ambitious policies, technological innovations, and structural challenges. The transition will require a continued focus on decarbonizing electricity grids, advancing frontier technologies such as inert anodes, and addressing the systemic challenges posed by global competition and carbon leakage. The CBAM, while a promising tool, will need refinements to capture the full carbon impact of aluminum production, especially with regard to indirect emissions and downstream products. Europe's success in decarbonizing aluminum will depend on coordinated efforts at both the EU and Member State levels, ensuring a competitive yet decarbonized industry.

SUMMARY OF RECOMMENDATIONS FOR A EUROPEAN INDUSTRIAL STRATEGY TO DECARBONIZE THE ALUMINUM SECTOR

Recommendation A

Extend Carbon Border Adjustment Mechanism Coverage and Enhance Monitoring

1. **Broaden the scope of the CBAM:** Expand the CBAM to include semifinished and selected finished aluminum products as soon as possible. This would capture a larger share of embedded emissions and prevent carbon leakage throughout the value chain.
2. **Simplify administrative procedures:** Develop streamlined procedures and clear guidelines for calculating embodied emissions in semifinished and finished products. This will reduce administrative burdens and compliance costs for businesses.
3. **Enhance monitoring and enforcement:** Strengthen monitoring and enforcement mechanisms to prevent circumvention of the CBAM and ensure that all relevant products are subject to it. This will help maintain a level playing field within the industry.
4. **Apply average electricity mix emissions factors:** To prevent the bypass of the CBAM by non-European producers, consider applying the average electricity mix emissions factor of the exporting country to the export data, even as a transitory measure. Although controversial, this approach could ensure a more accurate representation of the carbon footprint of imported aluminum products.

Recommendation B

Support for Research on and Deployment of Technology

1. **Increase funding for research on and deployment of low-carbon technologies:** Increase funding and support for the research, development, and deployment of low-carbon technologies. This includes financial incentives and regulatory support to accelerate the adoption of innovations such as **inert anodes and hydrogen-based processes**.
2. **Support the transition and competitiveness of the EU aluminum sector:** Implement complementary measures such as financial support for innovation, energy efficiency improvements, and transition assistance to help the industry adapt to the new regulatory environment.

Recommendation C

Promote Green Standardization for Aluminum

1. **Enhance recycling standards and competitiveness:** Address the challenge of standardization to meet CO_2 emissions targets. The aluminum sector has significant potential for GHG emissions reduction through increased recycling rates. **Ensure competitive pricing for green recycled aluminum** to prevent substitution by more carbon-intensive materials such as plastic in relevant applications. Establish fair standards to facilitate an equitable comparison between green recycled aluminum and its carbon-intensive counterparts.
2. **Support standardization in the downstream industry:** Promote standardization to create compatibility between green aluminum and steel and ensure fair pricing. As the Life-Cycle Assessment (LCA) methodology for green cars is expected to be established between 2024 and 2026, this will drive competition in the automotive market to reduce GHG emissions. **Public procurement** and **government support are needed** to support the green premium market and ensure fair competition **based on standardized measurements**.

Recommendation D

Bridging the Cost Gap

1. **Facilitate capital investments:** To support capital investments in the aluminum (and steel) industries for green premium goods, **government support through sizable public investments is crucial**.
2. **Adopt OPEX-support mechanisms during the transition period: This will help alter demand uncertainty** and encourage the adoption of green premium goods in the market.