Steel Decarbonization in China:

Provincial Implementation Strategies and the Path to Carbon Neutrality by 2060

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MIFUS Project
A Global Journey Through Steel Decarbonization

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This document represents a comprehensive update and expansion of the preliminary China steel policy analysis (C_ChinaSteelPolicyDeep01.pdf), incorporating October 2025 government policy drafts and recent provincial developments. The analysis was completed through human-AI collaboration between Prof. Fabio Miani and Anthropic's Claude system and DeepSeek.
The opinions presented here do not reflect those of any specific organization in Italy—specifically my own university—or abroad, and are presented solely for teaching purposes. Success probability assessments should be considered as illustrative scenarios rather than precise predictions.

Abstract

This comprehensive study analyzes China's steel decarbonization strategy through the critical lens of provincial implementation during the 15th Five-Year Plan period (2026-2030) and beyond to the 2060 carbon neutrality target. Building upon the preliminary MIFUS framework analysis, this document incorporates the transformative October 2025 draft policy on capacity replacement (implementing a strict 1.5:1 reduction ratio), recent developments in key steel-producing provinces (Hebei, Jiangsu, Shandong, Liaoning), and emerging strategies in Guangdong and Inner Mongolia.

China's approach represents the world's most ambitious industrial decarbonization program, encompassing approximately 1,065 million tonnes of annual crude steel production (54% of global output) and requiring coordinated transformation across diverse provincial contexts. The analysis reveals three fundamental operational pillars: (1) forced industrial consolidation through enhanced capacity swap mechanisms that mandate net capacity reductions, (2) comprehensive ultra-low emissions retrofitting creating a significant CO_2 penalty that paradoxically accelerates innovation, and (3) strategic piloting of breakthrough technologies including hydrogen-based direct reduction (H_2-DRI), carbon capture utilization and storage (CCUS), and expanded electric arc furnace (EAF) capacity.

Provincial analysis demonstrates striking divergence in implementation strategies based on local conditions. Hebei Province (225-250 Mt/a, 21-24% national share) faces the most severe transformation pressure due to Beijing proximity, pioneering HBIS Zhangjiakou's 1.2 Mt operational H_2-DRI facility with plans for 8-10 Mt by 2030. Jiangsu (120-130 Mt/a) pursues an EAF-centric pathway leveraging superior scrap availability and coastal infrastructure. Shandong (100-110 Mt/a) balances conventional BF-BOF optimization with selective H_2-DRI deployment. Liaoning (70-75 Mt/a) exploits China's lowest levelized cost of steel production through abundant renewable energy and nuclear power. Inner Mongolia emerges as the critical enabler, positioned to become China's green hydrogen production hub with pipeline infrastructure connecting to major steel provinces. Guangdong represents the high-value manufacturing integration model, linking steel transformation to advanced automotive and electronics sectors.

Investment requirements are extraordinary: RMB 2.0-2.5 trillion (approximately USD 280-350 billion) nationally through 2040, with Hebei alone requiring RMB 200-300 billion. Social dimensions are equally profound, with 300,000-500,000 direct steel jobs at risk nationally, necessitating comprehensive just transition programs encompassing retraining, early retirement, regional economic diversification, and social safety net strengthening.

Critical success factors include: achieving green hydrogen costs of RMB 8-12/kg by 2030 (from current RMB 18-25/kg), maintaining political will across economic cycles, developing extensive infrastructure (pipelines, electrolyzers, grid reinforcement, CO_2 storage), creating viable markets for green steel products, and managing social transitions without instability. Technology pathways show provincial specialization: Hebei and Liaoning lead H_2-DRI demonstration, Jiangsu and Guangdong expand EAF capacity, Shandong and Shanxi deploy CCUS on existing BF-BOF infrastructure.

The study contextualizes China's approach against global frameworks, particularly contrasting with Germany's hydrogen-focused strategy and EU's Carbon Border Adjustment Mechanism (CBAM). China's state-coordinated, market-enabled model treats steel decarbonization as a complex national engineering challenge requiring integrated technological, geographical, spatial, and institutional solutions rather than merely an environmental compliance issue. The October 2025 policy represents a decisive shift from incremental improvement toward structural transformation, with inter-provincial capacity trading eliminated by 2027 and replacement ratios uniformly set at minimum 1.5:1 (retirement:construction).

Scenario analysis projects three pathways: (1) "Green Steel Pioneer" (20-25% probability) achieving 60-70% national emissions reduction by 2040 through rapid H_2-DRI scaling; (2) "Managed Transformation" (50-55% probability) reaching 50-60% reduction with moderate delays and cost overruns; (3) "Troubled Transition" (20-25% probability) limited to 40-45% reduction if hydrogen economics fail or social instability emerges.

This research demonstrates that China's provincial steel transformation, with Hebei as the flagship case, constitutes the critical determinant of global steel sector emissions trajectories. Success would validate hydrogen steelmaking at commercial scale (40-60 Mt H_2-DRI capacity by 2035), eliminate 500-700 Mt CO_2 annually (15-19% of global steel emissions), and position China as green steel technology leader. Failure would undermine carbon neutrality credibility globally and suggest fundamental economic unviability of industrial decarbonization at scale. The next five years (2025-2030) are decisive, with HBIS Zhangjiakou scaling, hydrogen cost trajectories, and just transition program effectiveness becoming clear by 2028-2029.

Keywords: Steel decarbonization, China, hydrogen direct reduction, provincial policy, capacity replacement, Hebei, Jiangsu, Shandong, Liaoning, Inner Mongolia, Guangdong, carbon neutrality, 15th Five-Year Plan, HBIS Group, just transition, CCUS, EAF, green hydrogen

Contents

1 Introduction: China's Steel Decarbonization as Global Imperative

1.1 The Scale and Significance of China's Steel Sector

China's steel industry represents one of the most consequential industrial systems in human history, simultaneously embodying remarkable achievement and profound challenge. With approximately 1,065 million tonnes of crude steel production in 2024, China accounts for 54% of global output—more than the next 10 countries combined. This production scale supports China's urbanization, infrastructure development, and manufacturing prowess, but also generates approximately 2,300-2,500 Mt CO_2 annually, representing roughly 15% of global industrial CO_2 emissions and 18-20% of China's national emissions total.

The sector's transformation is thus not merely a Chinese domestic concern but a global climate imperative. If China fails to decarbonize steel, global Paris Agreement targets become mathematically unattainable. Conversely, successful transformation would eliminate nearly one-fifth of global industrial emissions while demonstrating technical and economic viability of green steel pathways at commercial scale.

This study analyzes China's approach through the granular lens of provincial implementation, recognizing that China's "big country strategy" necessitates differentiated regional pathways adapted to local conditions, resources, and industrial structures. The analysis builds upon the MIFUS (A Global Journey Through Steel Decarbonization) framework, which provides comparative context with global steel transformation efforts, particularly in Europe, Japan, and other major producing regions.

1.2 From Preliminary Analysis to Comprehensive Assessment

This document represents a radical expansion and update of the preliminary study "Steel Decarbonization in China's 15th Five-Year Plan Period: A Call for Collaborative Analysis" (C_ChinaSteelPolicyDeep0 November 2025). That initial work, produced through collaboration between human expertise and AI analytical systems, identified three operational pillars of China's approach:

1. **Forced industrial consolidation** through capacity swap mechanisms
2. **Ultra-low emissions (ULE) retrofitting** of existing infrastructure
3. **Strategic piloting** of breakthrough technologies

The current analysis substantially enhances this framework by incorporating:

October 2025 Government Policy Draft: The Ministry of Industry and Information Technology (MIIT) released draft "Implementation Measures for Capacity Replacement in the Steel Industry" for public comment in October 2025, representing the most significant policy evolution since 2021. Key provisions include:

- Stricter capacity replacement ratios: minimum 1.5:1 (retired:construction) vs previous 1.25:1-1.4:1
- Phase-out of inter-enterprise capacity trading by 2027, forcing genuine consolidation through mergers and acquisitions
- Enhanced restrictions on capacity transfers to "Key Regions" (Beijing-Tianjin-Hebei, Yangtze River Delta, Fen-Wei Plains)

- Special incentives for electric arc furnace (EAF) and hydrogen metallurgy development through equal replacement allowances
- Strengthened enforcement with 24-month project completion deadlines and automatic revocation for non-compliance

Provincial Deep-Dive Analysis: Detailed examination of implementation strategies, challenges, and progress in four major steel-producing provinces:

- **Hebei Province:** 225-250 Mt/a production (21-24% national share), facing most severe environmental pressure due to Beijing proximity, pioneering HBIS Zhangjiakou H_2-DRI demonstration at 1.2 Mt operational capacity
- **Jiangsu Province:** 120-130 Mt/a, pursuing EAF-centric strategy leveraging superior scrap availability and coastal access
- **Shandong Province:** 100-110 Mt/a, balancing conventional optimization with selective technology transformation
- **Liaoning Province:** 70-75 Mt/a, exploiting China's lowest levelized cost of steel (LCOS) through renewable energy advantages

Emerging Strategic Regions:

- **Inner Mongolia:** Positioned as China's green hydrogen production hub with abundant wind and solar resources, developing pipeline infrastructure to supply coastal steel provinces
- **Guangdong Province:** High-value manufacturing integration model linking steel transformation to advanced automotive and electronics sectors

Social and Employment Dimensions: Comprehensive analysis of just transition requirements, with 300,000-500,000 direct steel jobs at risk nationally and Hebei alone facing displacement of 150,000-200,000 workers.

Technology Pathway Economics: Detailed cost analysis of H_2-DRI, CCUS-equipped BF-BOF, and EAF routes, including critical hydrogen cost trajectories (current RMB 18-25/kg, target RMB 8-12/kg by 2030) and infrastructure investment requirements (RMB 2.0-2.5 trillion nationally through 2040).

1.3 Methodological Evolution and AI Collaboration

The preliminary study pioneered transparent integration of AI analytical capabilities (Anthropic Claude and Deepseek systems) with human academic expertise. This approach has evolved significantly:

Enhanced AI-Human Collaboration: The current analysis leverages Claude's advanced policy document processing, institutional mapping, and comparative analysis capabilities, augmented by systematic web search integration to capture October 2025 policy developments and recent provincial announcements. Human oversight ensures technical metallurgical accuracy, contextual interpretation, and strategic assessment.

Multi-Source Synthesis: Integration of:

- Official Chinese government policy documents (MIIT, NDRC, MEE)
- Provincial development plans and implementation reports
- Corporate sustainability disclosures (HBIS Group, China Baowu, etc.)
- Academic research on steel decarbonization technologies and economics
- Industry analysis from specialized consultancies and media
- International comparative frameworks (MIFUS Japan document, Germany analysis)

Validation through Peer Engagement: The preliminary document was shared on professional platforms (LinkedIn) to solicit expert feedback, criticism, and additional insights, embodying the "Call for Collaborative Analysis" approach.

1.4 Structural Organization of This Document

This comprehensive analysis is organized into modular sections designed for flexible assembly in Overleaf:

Part 1 (Current): Preamble, title page, abstract, and introduction establishing scope, methodology, and context

Part 2A (Next): Main body sections covering:

- Detailed analysis of October 2025 capacity replacement policy
- Provincial implementation strategies (Hebei, Jiangsu)
- Technology pathways and economic assessment

Part 2B (Following): Main body continuation:

- Provincial strategies continued (Shandong, Liaoning)
- Emerging regions (Inner Mongolia, Guangdong)
- Social and employment dimensions
- Infrastructure and investment requirements

Part 3: Conclusions, scenario analysis, strategic recommendations, and bibliography

Part 4: Appendices with detailed tables, provincial data, technology specifications, and comparative frameworks

Each part is designed as a standalone `.tex` file that can be saved separately and later combined, ensuring token efficiency and modular development.

1.5 Contextualizing China's Approach: Divergence from Global Narratives

The preliminary study identified a fundamental divergence between Chinese and European perceptions of steel. This observation bears expansion:

European Narrative: Steel as Legacy Burden In many European contexts, steel is increasingly framed as a "sunset industry"—environmentally problematic, economically marginal, and technologically stagnant. University metallurgy programs face declining enrollment. Industrial steel projects encounter local opposition and regulatory hurdles. Investment flows toward digital and service sectors. The very phrase "old economy" connotes steel as antithetical to innovation.

This narrative, while containing elements of truth regarding specific challenges, risks becoming self-fulfilling. If steel is treated as a legacy burden, the sector struggles to attract capital, talent, and political support necessary for transformation. Germany's hydrogen steel initiatives, while ambitious, operate within this constrained narrative space, requiring extraordinary political will to overcome prevailing skepticism.

Chinese Narrative: Steel as Strategic High-Technology Sector China approaches steel from a fundamentally different premise: steel remains central to national development, technological sovereignty, and strategic autonomy. This framing manifests in multiple dimensions:

1. **National Security:** Steel capacity viewed as strategic reserve, essential for infrastructure, military capability, and industrial resilience
2. **Technological Leadership:** Advanced steel grades for automotive, aerospace, and energy sectors positioned as innovation frontiers
3. **Integration with Future Industries:** Steel transformation linked to hydrogen economy development, renewable energy integration, and carbon management technologies
4. **Global Competitive Positioning:** Green steel capacity as future export advantage, anticipating CBAM and international environmental standards
5. **Employment and Social Stability:** Steel sector jobs valued for skilled industrial employment base and regional economic anchors

This divergence has profound implications:

- **Research Investment:** China sustains major steel R&D programs in universities and corporate laboratories; Europe allows capacity to atrophy
- **Talent Pipeline:** Chinese metallurgy programs remain robust and well-funded; European programs face existential challenges
- **Political Support:** Chinese steel transformation receives top-level government backing and coordination; European projects navigate complex multi-level governance and public skepticism
- **Capital Mobilization:** China channels state and private capital at massive scale; Europe relies on fragmented national programs and uncertain private investment

Implications for Global Collaboration Understanding this narrative divergence is essential for constructive international engagement. Collaborative research initiatives like MIFUS must navigate between these worldviews, finding common ground in technical challenges, shared environmental imperatives, and mutual interest in stable global markets. The risk is that incompatible narratives preclude meaningful cooperation precisely when global coordination is most needed.

1.6 Research Questions and Analytical Framework

This study addresses five core research questions:

1. **Policy Effectiveness:** How does China's October 2025 capacity replacement policy mechanism compare to market-based approaches (EU ETS, CBAM) in driving structural transformation?
2. **Provincial Differentiation:** What explains divergent provincial implementation strategies, and which models prove most effective for specific contexts?
3. **Technology Economics:** Under what conditions do H_2-DRI, CCUS-equipped BF-BOF, and EAF pathways achieve cost competitiveness, and what are critical breakeven thresholds?
4. **Social Transitions:** How can China manage employment displacement of 300,000-500,000 workers without triggering social instability that could derail transformation?
5. **Global Implications:** If China achieves stated decarbonization targets, what are consequences for global steel markets, technology diffusion, and climate goal attainability?

The analytical framework integrates:

- **Policy Architecture Analysis:** Mapping governance structures, policy instruments, and implementation mechanisms
- **Technology Pathway Assessment:** Evaluating technical maturity, economic viability, and scaling potential of alternative routes
- **Provincial Comparative Study:** Systematic comparison of strategies, resources, constraints, and outcomes across regions
- **Social Impact Analysis:** Quantifying employment effects and assessing just transition program adequacy
- **Scenario Modeling:** Projecting outcomes under optimistic, baseline, and pessimistic assumptions
- **Global Contextualization:** Comparing Chinese approaches with European, Japanese, and other national strategies

1.7 Critical Success Factors: Preview of Key Findings

The comprehensive analysis reveals six critical determinants of transformation success:

1. **Hydrogen Cost Trajectory:** Achieving RMB 8-12/kg green hydrogen by 2030 is non-negotiable. Current costs of RMB 18-25/kg render green steel economically unviable without massive subsidies. This requires: renewable electricity at RMB 0.20-0.25/kWh, electrolyzer capital cost reductions of 50-60%, and infrastructure scale economies.
2. **HBIS Zhangjiakou Demonstration Success:** The 1.2 Mt H_2-DRI facility represents China's most advanced project and the critical technology validation case. Successful scaling to 5-10 Mt by 2028-2030 would prove commercial viability and provide replication blueprint for other provinces. Failure would force reliance on slower CCUS pathways.

3. **Infrastructure Development Pace:** Required by 2030: 20-30 GW electrolyzers, 2,000+ km hydrogen pipelines, 50+ GW additional renewable energy capacity, CO_2 transport and storage infrastructure. Any 3-5 year delays cascade throughout system, jeopardizing targets.

4. **Political Will Sustainability:** Maintaining transformation pressure through economic downturns, leadership transitions, and competing priorities. Hebei's 50 Mt capacity reduction (20% of base) creates severe GDP and employment shocks that could trigger policy reversal if political commitment weakens.

5. **Just Transition Program Delivery:** Re-employing 65-70% of displaced workers within 24 months, maintaining 80%+ income levels, providing generous early retirement, and creating alternative employment through economic diversification. Program failure risks social instability that could halt transformation.

6. **Green Steel Market Creation:** Ensuring demand exists for 40-50 Mt green steel production by 2030 through: domestic procurement mandates (government infrastructure projects), automotive sector commitments (Great Wall Motors, Geely, BYD, NIO), construction sector adoption, and CBAM-compliant exports. Without viable markets, producers revert to conventional production despite capacity constraints.

1.8 Document Structure and Reading Guide

For readers with specific interests:

Policy and Governance: Focus on Section 2 (October 2025 policy analysis) and Section 3.1 (institutional framework)

Technology and Economics: Prioritize Section 4 (technology pathways), Section 5 (provincial strategies with technology focus), and Section 7 (cost analysis)

Social and Employment: See Section 8 (just transition analysis) and provincial sections' employment subsections

Provincial Implementation: Section 5 provides detailed case studies of Hebei, Jiangsu, Shandong, Liaoning, with Section 6 covering Inner Mongolia and Guangdong

Global Context and Comparison: Section 9 contrasts Chinese approaches with Germany, Japan, and EU frameworks

Strategic Assessment: Section 10 (scenario analysis) and Section 11 (conclusions and recommendations)

1.9 Acknowledgments and Collaborative Research Philosophy

This research embodies the "Call for Collaborative Analysis" philosophy articulated in the preliminary study. Steel decarbonization challenges transcend individual expertise, national boundaries, and traditional research methodologies. Solutions require integration of:

- Metallurgical engineering and process technology expertise
- Energy systems analysis and renewable integration

- Policy analysis and governance assessment
- Economic and financial evaluation
- Social science and labor market dynamics
- Regional development and spatial planning
- Environmental science and climate policy

The AI-human collaborative approach pioneered here represents one experimental methodology for addressing such complexity. Anthropic Claude's capabilities in processing large policy documents, maintaining consistency across extensive analysis, performing systematic comparisons, and generating structured frameworks complement human expertise in contextual interpretation, strategic judgment, technical validation, and creative synthesis.

This document remains a work in progress, welcoming critical engagement from:

- Chinese researchers and policy analysts with ground-level implementation insights
- International steel sector experts offering comparative perspectives
- Metallurgists and engineers assessing technical feasibility claims
- Economists evaluating cost projections and market assumptions
- Social scientists examining just transition approaches
- Climate policy specialists contextualizing within global decarbonization frameworks

Constructive criticism, corrections, and collaborative refinement are essential to advancing understanding of this globally consequential transformation.

2 National Policy Framework for Steel Decarbonization (2024-2025)

2.1 The Special Action Plan for Energy Conservation and Carbon Reduction

In May 2024, the Chinese government issued the *Special Action Plan for Energy Conservation and Carbon Reduction in the Steel Industry*, representing the most comprehensive policy framework for steel sector decarbonization during the 14th Five-Year Plan (FYP) period. The plan establishes ambitious quantitative targets for the 2024-2025 timeframe, aimed at achieving the emissions reduction commitments under China's dual carbon goals.

The Special Action Plan sets a primary objective to reduce carbon dioxide (CO_2) emissions by approximately 53 million tonnes between 2024 and 2025 compared to 2023 levels. This reduction target is accompanied by specific energy efficiency improvements: a 2% reduction in energy consumption per tonne of steel compared to 2023 levels, and an increase in self-generated waste heat and pressure utilization by at least 3%. Additionally, the plan targets a reduction of 20 million tonnes of standard coal consumption over the same period.

The policy operates through two principal mechanisms:

2.1.1 Capacity Regulation and Output Management

The first pillar involves strengthening capacity regulation through several measures. The plan mandates the elimination of outdated production capacity, prohibits the addition of new steel capacity under the guise of mechanical processing or casting operations, and implements strict controls on crude steel output. This represents a continuation and intensification of China's long-standing efforts to address overcapacity in the steel sector, now explicitly linked to carbon reduction objectives.

A significant policy development occurred in August 2024 when the Ministry of Industry and Information Technology (MIIT) suspended approvals for new steelmaking production projects. This suspension was implemented to allow for a comprehensive review of the capacity replacement policy that had been in place since 2014. The capacity replacement policy had previously required steelmakers to offset new production projects by retiring outdated equipment at ratios of 1.5:1 for blast furnace (BF) capacity and 1:1 for electric arc furnace (EAF) capacity.

Notably, during the first half of 2024, no new coal-based steelmaking facilities were permitted for the entire half-year period. From January to June 2024, provincial governments approved only 7.1 million tonnes per annum of new steelmaking capacity, all of which were EAF projects. This marked the first half-year period with no coal-based Basic Oxygen Furnace (BOF) approvals since China announced its dual carbon goals in September 2020, representing a potential turning point for decarbonization in the Chinese steel industry.

2.1.2 Transition to Electric Arc Furnaces

The second fundamental pillar of the Special Action Plan emphasizes the development and deployment of EAF technology to replace the blast furnace-basic oxygen furnace (BF-BOF) steelmaking route. The plan sets a target to increase the share of EAF-produced steel from the current 10% to 15% by 2025, with a longer-term objective of reaching 20% by 2030.

This transition strategy is premised on securing sufficient scrap steel as the primary feedstock for EAF production. China's steel industry is heavily reliant on BF technology, which uses iron ore, coal, and coke as primary inputs. These resources account for approximately 90% of the industry's energy consumption. In comparison, the EAF approach primarily relies on scrap steel as the main feedstock, reducing emissions by up to 70% per tonne of steel produced compared to the BF-BOF route.

According to analysis by the Centre for Research on Energy and Clean Air, if EAF achieves a 15% share while steel production declines by 1% between 2024 and 2025, China's steel industry emissions could decline by 3%. This would translate into CO_2 emissions levels in 2025 being more than 200 million tonnes lower than the emissions peak recorded in 2020.

However, implementation has faced significant challenges. Despite policy support, EAF production has continued to hover around 10% through the first half of 2025, with utilization rates and profitability under sustained pressure. The primary constraint has been the availability and quality of scrap steel. China's scrap consumption in 2024 amounted to 214 million tonnes, but only approximately 30% of this volume was used in electric steel production, with a significant portion going to BOF operations together with pig iron.

2.2 Integration into the National Carbon Emissions Trading System

A critical policy development for the steel industry is its planned integration into China's national Emissions Trading System (ETS). According to the *Work Plan for National Carbon Emissions Trading Market Covering Cement, Steel, and Primary Aluminum Sectors* (Draft for Public Comments) issued by the Ministry of Ecology and Environment in September 2024, the steel industry entered its first year of control in 2024 and will complete its first compliance cycle by 2025.

The expansion of the ETS to include steel represents a significant shift in carbon pricing policy. As of 2024, China's national carbon market included 2,162 power companies, representing 99.5% of all market participants. From 2022 to 2024, total quota trading volume reached 634 million tonnes, with a cumulative market value of USD 6.06 billion. This included 188 million tonnes traded in 2024 alone, valued at USD 2.52 billion.

Carbon prices in the Chinese ETS have shown an upward trend, more than doubling in less than three years to exceed 100 RMB per tonne CO_2 (approximately USD 14) in May 2024. In March 2025, Chinese Certified Emission Reductions (CCER) credits from the voluntary market surged to 107 RMB (USD 14.8) per tonne, about 21% higher than the mandatory carbon allowance prices.

For the steel sector, which accounts for approximately 17% of China's total CO_2 emissions, integration into the ETS will introduce carbon costs as a key competitive factor. Initially, emission allowances will be allocated to steel companies free of charge, following the model used for the power sector. However, the total quota is expected to be reduced over time, leading to an increase in the price of emissions and strengthening the economic incentive for decarbonization.

The ETS integration is complemented by differentiated electricity tariffs based on environmental performance. Higher electricity tariffs are being introduced for steel companies with Class C and D environmental performance ratings. These combined mechanisms are designed to accelerate the industry's transition toward low-carbon production methods.

2.3 Policy Targets and Implementation Challenges

The Chinese government has established a comprehensive set of targets for steel sector decarbonization, extending beyond the immediate 2024-2025 timeframe. Following President Xi Jinping's pledge in September 2020 for China to peak carbon emissions before 2030 and achieve carbon neutrality by 2060, specific sectoral targets have been developed.

The official target for the steel sector is to peak emissions before 2030, a timeline that was less ambitious than an earlier draft that aimed for peak emissions by 2025 and a 30% emissions reduction by 2030. Nevertheless, this more stringent target has been backed by the China Iron and Steel Association and mentioned by the Coking Industry Association in their emissions peaking plans, suggesting that the industry may still be guided by these more ambitious objectives as unofficial targets.

Additional targets for 2025 include:

- Achieving ultra-low emission retrofits for more than 80% of steel production capacity
- Reducing energy intensity by more than 2% per tonne of steel compared to 2020 levels
- Increasing the proportion of energy-efficient capacity meeting benchmark levels to 30% or more
- Expanding the use of waste heat and pressure recovery systems

However, implementation faces several significant challenges. First, overcapacity remains a persistent issue despite decades of policy interventions. While the capacity replacement policy has led to modernization and consolidation, it has not prevented continued expansion in many regions. The use of more efficient technologies through capacity replacement has resulted in increased steel production without commensurate increases in nominal capacity.

Second, economic pressures have intensified. The steel sector's profitability has declined sharply, with average net profit margins for steel enterprises falling to 0.71% in 2024, a year-on-year decrease of 0.63% according to the China Iron and Steel Association. Total profits dropped from 85.5 billion RMB in 2023 to 42.9 billion RMB in 2024, far below the investment needed for comprehensive decarbonization. This financial pressure makes it challenging for companies to invest in low-carbon technologies that typically require substantial capital expenditure and have extended payback periods.

Third, the ongoing property crisis in China has reduced downstream demand for steel, particularly for construction-related products. This has prompted many steel companies to adjust their product mix toward higher-value products like precision machinery parts and automotive materials, but this shift focuses more on extending production chains than embracing low-carbon technologies.

2.4 Circular Economy Integration: The Trade-In Program

The Special Action Plan is designed to work in tandem with China's national program for promoting large-scale equipment upgrades and trade-ins of old consumer goods (Trade-in Program). This integration represents an attempt to create a circular economy ecosystem where supply-side and demand-side measures reinforce each other.

The Trade-in Program aims to stimulate consumer demand while simultaneously increasing the supply of scrap steel, which is essential for EAF expansion. Within the first six months of implementation, applications for scrap-vehicle recovery exceeded 680,000 units. Nationwide, scrap-vehicle recovery reached 3.6 million units between January and July 2024, up 37.4% year-on-year.

Government support mechanisms include subsidies and tax deductions for scrap sales, which have reduced operational costs and rendered the recycling business more economically viable. The theory underlying this policy integration is that the increase in scrap steel supply driven by the Trade-in Program will directly support the expansion of EAF capacity mandated by the Special Action Plan, enabling the industry to meet its decarbonization targets while simultaneously addressing overcapacity through demand-side stimulus.

Major steel producers have begun to adapt their business models to this circular economy approach. China Baowu Steel Group, the world's largest steelmaker, has developed ultra-low-carbon cold-rolled and hot-dip-galvanized products for automotive use, utilizing scrap and EAF processes that reduce carbon emissions by over 60%. This aligns with Baowu's 2021 decarbonization roadmap, which commits to reducing steelmaking carbon emissions by 30% between 2020 and 2035.

Similarly, Ansteel Group has made significant progress in producing low-carbon automotive steel. The company announced in 2024 that it has achieved stable mass production of long-process automotive steel that reduces carbon emissions by 30%. These examples demonstrate that leading Chinese steel companies are actively working to integrate low-carbon production methods with market demand for sustainable materials.

2.5 Financing Mechanisms and Transition Finance

The transition to low-carbon steel production requires substantial capital investment. Estimates suggest that nearly 3.5 trillion RMB will be needed for China's iron and steel industry to reach peak carbon emissions, with achieving carbon neutrality requiring an additional 19 trillion RMB. Advanced steel production processes like scrap-EAF, direct reduced iron (DRI)-EAF, and carbon capture and storage (CCS) technologies have high costs due to expensive construction and limited economies of scale at present.

Traditional green finance instruments, designed primarily for renewable energy and other inherently "green" sectors, are not well-suited for high-emissions, high-energy-consumption industries like steelmaking. This financing gap has led to the development of transition finance as a distinct category. Transition finance addresses the broader needs of industries undergoing decarbonization, helping these sectors manage funding gaps and facilitate industrial emission reduction and efficiency optimization.

At the national level, the People's Bank of China and relevant agencies are developing a comprehensive transition finance catalogue targeting high-emitting industries, with the steel sector as a key focus. This national framework is being informed by subnational pilots and initiatives.

The scale of transition finance remains significantly smaller than green finance. By the end of 2024, the cumulative issuance of green bonds in China reached 4.16 trillion RMB, while transition bonds accounted for only 215.42 billion RMB, approximately 5.18% of the green bond total. This discrepancy is misaligned with the reality of China's low-carbon transition, given that approximately 90% of national GDP comes from industries that are not purely "green" and require transition finance rather than traditional green finance.

3 The October 2025 Capacity Replacement Policy: A Paradigm Shift

3.1 Policy Evolution and Strategic Intent

The October 2025 draft *Implementation Measures for Capacity Replacement in the Steel Industry* represents a qualitative intensification of China's capacity governance approach, building upon but substantially strengthening the 2021 measures. Released by the Ministry of Industry and Information Technology (MIIT) for public comment with a deadline of November 23, 2025, this policy framework crystallizes China's determination to achieve absolute capacity reduction while simultaneously accelerating technological transformation.

The policy's strategic objectives extend beyond simple environmental compliance, targeting three interconnected goals:

1. **Absolute Capacity Reduction**: Net reduction of national steel capacity through stricter replacement ratios
2. **Technology Transformation**: Incentivizing shift toward electric arc furnaces (EAF) and hydrogen metallurgy
3. **Industrial Consolidation**: Forcing mergers and acquisitions through elimination of inter-enterprise capacity trading

3.2 Key Policy Mechanisms and Changes from 2021

3.2.1 Replacement Ratio Intensification

The policy establishes a hierarchical replacement ratio structure:

- **Standard Ratio**: $\geq 1.5 : 1$ (retired capacity : construction capacity)
  - For every 1 tonne of new capacity, at least 1.5 tonnes of old capacity must be permanently retired
  - Represents 33% net reduction per replacement transaction
- **Merger & Acquisition Exception**: $\geq 1.25 : 1$
  - Applies only to substantive M&A completed after June 2021

  - Requires legal, equity, and operational integration
  - Still mandates 20% net reduction
- **Equal Replacement (1:1)**: Three qualifying categories
  1. On-site major overhauls with no change in equipment type/capacity
  2. Special EAF processes for high-end specialty steel
  3. Projects in Qinghai and Tibet (recognizing unique regional circumstances)

This contrasts sharply with the 2021 policy's more permissive ratios (ranging from 1.1:1 to 1.5:1) and represents an approximately 20-30% intensification of capacity reduction pressure.

3.2.2 Prohibition of Inter-Enterprise Capacity Trading

The most structurally significant change addresses capacity trading mechanisms:

- **Before 2027**: Inter-enterprise capacity replacement allowed nationwide
- **From 2027 onward**: Inter-enterprise replacement *prohibited*
- **Permitted post-2027**: Only mergers & acquisitions or intra-group transfers
- **Rationale**: "Capacity and equipment must correspond one-to-one; no separation allowed"

This prohibition fundamentally transforms industry structure by:

1. Eliminating the capacity trading market that previously allowed small, inefficient producers to monetize retirement by selling capacity rights
2. Forcing genuine consolidation through M&A rather than financial transactions
3. Preventing wealthy producers from accumulating capacity rights without retiring their own equipment
4. Ensuring actual equipment retirement rather than paper transactions

3.2.3 Low-Carbon Technology Incentives

Article 11 introduces unprecedented incentives for breakthrough technologies, allowing equal replacement (1:1 ratio) for:

1. **Converter + Blast Furnace to EAF Conversion**
   - Retiring both converters and blast furnaces to build EAFs
   - Recognizes complete process transformation
   - Major incentive for fundamental infrastructure change
2. **EAF-to-EAF Replacement**
   - Modernizing existing EAF operations
   - Supports scrap-based production enhancement
3. **Hydrogen Ironmaking ($\geq$ 60% Carbon Reduction)**
   - Applies when hydrogen-based DRI achieves $\geq$ 60% emissions reduction vs conventional blast furnace
   - Critical threshold recognizes both natural gas-based and green hydrogen routes
   - Provides pathway for H2-DRI demonstration and scaling

3.3 Regional Restrictions and Environmental Priorities

3.3.1 Key Regions Definition

The policy designates specific regions for maximum restriction (Article 9):

- **Beijing-Tianjin-Hebei (Jing-Jin-Ji)**
- **Yangtze River Delta**
- **Fen-Wei Plain**
- **Yangtze River Economic Belt**: Special restrictions on new projects outside compliant industrial parks

These regions face:

- No net capacity increase permitted
- No inbound capacity transfers from other regions
- Provinces with national capacity caps cannot accept external transfers

3.3.2 Environmental Justice Rationale

The regional restrictions reflect explicit environmental justice and air quality priorities:

1. Beijing-Tianjin-Hebei suffers China's most severe air pollution, with steel contributing significantly to PM2.5 and NOx
2. Yangtze River Delta hosts China's most economically valuable urban agglomerations, where air quality directly affects hundreds of millions
3. These restrictions force production capacity shift toward coastal areas with better environmental capacity and logistics efficiency

3.4 Implementation Timeline and Enforcement

3.4.1 Project Timeline Restrictions

The policy introduces strict temporal controls (Articles 18-19):

- **24-Month Validity**: Approved capacity replacement plans must commence construction within 24 months
- **Automatic Revocation**: Plans not implemented within timeline are automatically void
- **No Extensions**: Policy explicitly prevents indefinite holding of replacement rights

3.4.2 Mandatory Equipment Dismantling

Critical enforcement mechanism requires:

- Retired equipment must be physically dismantled before new production commences
- Provincial acceptance inspections verify actual equipment removal
- Photographic and site documentation required
- Prevents simultaneous operation of old and new capacity

3.5 Quantitative National Impact Projections

Based on provincial capacity distributions and policy ratios, projected national impacts through 2030:

Table 1: Projected National Steel Capacity Under 1.5:1 Policy (2024-2030)

Metric	2024 Baseline	2030 Target	Change (%)
Total Capacity (Mt)	1,100-1,150	950-1,000	-13 to -17%
BF-BOF Capacity (Mt)	950-1,000	600-650	-35 to -40%
EAF Capacity (Mt)	140-160	320-360	+114 to +129%
H2-DRI Capacity (Mt)	1-2	20-30	+900 to +2,900%
Emissions (Mt CO_2)	**2,100-2,200**	**1,500-1,650**	**-25 to -33%**

Key Observations:

- Absolute capacity reduction of 100-200 Mt (9-17% of 2024 levels)
- Dramatic technology mix transformation: BF-BOF from 87% to 60-65% share
- EAF share increases from 13% to 32-36%
- If targets achieved, China's steel emissions would decline by 500-700 Mt CO_2 annually
- This single-sector reduction exceeds total annual emissions of Germany or Japan

3.6 Policy Challenges and Implementation Risks

3.6.1 Provincial GDP Dependencies

The policy's success depends on overcoming entrenched local economic interests:

- **Hebei Province**: Steel accounts for 15-20% of provincial GDP, employs 600,000-800,000 workers directly
- **Shanxi, Shandong, Liaoning**: Similar structural dependencies create resistance
- **Central-Local Tension**: Beijing mandates conflict with provincial employment and fiscal revenue priorities

3.6.2 Scrap Availability Constraints

The policy's emphasis on EAF expansion faces fundamental material limits:

- **2024 Scrap Availability**: Approximately 260-280 Mt nationally
- **2030 EAF Requirement**: If 320-360 Mt EAF capacity operates at 90% utilization, requires 288-324 Mt scrap (or DRI substitute)
- **Gap**: Even with aggressive collection improvements (target 320 Mt scrap by 2025), near-complete utilization of available scrap required
- **Quality Challenge**: Automotive and high-grade steel applications require premium scrap, potentially limiting EAF product mix

3.6.3 DRI Supply Chain Development

The hydrogen DRI incentives depend on supply chains that barely exist:

- **Current Global DRI Capacity**: Approximately 130 Mt, predominantly natural gas-based in Middle East and India
- **China's H2-DRI Capacity (2024)**: < 2 Mt (primarily HBIS Zhangjiakou demonstration)
- **Required Growth**: To support 20-30 Mt H2-DRI usage by 2030 requires 10-15x capacity expansion in 5 years
- **Green Hydrogen Availability**: Currently < 100,000 tonnes/year production; need exceeds 2-3 Mt/year for steel sector

3.6.4 Enforcement Consistency

Historical precedents raise concerns about policy implementation rigor:

- Previous capacity policies saw widespread evasion through "zombie capacity" (reported as retired but maintained)
- Local governments sometimes prioritized GDP over environmental compliance
- Economic downturns previously triggered policy relaxation
- The 2027 inter-enterprise trading ban may face intense lobbying for extension or modification

3.7 International Comparative Context

China's 1.5:1 policy represents the world's most aggressive mandatory capacity reduction mechanism:

Table 2: International Steel Capacity Governance Comparison

Region	**Mechanism**	**Stringency**	**Enforcement**
China	Mandatory 1.5:1 replacement ratio	Very High	State directive with provincial implementation
European Union	Market-driven through ETS carbon pricing	Moderate	Market mechanism + regulatory oversight
Japan	Voluntary industry coordination	Low-Moderate	Industry self-regulation
United States	No federal capacity policy	Very Low	Market forces only
India	Informal government guidance	Low	Limited enforcement

Observation: China's approach trades economic flexibility for environmental certainty, reflecting different governance models and climate commitment mechanisms.

4 Provincial Implementation Strategies: Divergent Pathways

4.1 Framework for Provincial Analysis

China's provincial steel landscapes exhibit extraordinary diversity in production scale, technology mix, economic structure, and decarbonization potential. This section examines four critical provinces—Hebei, Jiangsu, Shandong, and Liaoning—representing distinct transformation pathways, plus emerging developments in Guangdong and Inner Mongolia.

4.1.1 Analytical Dimensions

Provincial analysis considers:

1. **Production Scale and Technology Mix**: Current capacity, BF-BOF vs EAF distribution
2. **Economic Dependency**: Steel's contribution to provincial GDP and employment
3. **Environmental Pressure**: Air quality status, proximity to population centers, political urgency
4. **Infrastructure Enablers**: Scrap availability, renewable energy access, hydrogen potential, grid capacity
5. **Cost Competitiveness**: Levelised Cost of Steel (LCOS) for different technology pathways
6. **Policy Implementation Capacity**: Provincial government resources and political will

4.2 Hebei Province: The Heavy Lifting Province

4.2.1 Strategic Position and Challenge Scale

Hebei Province represents the epicenter of global steel decarbonization:

Production Profile:

- Annual capacity: 225-250 Mt (21-24% of China, 12-13% of world)
- Current technology: 92% BF-BOF, 8% EAF
- Annual emissions: 500-550 Mt CO_2 (15% of China's industrial emissions)
- Direct employment: 600,000-800,000 workers

The Quadruple Crisis:

1. **Environmental Emergency**: Surrounds Beijing; PM2.5 levels frequently exceed standards 3-5x
2. **Economic Dependency**: Steel contributes 15-20% of provincial GDP
3. **Technology Lock-in**: Aging BF infrastructure averaging 15-20 years old
4. **Social Stability Risk**: Capacity reduction threatens 150,000-200,000 jobs

4.2.2 Hebei's Transformation Strategy: Hydrogen-Centered

Unlike Jiangsu's EAF focus, Hebei pursues hydrogen direct reduction:

HBIS Zhangjiakou H2-DRI Demonstration:

- **Phase 1 (Operational 2023)**: 1.2 Mt/year capacity
- **Hydrogen Source (Current)**: Grey hydrogen from coke oven by-products (60,000-80,000 tonnes H_2/year)
- **Emissions Benefit**: 50% CO_2 reduction vs conventional BF-BOF (1.1-1.2 vs 2.2 t CO_2/t steel)
- **Green Hydrogen Transition (2027-2030)**:
  - Target: 200,000-300,000 tonnes green H_2/year
  - Electrolyzer capacity: 3-5 GW (alkaline and PEM)
  - Renewable source: Zhangjiakou renewable energy zone + Inner Mongolia imports
  - Cost target: RMB 12-15/kg (2027) declining to RMB 8-10/kg (2030)
- **Scaling Plan**: 8-10 Mt provincial H2-DRI capacity by 2030

Projected Technology Mix 2030:

Table 3: Hebei Province Steel Technology Evolution

Technology	2024	2030	2035	2050
BF-BOF (conventional)	92%	60%	30%	0%
BF-BOF with CCUS	0%	15%	35%	15%
H2-DRI-EAF	1%	15%	25%	60%
Scrap-based EAF	7%	10%	10%	25%
Total Capacity (Mt)	**250**	**200**	**180**	**150-160**

4.2.3 Critical Success Factors and Risks

Success Factors:

- **Political Will (Very High)**: Beijing proximity ensures maximum pressure and oversight
- **Technical Demonstration**: HBIS Zhangjiakou proving H2-DRI viability at commercial scale
- **Renewable Access**: Zhangjiakou designated National Renewable Energy Demonstration Zone, target 30 GW wind/solar by 2030
- **Financial Resources**: RMB 200-300 billion provincial + national support allocated

Critical Risks:

- **Hydrogen Cost (High Risk)**: Current green H_2 at RMB 18-25/kg makes steel uncompetitive; requires 50-60% cost reduction
- **Infrastructure Delays (Medium-High Risk)**: Hydrogen pipelines, electrolyzers, grid upgrades face 3-5 year timelines

- **Social Unrest (Medium Risk)**: 150,000-200,000 job losses require RMB 60-90 billion just transition programs
- **GDP Pressure (Medium Risk)**: 15-20% provincial GDP from steel creates political resistance

Assessment: Hebei's success probability approximately 50-55% for "Managed Transformation" scenario (60-65% emissions reduction by 2040), with 20-25% probability of "Green Steel Pioneer" outcome (70%+ reduction) and 20-25% risk of "Troubled Transition" ($<50\%$ reduction).

4.3 Jiangsu Province: The EAF Transformation Leader

4.3.1 Strategic Advantages for Scrap-Based Pathway

Jiangsu represents the polar opposite approach to Hebei:

Production Profile:

- Annual capacity: 119-121 Mt (11-12% of China)
- Current technology: 82% BF-BOF, 18% EAF
- Target 2030: 40-45% BF-BOF, 55-60% EAF
- Current emissions: 240-260 Mt CO_2/year

Comparative Advantages:

1. **Lower Steel Dependency**: Steel contributes only 5-8% of provincial GDP (vs 15-20% Hebei)
2. **Scrap Availability**: 28-38 Mt currently available, expandable to 60-71 Mt by 2030
    - Manufacturing scrap from automotive/appliances/machinery: 12-15 Mt
    - End-of-life vehicles: 4-6 Mt (expandable to 12-14 Mt)
    - Construction/demolition: 5-7 Mt (expandable to 10-12 Mt)
    - Scrap imports via Shanghai/Nanjing ports: 4-6 Mt (expandable to 12-14 Mt)
3. **Grid Infrastructure**: 150+ GW installed capacity, one of China's most reliable grids (99.9% uptime)
4. **Renewable Electricity**:
    - Offshore wind: 12 GW (2024) → 25 GW (2030)
    - Distributed solar: potential for 2-3 GW dedicated to steel sector
    - Western China renewable imports via ultra-high voltage transmission
    - Target: 80-100 TWh renewable electricity for steel sector by 2030
5. **Coastal Location**: Port access enables efficient scrap imports and finished steel exports

4.3.2 Jiangsu Shagang Group: Provincial Champion

Jiangsu's transformation centers on its flagship producer:

- **Production**: 41.45 Mt annually (Global Rank #6, China's largest private steelmaker)
- **Current EAF Share**: Approximately 20%
- **Target 2030**: 70% EAF share
- **Strategic Advantages**:
  - Private ownership enables faster decision-making vs state-owned enterprises
  - Known for cost efficiency and operational flexibility
  - Active Environmental Product Declaration (EPD) certification leadership
  - Preparing for EU CBAM compliance and green steel premium markets
- **Decarbonization Approach**:
  - Focus on scrap-based EAF expansion rather than hydrogen DRI
  - Closed-loop recycling partnerships with automotive and appliance sectors
  - Investments in advanced scrap processing and sorting technology (RMB 3-5 billion)
  - Long-term renewable electricity Power Purchase Agreements

4.3.3 Cost Competitiveness Analysis

Jiangsu's EAF pathway offers substantial cost advantages over hydrogen routes:

Table 4: Levelised Cost of Steel (LCOS) Comparison - 2030 Projections

Technology & Location	Capital ($/tonne)	Operating ($/tonne)	Total LCOS ($/tonne)
Jiangsu - EAF (grid mix)	350	380	730
Jiangsu - EAF (renewable)	380	400	780
Jiangsu - H2-DRI	950	450	1,400
Hebei - H2-DRI	1,100	480	1,580
Germany - H2-DRI	1,200	520	1,720
Liaoning - H2-DRI (lowest China)	900	410	1,310

Key Insights:

- Jiangsu EAF offers 55-60% cost advantage over Hebei H2-DRI
- Even renewable-powered EAF (LCOS $780) significantly cheaper than H2-DRI routes
- Capital cost for EAF ($350-380/t) is 60-70% lower than H2-DRI ($900-1,200/t)
- Jiangsu's renewable EAF achieves 0.1 t CO_2/t steel at $780/t; Hebei's H2-DRI achieves 0.6 t CO_2/t at $1,580/t

4.3.4 Implementation Roadmap

Phase 1: Foundation (2025-2027):

- Retire 25 Mt oldest BF-BOF capacity
- Commission 10-12 Mt new EAF capacity
- Net reduction: 13-15 Mt (10-12%)
- Establish integrated scrap collection network targeting 30-35 Mt/year
- Secure renewable electricity PPAs for 40-50 TWh annually

Phase 2: Acceleration (2027-2030):

- Retire additional 40 Mt BF-BOF capacity
- Commission 30 Mt new EAF capacity
- Cumulative net reduction: 25-30 Mt (20-24%)
- Scrap processing capacity: 50-60 Mt annually
- Renewable electricity: 80-100 TWh for steel sector
- Hybrid DRI-scrap EAF: 3-5 Mt capacity (60% DRI + 40% scrap)

Projected Emissions Impact:

- 2024 Emissions: 236.8 Mt CO_2
- 2030 Emissions: 107.3 Mt CO_2
- **Reduction: 129.5 Mt CO_2 (54.7% reduction)**

This exceeds the national target of 18-22% emissions reduction, positioning Jiangsu as a provincial leader.

4.3.5 Critical Challenges

Despite advantages, Jiangsu faces specific challenges:

Scrap Quality Management:

- **Residual Elements**: Copper, tin accumulate in recycled steel, affecting properties
- **Quality Degradation**: Each recycling cycle introduces impurities
- **Automotive Grade Requirements**: High-strength steel requires careful scrap selection
- **Mitigation**: Advanced sorting technology (X-ray, laser, infrared), closed-loop systems with OEMs, 20-30% DRI blending

Grid Integration:

- **Power Fluctuations**: EAF operations cause voltage flicker and harmonic distortion
- **Peak Demand**: Ultra-high power furnaces require 100-200 MW each

- **Mitigation**: Static VAR compensators, energy storage systems, demand response programs

Capital Investment:

- **Total Requirement 2025-2030**: RMB 100-150 billion ($14-21 billion)
- **Breakdown**:
  - EAF capacity: RMB 60-80 billion
  - Scrap infrastructure: RMB 10-15 billion
  - Grid upgrades: RMB 5-8 billion
  - Renewable energy: RMB 20-30 billion
  - R&D and quality control: RMB 5-10 billion
- **Challenge**: Private companies like Shagang face capital constraints vs state-owned enterprises

4.3.6 Global Replicability

Jiangsu's EAF-centered model offers lessons for other regions:

Applicable Regions:

- Coastal industrialized areas: North Italy, South Korea coastal zones, US Great Lakes region
- Regions with mature manufacturing and construction sectors providing scrap
- Areas with strong electricity infrastructure
- Markets with growing renewable electricity availability

Key Success Factors:

- Diversified economy reducing steel sector political power
- Abundant scrap availability or import access
- Grid capacity and renewable integration capability
- Capital availability or access to green finance
- Market for green steel products willing to pay modest premiums

Conclusion: If successful, Jiangsu demonstrates that circular economy principles applied at massive scale through EAF technology can achieve deep decarbonization while maintaining economic competitiveness, providing a potentially more cost-effective and rapidly deployable alternative to hydrogen-intensive pathways.

5 Synthesis and Strategic Assessment

5.1 Provincial Transformation Pathways: Divergence and Complementarity

The analysis of China's steel decarbonization reveals a sophisticated strategy of differentiated provincial pathways, each adapted to local conditions while contributing to national objectives. This "big country strategy" recognizes that no single technology or policy approach can address the diversity of China's steel landscape.

5.1.1 Technology Portfolio Specialization

China's approach generates a complementary technology portfolio:

Table 5: Provincial Technology Specialization and National Portfolio (2030 Projection)

Province	Capacity (Mt)	Primary Pathway	Secondary	Rationale
Hebei	200	H_2-DRI (30%)	CCUS (35%)	Air quality urgency
Jiangsu	95	EAF (60%)	H_2-DRI (15%)	Scrap availability
Shandong	90	CCUS (40%)	EAF (30%)	BF optimization
Liaoning	65	H_2-DRI (25%)	EAF (35%)	Low-cost renewables
Shanxi	60	CCUS (50%)	BF retrofit (40%)	Coal infrastructure
Inner Mongolia	45	H_2-DRI (40%)	CCUS (30%)	Green H_2 hub
Guangdong	40	EAF (70%)	H_2-DRI (15%)	High-value products
Other provinces	355	Mixed	–	Various
National Total	**950**	**Distribution:** H_2-DRI: 25% CCUS-BF: 35% EAF: 40%	–	–

This diversification provides critical benefits:

1. **Risk Mitigation**: If hydrogen costs remain elevated, China still achieves 40-45% emissions reduction through CCUS and EAF
2. **Technology Learning**: Multiple pathways generate comparative data on economics and performance
3. **Supply Chain Development**: Parallel development of hydrogen, CCUS, and scrap infrastructure
4. **Market Segmentation**: Different steel grades served by optimal production routes
5. **Regional Economic Alignment**: Technologies matched to local resources and industrial structure

5.1.2 Cross-Provincial Synergies

The provincial strategies create interdependencies that strengthen the national system:

Inner Mongolia → Coastal Provinces Hydrogen Supply:

- Inner Mongolia develops 30-40 GW renewable energy and 5-7 GW electrolyzers by 2030
- Pipeline infrastructure connects to Hebei, Shandong, Liaoning
- Delivers 300,000-500,000 tonnes green H_2 annually by 2030
- Enables hydrogen steel production in regions with limited renewable resources

Jiangsu-Guangdong Scrap Trading Network:

- Guangdong's manufacturing generates premium scrap (automotive, electronics)
- Jiangsu's EAF capacity processes both local and imported scrap
- Coastal shipping creates efficient inter-provincial logistics

- Closed-loop systems with automotive OEMs span provinces

Technology Transfer from Leaders to Followers:

- HBIS Zhangjiakou H_2-DRI technology licensed to Liaoning, Inner Mongolia facilities
- Jiangsu Shagang EAF expertise supports Guangdong expansion
- Shandong CCUS demonstrations inform Shanxi, Hebei retrofits

5.2 The October 2025 Policy: Enforcement and Adaptation

5.2.1 Policy Effectiveness Assessment

The October 2025 capacity replacement policy represents a decisive strengthening of China's regulatory framework. Its effectiveness depends on three factors:

1. Enforcement Capacity and Political Will

- **Strengths**:
  - Clear, quantitative replacement ratios (1.5:1 standard) eliminate ambiguity
  - 24-month project timelines with automatic revocation prevent indefinite capacity hoarding
  - Physical equipment dismantling requirements verified through provincial inspections
  - 2027 inter-enterprise trading ban forces genuine consolidation
  - Beijing-level oversight maintains pressure on provincial governments
- **Vulnerabilities**:
  - Economic downturn could trigger policy relaxation or exemptions
  - Provincial GDP dependencies create local resistance
  - Smaller producers may declare bankruptcy while secretly maintaining capacity ("zombie capacity 2.0")
  - Inter-enterprise trading ban may face intense lobbying for delays or modifications
- **Probability Assessment**: 70-75% chance of rigorous enforcement through 2027; declining to 55-60% post-2027 if economic conditions deteriorate

2. Technology Incentive Effectiveness

The equal replacement (1:1) provisions for EAF and H_2-DRI ($\geq$60% carbon reduction) create powerful economic incentives:

- **EAF Incentive Value**:
  - Standard 1.5:1 replacement: Must retire 1.5 Mt to build 1 Mt = 500,000 tonnes lost capacity
  - EAF 1:1 replacement: Retire 1 Mt to build 1 Mt = zero capacity loss
  - Financial value: Capacity rights valued at RMB 500-800/tonne = RMB 250-400 million ($35-56 million) per Mt project
  - This subsidy equivalent significantly improves EAF economics
- **H_2-DRI Incentive Value**:

  - Similar capacity preservation benefit as EAF
  - Critical for first-mover projects with higher capital costs
  - Enables technology demonstration without capacity penalty
  - However, overall H_2-DRI economics still challenged by hydrogen costs

- **Expected Impact**:
  - Accelerates EAF share from 13% (2024) to 32-36% (2030) = 20-23 percentage point increase
  - Enables H_2-DRI scaling from 1-2 Mt (2024) to 20-30 Mt (2030) = 10-15x growth
  - Without these incentives, transformation would be 5-7 years slower

3. Regional Restriction Credibility
The policy's prohibitions on capacity transfers to Key Regions face implementation challenges:

- **Beijing-Tianjin-Hebei**: Restrictions likely to hold due to air quality crisis visibility
- **Yangtze River Delta**: Moderate enforcement, with exceptions for high-tech steel projects
- **Fen-Wei Plain**: Weakest enforcement probability; local governments may grant exemptions
- **Risk**: Creative legal interpretations ("not technically a capacity transfer but a joint venture restructuring")

5.2.2 Comparative Policy Assessment: China vs Global Approaches

China's mandatory capacity replacement contrasts sharply with market-based mechanisms:

Table 6: Steel Decarbonization Policy Mechanisms: Comparative Assessment

Region	Mechanism	Advantages	Disadvantages	Effectiveness
China	Mandatory 1.5:1 capacity replacement	- Predictable outcomes - Rapid action - Forces consolidation	- Economic rigidity - Potential evasion - GDP conflict	High (70-75% target achievement probability)
EU	ETS carbon pricing + CBAM	- Market efficiency - Innovation incentives - Revenue generation	- Price volatility - Carbon leakage risk - Slow deployment	Medium (50-60% target achievement)
Germany	CCfD contracts + subsidies	- De-risks investment - Technology-specific - Consensual	- High public cost - Limited scale - Bureaucratic	Medium-High (60-70% for Germany alone)
Japan	Industry voluntary coordination	- Flexible adaptation - Minimizes disruption - Preserves competitiveness	- Insufficient ambition - Slow progress - Free-rider problem	Low-Medium (35-45% target achievement)
US	IRA subsidies + limited mandates	- Innovation support - Political feasibility	- Fragmented approach - State variation - Uncertain longevity	Low-Medium (30-40%)

Key Insights:

- China's approach trades economic flexibility for environmental certainty

- EU mechanism generates revenue (ETS proceeds) while China's requires fiscal support
- Germany's CCfD model most similar to China but at much smaller scale
- No single model clearly superior; effectiveness depends on governance capacity and political context

5.3 Critical Success Factors: Integrated Assessment

Six critical factors determine transformation success, with quantified probability assessments:

5.3.1 Factor 1: Hydrogen Cost Trajectory (Weight: 30%)

Current Status:

- Green hydrogen: RMB 18-25/kg ($2.50-3.50/kg)
- Grey hydrogen: RMB 8-12/kg ($1.10-1.65/kg)
- Target green hydrogen 2030: RMB 8-12/kg ($1.10-1.65/kg)

Required Cost Reduction: 50-60% over 5 years (2025-2030)
Feasibility Assessment:

- **Probability of Success (50-60%)**:
  - Requires: Renewable electricity at RMB 0.20-0.25/kWh (achievable through Inner Mongolia wind/solar)
  - Electrolyzer CAPEX reduction: $800/kW (current) → $400/kW (2030) through manufacturing scale-up
  - Efficiency improvements: 55 kWh/kg (current) → 48-50 kWh/kg (2030) through technology advances
  - Precedent: Solar PV achieved 80-90% cost reduction over 15 years; similar trajectory possible for electrolyzers
- **Mitigation if Costs Remain High**:
  - Government subsidies: RMB 2-5/kg bridge support (precedent exists in renewable energy)
  - Extended use of grey hydrogen with CCUS (50% emissions reduction acceptable interim step)
  - Shift emphasis toward EAF expansion and away from H_2-DRI
  - Delay full green steel deployment to 2035 rather than 2030

5.3.2 Factor 2: HBIS Zhangjiakou Scaling Success (Weight: 20%)

Current Status:

- Phase 1: 1.2 Mt H_2-DRI operational (2023-present)
- Technical performance: 92-95% metallization, stable operation
- Economic performance: RMB 500-600/tonne premium vs conventional steel

Required Scaling:

- Phase 2: 2.5 Mt capacity by 2027
- Phase 3: 5-10 Mt capacity by 2030
- National replication: 20-30 Mt total H_2-DRI capacity across provinces

Success Probability Assessment (60-65%):

- **Technical Scaling (High Confidence)**:
  - Shaft furnace DRI technology proven at multi-Mt scale internationally (Middle East, India)
  - HBIS has demonstrated operational capability at 1.2 Mt
  - Engineering challenges (materials, gas distribution, thermal management) well-understood
- **Economic Viability (Medium Confidence)**:
  - Current cost penalty diminishes with scale and learning
  - Critical dependency on hydrogen cost trajectory
  - If green H_2 reaches RMB 10-12/kg by 2030, economics approach parity with CCUS-equipped BF
  - Without cost reduction, requires sustained subsidies or carbon pricing of RMB 150-200/t CO_2
- **Supply Chain Development (Medium Confidence)**:
  - DRI-grade pellet production must expand 20-fold (currently 1-2 Mt capacity in China)
  - Hydrogen pipeline infrastructure: 1,200+ km needed for Hebei-Inner Mongolia connection
  - Electrolyzer manufacturing: China currently produces 1-2 GW/year; needs 5-7 GW/year by 2028

Impact of Failure:

- National H_2-DRI target reduced from 25% (240 Mt) to 10-12% (95-115 Mt) by 2035
- Compensatory increase in CCUS deployment and extended BF operation
- Emissions reduction trajectory delayed 3-5 years
- China loses first-mover advantage in hydrogen steel technology to potential competitors (Middle East, India with natural gas DRI transition)

5.3.3 Factor 3: Infrastructure Development Pace (Weight: 15%)

Required Infrastructure by 2030:

Table 7: Critical Infrastructure Requirements (National Level)

Infrastructure Type	Current (2024)	Required (2030)
Electrolyzers (GW)	0.5-1.0	20-30
H_2 Pipelines (km)	<100	2,000-3,000
Renewable Energy (GW)	1,200 (total)	+200-300 (dedicated steel)
CO_2 Pipeline (km)	Minimal	500-800
CO_2 Storage (Mt/year)	1-2	50-80
Grid Upgrades (GW)	–	30-50 (for EAF)

Development Probability (55-60%):

- **High Confidence (75-80% probability)**:
  - Renewable energy: China installs 150-200 GW wind/solar annually; dedicating 40-50 GW to steel sector feasible
  - Grid infrastructure: State Grid Corporation has proven execution capability
- **Medium Confidence (60-65% probability)**:
  - Hydrogen pipelines: 3-5 year construction timelines face permitting delays, financing challenges
  - Electrolyzers: Manufacturing scale-up requires sustained investment and technology transfer
- **Lower Confidence (40-50% probability)**:
  - CO_2 storage: Geological surveys incomplete; offshore Bohai Bay storage promising but uncertain
  - International comparison: Norway's Longship CCS project faced 5+ year delays; China's larger scale increases risk

Mitigation Strategies:

- Prioritize hydrogen pipeline as national strategic infrastructure project
- Accept phased implementation with temporary truck-based hydrogen transport
- CCUS: Focus on utilization (CO_2 for chemicals) rather than storage in near term
- Coordinate infrastructure development with steel capacity replacement timelines to avoid stranded assets

5.3.4 Factor 4: Political Will Sustainability (Weight: 15%)

Challenge

6 The October 2025 Capacity Replacement Policy: A Paradigm Shift

6.1 Policy Evolution and Strategic Intent

The October 2025 draft *Implementation Measures for Capacity Replacement in the Steel Industry* represents a qualitative intensification of China's capacity governance approach, building upon but substantially strengthening the 2021 measures. Released by the Ministry of Industry and Information Technology (MIIT) for public comment with a deadline of November 23, 2025, this policy framework crystallizes China's determination to achieve absolute capacity reduction while simultaneously accelerating technological transformation.

The policy's strategic objectives extend beyond simple environmental compliance, targeting three interconnected goals:

1. **Absolute Capacity Reduction**: Net reduction of national steel capacity through stricter replacement ratios
2. **Technology Transformation**: Incentivizing shift toward electric arc furnaces (EAF) and hydrogen metallurgy
3. **Industrial Consolidation**: Forcing mergers and acquisitions through elimination of inter-enterprise capacity trading

6.2 Key Policy Mechanisms and Changes from 2021

6.2.1 Replacement Ratio Intensification

The policy establishes a hierarchical replacement ratio structure:

- **Standard Ratio**: $\geq 1.5 : 1$ (retired capacity : construction capacity)
  - For every 1 tonne of new capacity, at least 1.5 tonnes of old capacity must be permanently retired
  - Represents 33% net reduction per replacement transaction
- **Merger & Acquisition Exception**: $\geq 1.25 : 1$
  - Applies only to substantive M&A completed after June 2021
  - Requires legal, equity, and operational integration
  - Still mandates 20% net reduction
- **Equal Replacement (1:1)**: Three qualifying categories
  1. On-site major overhauls with no change in equipment type/capacity
  2. Special EAF processes for high-end specialty steel
  3. Projects in Qinghai and Tibet (recognizing unique regional circumstances)

This contrasts sharply with the 2021 policy's more permissive ratios (ranging from 1.1:1 to 1.5:1) and represents an approximately 20-30% intensification of capacity reduction pressure.

6.2.2 Prohibition of Inter-Enterprise Capacity Trading

The most structurally significant change addresses capacity trading mechanisms:

- **Before 2027**: Inter-enterprise capacity replacement allowed nationwide
- **From 2027 onward**: Inter-enterprise replacement *prohibited*
- **Permitted post-2027**: Only mergers & acquisitions or intra-group transfers

- **Rationale**: "Capacity and equipment must correspond one-to-one; no separation allowed"

This prohibition fundamentally transforms industry structure by:

1. Eliminating the capacity trading market that previously allowed small, inefficient producers to monetize retirement by selling capacity rights
2. Forcing genuine consolidation through M&A rather than financial transactions
3. Preventing wealthy producers from accumulating capacity rights without retiring their own equipment
4. Ensuring actual equipment retirement rather than paper transactions

6.2.3 Low-Carbon Technology Incentives

Article 11 introduces unprecedented incentives for breakthrough technologies, allowing equal replacement (1:1 ratio) for:

1. **Converter + Blast Furnace to EAF Conversion**
   - Retiring both converters and blast furnaces to build EAFs
   - Recognizes complete process transformation
   - Major incentive for fundamental infrastructure change
2. **EAF-to-EAF Replacement**
   - Modernizing existing EAF operations
   - Supports scrap-based production enhancement
3. **Hydrogen Ironmaking ($\geq$ 60% Carbon Reduction)**
   - Applies when hydrogen-based DRI achieves $\geq$ 60% emissions reduction vs conventional blast furnace
   - Critical threshold recognizes both natural gas-based and green hydrogen routes
   - Provides pathway for H2-DRI demonstration and scaling

6.3 Regional Restrictions and Environmental Priorities

6.3.1 Key Regions Definition

The policy designates specific regions for maximum restriction (Article 9):

- **Beijing-Tianjin-Hebei (Jing-Jin-Ji)**
- **Yangtze River Delta**
- **Fen-Wei Plain**
- **Yangtze River Economic Belt**: Special restrictions on new projects outside compliant industrial parks

These regions face:

- No net capacity increase permitted
- No inbound capacity transfers from other regions
- Provinces with national capacity caps cannot accept external transfers

6.3.2 Environmental Justice Rationale

The regional restrictions reflect explicit environmental justice and air quality priorities:

1. Beijing-Tianjin-Hebei suffers China's most severe air pollution, with steel contributing significantly to PM2.5 and NOx
2. Yangtze River Delta hosts China's most economically valuable urban agglomerations, where air quality directly affects hundreds of millions
3. These restrictions force production capacity shift toward coastal areas with better environmental capacity and logistics efficiency

6.4 Implementation Timeline and Enforcement

6.4.1 Project Timeline Restrictions

The policy introduces strict temporal controls (Articles 18-19):

- **24-Month Validity**: Approved capacity replacement plans must commence construction within 24 months
- **Automatic Revocation**: Plans not implemented within timeline are automatically void
- **No Extensions**: Policy explicitly prevents indefinite holding of replacement rights

6.4.2 Mandatory Equipment Dismantling

Critical enforcement mechanism requires:

- Retired equipment must be physically dismantled before new production commences
- Provincial acceptance inspections verify actual equipment removal
- Photographic and site documentation required
- Prevents simultaneous operation of old and new capacity

6.5 Quantitative National Impact Projections

Based on provincial capacity distributions and policy ratios, projected national impacts through 2030:

Table 8: Projected National Steel Capacity Under 1.5:1 Policy (2024-2030)

Metric	2024 Baseline	2030 Target	Change (%)
Total Capacity (Mt)	1,100-1,150	950-1,000	-13 to -17%
BF-BOF Capacity (Mt)	950-1,000	600-650	-35 to -40%
EAF Capacity (Mt)	140-160	320-360	+114 to +129%
H2-DRI Capacity (Mt)	1-2	20-30	+900 to +2,900%
Emissions (Mt CO_2)	**2,100-2,200**	**1,500-1,650**	**-25 to -33%**

Key Observations:

- Absolute capacity reduction of 100-200 Mt (9-17% of 2024 levels)

- Dramatic technology mix transformation: BF-BOF from 87% to 60-65% share
- EAF share increases from 13% to 32-36%
- If targets achieved, China's steel emissions would decline by 500-700 Mt CO_2 annually
- This single-sector reduction exceeds total annual emissions of Germany or Japan

6.6 Policy Challenges and Implementation Risks

6.6.1 Provincial GDP Dependencies

The policy's success depends on overcoming entrenched local economic interests:

- **Hebei Province**: Steel accounts for 15-20% of provincial GDP, employs 600,000-800,000 workers directly
- **Shanxi, Shandong, Liaoning**: Similar structural dependencies create resistance
- **Central-Local Tension**: Beijing mandates conflict with provincial employment and fiscal revenue priorities

6.6.2 Scrap Availability Constraints

The policy's emphasis on EAF expansion faces fundamental material limits:

- **2024 Scrap Availability**: Approximately 260-280 Mt nationally
- **2030 EAF Requirement**: If 320-360 Mt EAF capacity operates at 90% utilization, requires 288-324 Mt scrap (or DRI substitute)
- **Gap**: Even with aggressive collection improvements (target 320 Mt scrap by 2025), near-complete utilization of available scrap required
- **Quality Challenge**: Automotive and high-grade steel applications require premium scrap, potentially limiting EAF product mix

6.6.3 DRI Supply Chain Development

The hydrogen DRI incentives depend on supply chains that barely exist:

- **Current Global DRI Capacity**: Approximately 130 Mt, predominantly natural gas-based in Middle East and India
- **China's H2-DRI Capacity (2024)**: $<$ 2 Mt (primarily HBIS Zhangjiakou demonstration)
- **Required Growth**: To support 20-30 Mt H2-DRI usage by 2030 requires 10-15x capacity expansion in 5 years
- **Green Hydrogen Availability**: Currently $<$ 100,000 tonnes/year production; need exceeds 2-3 Mt/year for steel sector

6.6.4 Enforcement Consistency

Historical precedents raise concerns about policy implementation rigor:

- Previous capacity policies saw widespread evasion through "zombie capacity" (reported as retired but maintained)
- Local governments sometimes prioritized GDP over environmental compliance
- Economic downturns previously triggered policy relaxation
- The 2027 inter-enterprise trading ban may face intense lobbying for extension or modification

6.7 International Comparative Context

China's 1.5:1 policy represents the world's most aggressive mandatory capacity reduction mechanism:

Table 9: International Steel Capacity Governance Comparison

Region	Mechanism	Stringency	Enforcement
China	Mandatory 1.5:1 replacement ratio	Very High	State directive with provincial implementation
European Union	Market-driven through ETS carbon pricing	Moderate	Market mechanism + regulatory oversight
Japan	Voluntary industry coordination	Low-Moderate	Industry self-regulation
United States	No federal capacity policy	Very Low	Market forces only
India	Informal government guidance	Low	Limited enforcement

Observation: China's approach trades economic flexibility for environmental certainty, reflecting different governance models and climate commitment mechanisms.

7 Provincial Implementation Strategies: Divergent Pathways

7.1 Framework for Provincial Analysis

China's provincial steel landscapes exhibit extraordinary diversity in production scale, technology mix, economic structure, and decarbonization potential. This section examines four critical provinces—Hebei, Jiangsu, Shandong, and Liaoning—representing distinct transformation pathways, plus emerging developments in Guangdong and Inner Mongolia.

7.1.1 Analytical Dimensions

Provincial analysis considers:

1. **Production Scale and Technology Mix**: Current capacity, BF-BOF vs EAF distribution
2. **Economic Dependency**: Steel's contribution to provincial GDP and employment

3. **Environmental Pressure**: Air quality status, proximity to population centers, political urgency
4. **Infrastructure Enablers**: Scrap availability, renewable energy access, hydrogen potential, grid capacity
5. **Cost Competitiveness**: Levelised Cost of Steel (LCOS) for different technology pathways
6. **Policy Implementation Capacity**: Provincial government resources and political will

7.2 Hebei Province: The Heavy Lifting Province

7.2.1 Strategic Position and Challenge Scale

Hebei Province represents the epicenter of global steel decarbonization:

Production Profile:

- Annual capacity: 225-250 Mt (21-24% of China, 12-13% of world)
- Current technology: 92% BF-BOF, 8% EAF
- Annual emissions: 500-550 Mt CO_2 (15% of China's industrial emissions)
- Direct employment: 600,000-800,000 workers

The Quadruple Crisis:

1. **Environmental Emergency**: Surrounds Beijing; PM2.5 levels frequently exceed standards 3-5x
2. **Economic Dependency**: Steel contributes 15-20% of provincial GDP
3. **Technology Lock-in**: Aging BF infrastructure averaging 15-20 years old
4. **Social Stability Risk**: Capacity reduction threatens 150,000-200,000 jobs

7.2.2 Hebei's Transformation Strategy: Hydrogen-Centered

Unlike Jiangsu's EAF focus, Hebei pursues hydrogen direct reduction:

HBIS Zhangjiakou H2-DRI Demonstration:

- **Phase 1 (Operational 2023)**: 1.2 Mt/year capacity
- **Hydrogen Source (Current)**: Grey hydrogen from coke oven by-products (60,000-80,000 tonnes H_2/year)
- **Emissions Benefit**: 50% CO_2 reduction vs conventional BF-BOF (1.1-1.2 vs 2.2 t CO_2/t steel)
- **Green Hydrogen Transition (2027-2030)**:
  - Target: 200,000-300,000 tonnes green H_2/year
  - Electrolyzer capacity: 3-5 GW (alkaline and PEM)
  - Renewable source: Zhangjiakou renewable energy zone + Inner Mongolia imports
  - Cost target: RMB 12-15/kg (2027) declining to RMB 8-10/kg (2030)
- **Scaling Plan**: 8-10 Mt provincial H2-DRI capacity by 2030

Projected Technology Mix 2030:

Table 10: Hebei Province Steel Technology Evolution

Technology	**2024**	**2030**	**2035**	**2050**
BF-BOF (conventional)	92%	60%	30%	0%
BF-BOF with CCUS	0%	15%	35%	15%
H2-DRI-EAF	1%	15%	25%	60%
Scrap-based EAF	7%	10%	10%	25%
Total Capacity (Mt)	**250**	**200**	**180**	**150-160**

7.2.3 Critical Success Factors and Risks

Success Factors:

- **Political Will (Very High)**: Beijing proximity ensures maximum pressure and oversight
- **Technical Demonstration**: HBIS Zhangjiakou proving H2-DRI viability at commercial scale
- **Renewable Access**: Zhangjiakou designated National Renewable Energy Demonstration Zone, target 30 GW wind/solar by 2030
- **Financial Resources**: RMB 200-300 billion provincial + national support allocated

Critical Risks:

- **Hydrogen Cost (High Risk)**: Current green H_2 at RMB 18-25/kg makes steel uncompetitive; requires 50-60% cost reduction
- **Infrastructure Delays (Medium-High Risk)**: Hydrogen pipelines, electrolyzers, grid upgrades face 3-5 year timelines
- **Social Unrest (Medium Risk)**: 150,000-200,000 job losses require RMB 60-90 billion just transition programs
- **GDP Pressure (Medium Risk)**: 15-20% provincial GDP from steel creates political resistance

Assessment: Hebei's success probability approximately 50-55% for "Managed Transformation" scenario (60-65% emissions reduction by 2040), with 20-25% probability of "Green Steel Pioneer" outcome (70%+ reduction) and 20-25% risk of "Troubled Transition" ($<$ 50% reduction).

7.3 Jiangsu Province: The EAF Transformation Leader

7.3.1 Strategic Advantages for Scrap-Based Pathway

Jiangsu represents the polar opposite approach to Hebei:

Production Profile:

- Annual capacity: 119-121 Mt (11-12% of China)
- Current technology: 82% BF-BOF, 18% EAF
- Target 2030: 40-45% BF-BOF, 55-60% EAF
- Current emissions: 240-260 Mt CO_2/year

Comparative Advantages:

1. **Lower Steel Dependency**: Steel contributes only 5-8% of provincial GDP (vs 15-20% Hebei)
2. **Scrap Availability**: 28-38 Mt currently available, expandable to 60-71 Mt by 2030
   - Manufacturing scrap from automotive/appliances/machinery: 12-15 Mt
   - End-of-life vehicles: 4-6 Mt (expandable to 12-14 Mt)
   - Construction/demolition: 5-7 Mt (expandable to 10-12 Mt)
   - Scrap imports via Shanghai/Nanjing ports: 4-6 Mt (expandable to 12-14 Mt)
3. **Grid Infrastructure**: 150+ GW installed capacity, one of China's most reliable grids (99.9% uptime)
4. **Renewable Electricity**:
   - Offshore wind: 12 GW (2024) → 25 GW (2030)
   - Distributed solar: potential for 2-3 GW dedicated to steel sector
   - Western China renewable imports via ultra-high voltage transmission
   - Target: 80-100 TWh renewable electricity for steel sector by 2030
5. **Coastal Location**: Port access enables efficient scrap imports and finished steel exports

7.3.2 Jiangsu Shagang Group: Provincial Champion

Jiangsu's transformation centers on its flagship producer:

- **Production**: 41.45 Mt annually (Global Rank #6, China's largest private steelmaker)
- **Current EAF Share**: Approximately 20%
- **Target 2030**: 70% EAF share
- **Strategic Advantages**:
  - Private ownership enables faster decision-making vs state-owned enterprises
  - Known for cost efficiency and operational flexibility
  - Active Environmental Product Declaration (EPD) certification leadership
  - Preparing for EU CBAM compliance and green steel premium markets
- **Decarbonization Approach**:
  - Focus on scrap-based EAF expansion rather than hydrogen DRI
  - Closed-loop recycling partnerships with automotive and appliance sectors
  - Investments in advanced scrap processing and sorting technology (RMB 3-5 billion)
  - Long-term renewable electricity Power Purchase Agreements

Table 11: Levelised Cost of Steel (LCOS) Comparison - 2030 Projections

Technology & Location	Capital ($/tonne)	Operating ($/tonne)	Total LCOS ($/tonne)
Jiangsu - EAF (grid mix)	350	380	730
Jiangsu - EAF (renewable)	380	400	780
Jiangsu - H2-DRI	950	450	1,400
Hebei - H2-DRI	1,100	480	1,580
Germany - H2-DRI	1,200	520	1,720
Liaoning - H2-DRI (lowest China)	900	410	1,310

7.3.3 Cost Competitiveness Analysis

Jiangsu's EAF pathway offers substantial cost advantages over hydrogen routes:

Key Insights:

- Jiangsu EAF offers 55-60% cost advantage over Hebei H2-DRI
- Even renewable-powered EAF (LCOS $780) significantly cheaper than H2-DRI routes
- Capital cost for EAF ($350-380/t) is 60-70% lower than H2-DRI ($900-1,200/t)
- Jiangsu's renewable EAF achieves 0.1 t CO_2/t steel at $780/t; Hebei's H2-DRI achieves 0.6 t CO_2/t at $1,580/t

7.3.4 Implementation Roadmap

Phase 1: Foundation (2025-2027):

- Retire 25 Mt oldest BF-BOF capacity
- Commission 10-12 Mt new EAF capacity
- Net reduction: 13-15 Mt (10-12%)
- Establish integrated scrap collection network targeting 30-35 Mt/year
- Secure renewable electricity PPAs for 40-50 TWh annually

Phase 2: Acceleration (2027-2030):

- Retire additional 40 Mt BF-BOF capacity
- Commission 30 Mt new EAF capacity
- Cumulative net reduction: 25-30 Mt (20-24%)
- Scrap processing capacity: 50-60 Mt annually
- Renewable electricity: 80-100 TWh for steel sector
- Hybrid DRI-scrap EAF: 3-5 Mt capacity (60% DRI + 40% scrap)

Projected Emissions Impact:

- 2024 Emissions: 236.8 Mt CO_2
- 2030 Emissions: 107.3 Mt CO_2
- **Reduction: 129.5 Mt CO_2 (54.7% reduction)**

This exceeds the national target of 18-22% emissions reduction, positioning Jiangsu as a provincial leader.

7.3.5 Critical Challenges

Despite advantages, Jiangsu faces specific challenges:

Scrap Quality Management:

- **Residual Elements**: Copper, tin accumulate in recycled steel, affecting properties
- **Quality Degradation**: Each recycling cycle introduces impurities
- **Automotive Grade Requirements**: High-strength steel requires careful scrap selection
- **Mitigation**: Advanced sorting technology (X-ray, laser, infrared), closed-loop systems with OEMs, 20-30% DRI blending

Grid Integration:

- **Power Fluctuations**: EAF operations cause voltage flicker and harmonic distortion
- **Peak Demand**: Ultra-high power furnaces require 100-200 MW each
- **Mitigation**: Static VAR compensators, energy storage systems, demand response programs

Capital Investment:

- **Total Requirement 2025-2030**: RMB 100-150 billion ($14-21 billion)
- **Breakdown**:
  - EAF capacity: RMB 60-80 billion
  - Scrap infrastructure: RMB 10-15 billion
  - Grid upgrades: RMB 5-8 billion
  - Renewable energy: RMB 20-30 billion
  - R&D and quality control: RMB 5-10 billion
- **Challenge**: Private companies like Shagang face capital constraints vs state-owned enterprises

7.3.6 Global Replicability

Jiangsu's EAF-centered model offers lessons for other regions:

Applicable Regions:

- Coastal industrialized areas: North Italy, South Korea coastal zones, US Great Lakes region
- Regions with mature manufacturing and construction sectors providing scrap
- Areas with strong electricity infrastructure
- Markets with growing renewable electricity availability

Key Success Factors:

- Diversified economy reducing steel sector political power
- Abundant scrap availability or import access

- Grid capacity and renewable integration capability
- Capital availability or access to green finance
- Market for green steel products willing to pay modest premiums

Conclusion: If successful, Jiangsu demonstrates that circular economy principles applied at massive scale through EAF technology can achieve deep decarbonization while maintaining economic competitiveness, providing a potentially more cost-effective and rapidly deployable alternative to hydrogen-intensive pathways.

7.4 Shandong Province: Balanced Coastal Transformation

7.4.1 Provincial Context and Production Profile

Shandong Province occupies a strategic middle position between Hebei's hydrogen-focused and Jiangsu's EAF-centered approaches, pursuing a balanced transformation strategy.

Production Characteristics:

- Annual capacity: 80-85 Mt (7-8% of China's total)
- National ranking: #3 among provinces (after Hebei, Jiangsu)
- Current technology mix: 85% BF-BOF, 15% EAF
- Geographic distribution: Concentrated in coastal cities (Rizhao, Qingdao) and Jinan area
- Annual emissions: 170-185 Mt CO_2

Economic and Social Context:

- Steel contribution to GDP: 8-12% (moderate dependency)
- Direct employment: 180,000-220,000 workers
- Economic structure: Diversified heavy industry (steel, petrochemicals, machinery)
- Political priority: Moderate environmental pressure, lower than Hebei, higher than Liaoning

7.4.2 Major Producers and Ownership Structure

Shandong's steel sector features a mix of state-owned and private enterprises:

Shandong Iron and Steel Group (Shandong Steel):

- Consolidated production: 25-30 Mt annually
- Formation: 2019 merger of Jinan Steel and Rizhao Steel groups
- Flagship facilities: Rizhao Precision Strip (coastal, modern), Laiwu Steel
- Technology focus: Modernizing integrated BF-BOF operations with selective EAF additions
- Decarbonization commitment: Emissions peak 2023, carbon neutrality 2060

Regional Producers:

- Multiple medium-scale integrated and EAF mills (capacity 2-8 Mt each)
- Higher vulnerability to 1.5:1 policy consolidation pressure
- Potential acquisition targets for provincial consolidation

7.4.3 Balanced Transformation Strategy

Unlike Hebei's hydrogen emphasis or Jiangsu's EAF focus, Shandong pursues three parallel pathways:

1. **Coastal Integrated Mill Optimization (40% of strategy)**:

- Leverage Rizhao and Qingdao port locations for efficient iron ore imports
- Implement ultra-low emissions retrofitting on newest BF-BOF facilities
- Deploy CCUS on 15-20 Mt capacity (utilizing Shengli Oilfield CO_2 storage potential)
- Maintain 35-40 Mt modern BF-BOF for high-grade products through 2035

2. **EAF Expansion with Scrap Development (40% of strategy)**:

- Current scrap availability: 18-22 Mt annually
- Target 2030 scrap mobilization: 32-38 Mt
- EAF capacity expansion: 15 Mt (current) → 35-40 Mt (2030)
- Focus on construction steel and industrial products
- Leverage Yellow River economic zone scrap generation

3. **Hydrogen DRI Pilot Projects (20% of strategy)**:

- Small-scale H2-DRI demonstration (2-3 Mt by 2030)
- Natural gas-based DRI as transitional technology
- Partnership with national hydrogen development initiatives
- Green hydrogen potential from Yellow River wind corridor and offshore wind

7.4.4 Infrastructure Enablers and Constraints

Advantages:

- **Port Infrastructure**: Rizhao Port (one of China's largest iron ore handling facilities), Qingdao Port
- **Renewable Energy**: Significant offshore and onshore wind potential (coastal location)
- **CO_2 Storage**: Shengli Oilfield provides enhanced oil recovery opportunities for CCUS
- **Market Access**: Proximity to major construction markets in eastern China

Constraints:

- **Scrap Limitations**: Lower scrap generation than Jiangsu (less automotive/appliance manufacturing)
- **Grid Capacity**: Adequate but not as robust as Jiangsu's 150+ GW system
- **Hydrogen Infrastructure**: Currently minimal; requires significant build-out
- **Capital Access**: Provincial SOEs have moderate financial capacity

Table 12: Shandong Province Technology Pathway 2024-2030

Technology	2024	2027	2030	2035
BF-BOF (conventional)	85%	70%	50%	35%
BF-BOF with CCUS	0%	5%	15%	20%
Scrap-EAF	15%	22%	30%	35%
H2-DRI-EAF	0%	3%	5%	10%
Total Capacity (Mt)	**82**	**75**	**68**	**62**
Emissions (Mt CO_2)	**178**	**145**	**115**	**85**
Intensity (t CO_2/t)	**2.17**	**1.93**	**1.69**	**1.37**

7.4.5 Projected Transformation Outcomes

Technology Mix Evolution:

Emissions Reduction:

- 2024 baseline: 178 Mt CO_2
- 2030 target: 115 Mt CO_2
- Reduction: 63 Mt CO_2 (35.4% reduction)
- Pathway: Approximately one-third each from capacity reduction, EAF expansion, and BF efficiency/CCUS

7.4.6 Risk Assessment and Critical Success Factors

Medium Risk Profile:

- **Technology Diversification (Advantage)**: Multiple pathways reduce dependence on single technology success
- **Balanced Approach (Advantage)**: Avoids extreme hydrogen cost risk (Hebei) or scrap availability risk (Jiangsu)
- **Moderate Capital Intensity (Advantage)**: $500-700/t blended LCOS vs Hebei's $800-1,200/t
- **Coordination Challenge (Risk)**: Managing three parallel strategies requires sophisticated planning
- **Limited Excellence (Risk)**: May not achieve leadership in any specific technology pathway

Success Probability: 60-65% for achieving 30-40% emissions reduction by 2030, representing moderate ambition with manageable risks.

7.5 Liaoning Province: The Cost-Competitive Hydrogen Path

7.5.1 Strategic Positioning and Unique Advantages

Liaoning Province, in China's northeastern rust belt, presents a distinctive decarbonization profile characterized by superior cost competitiveness for hydrogen-based steel production.

Production Profile:

- Annual capacity: 60-65 Mt (5-6% of China's total)

- National ranking: #4 among provinces
- Current technology: 88% BF-BOF, 12% EAF
- Key production centers: Anshan, Benxi, Dalian
- Annual emissions: 130-145 Mt CO_2

Economic Context:

- Steel contribution to GDP: 10-14% (significant but declining)
- Historical role: China's steel birthplace, but declining relative importance
- Direct employment: 140,000-180,000 workers
- Rust belt challenges: Aging workforce, limited alternative industries, out-migration

7.5.2 Cost Leadership in Hydrogen Steel Production

Liaoning exhibits China's **lowest Levelised Cost of Steel (LCOS) for H2-DRI production**, according to the Global Efficiency Intelligence 2022 analysis cited in MIFUS documentation:

Cost Advantages:

1. **Electricity Costs**:
    - Industrial power: RMB 0.30-0.38/kWh (vs RMB 0.46-0.62 in Hebei)
    - Drivers: Nuclear baseload (Hongyanhe, Xudabao), coal-fired generation, grid modernization
    - Renewable integration: Growing wind capacity with lower curtailment than western provinces
2. **Hydrogen Production Costs**:
    - Projected 2030 green H_2 cost: RMB 8-10/kg (vs RMB 10-12 in Hebei)
    - 20-25% lower than Hebei despite similar renewable resources
    - Nuclear-grid integration enables more stable electrolyzer operation
3. **Labor Costs**:
    - Rust belt wage levels 15-25% below coastal provinces
    - Skilled metallurgical workforce availability (legacy of Ansteel, Benxi Steel)
    - Lower cost structure for operations and maintenance
4. **Land and Infrastructure**:
    - Abundant industrial land from legacy facility closures
    - Existing rail and port infrastructure (Dalian Port for DRI/H_2 imports)
    - Lower real estate and site development costs

Comparative LCOS Analysis:

Key Insight: Liaoning's LCOS for H2-DRI is approximately 17-20% lower than Hebei and 24-25% lower than Germany, despite similar technology pathways. This positions Liaoning as the optimal location for demonstrating hydrogen steel economic viability in China.

Table 13: H2-DRI Cost Competitiveness: Liaoning vs Other Regions (2030 Projections)

Region	Electricity (RMB/kWh)	H_2 Cost (RMB/kg)	Capital ($/t)	Operating ($/t)	LCOS ($/t)
Liaoning	0.30-0.38	8-10	900	410	1,310
Hebei	0.46-0.62	10-12	1,100	480	1,580
Shandong	0.40-0.50	10-13	1,000	450	1,450
Inner Mongolia	0.25-0.35	7-9	950	390	1,340
Germany	*0.08-0.12€*	*3-5€*	*1,200*	*520*	*1,720*

7.5.3 Ansteel (Anshan Iron and Steel Group): Provincial Flagship

Ansteel represents Liaoning's transformation anchor:

Company Profile:

- Production: 35-40 Mt annually
- Ownership: State-owned enterprise under SASAC
- Facilities: Anshan (main), Bayuquan (coastal), smaller operations
- Products: Heavy rail, automotive steel, specialty products
- Historical significance: Founded 1916, one of China's oldest modern steelworks

Bayuquan Hydrogen DRI Project:

- Location: Bayuquan coastal facility, Yingkou City
- **Phase 1 (Under Construction)**: 1.5-2.0 Mt/year H2-DRI-EAF
- **Timeline**: First production targeted 2026-2027
- **Hydrogen Strategy**:
  - Initial phase: Grey hydrogen from coke ovens + natural gas reforming
  - Transition phase: 50% green hydrogen by 2028
  - Target: 80%+ green hydrogen by 2030
- **Cost Target**: Leverage Liaoning's electricity advantage for competitive green steel production
- **National Significance**: Demonstration of economically viable H2-DRI in China's cost-competitive location

Decarbonization Roadmap:

- Emissions peak: 2025 (committed)
- 2030 target: 30% reduction vs 2025 peak
- 2050 target: Carbon neutrality
- Primary pathway: H2-DRI expansion (60%), CCUS (25%), EAF (15%)

7.5.4 Transformation Strategy and Provincial Policy

Liaoning's Distinctive Approach:

1. **Technology Demonstration Role**:
   - Position Liaoning as China's hydrogen steel proving ground
   - Lower costs enable technology validation without massive subsidies
   - Success can provide blueprint for higher-cost provinces
2. **Just Transition Focus**:
   - Rust belt context requires careful workforce management
   - Phased capacity reduction (15-20 Mt by 2030) rather than aggressive cuts
   - Emphasis on retraining and alternative employment in renewable energy sector
   - RMB 20-30 billion provincial just transition fund
3. **Renewable Energy Integration**:
   - Target 2030: 15-20 GW dedicated renewable capacity for steel sector
   - Mix: Offshore wind (Bohai Bay), onshore wind (northern Liaoning), nuclear baseload
   - Grid modernization: RMB 8-12 billion investment
4. **Regional Revitalization Linkage**:
   - Steel transformation as component of broader rust belt revitalization
   - Leverage existing skilled workforce and infrastructure
   - Create "Northeast Hydrogen Economy Zone" centered on steel decarbonization

Projected Outcomes:

Table 14: Liaoning Steel Transformation Pathway 2024-2035

Technology	2024	2030	2035	2040
BF-BOF (conventional)	88%	55%	35%	15%
BF-BOF with CCUS	0%	15%	25%	20%
H2-DRI-EAF	0%	20%	30%	50%
Scrap-EAF	12%	10%	10%	15%
Total Capacity (Mt)	**63**	**50**	**45**	**40**
Emissions (Mt CO_2)	**137**	**92**	**63**	**38**

7.5.5 Critical Success Factors and Challenges

Advantages:

- **Cost Competitiveness**: 20%+ LCOS advantage over other hydrogen provinces
- **Demonstration Value**: Success enables national scaling
- **Skilled Workforce**: Legacy steelmaking expertise
- **Lower Political Resistance**: Declining relative economic importance reduces resistance to change

Challenges:

- **Rust Belt Economics**: Limited provincial financial resources for subsidies
- **Population Decline**: Out-migration reduces domestic market and workforce
- **Infrastructure Aging**: Some facilities and supporting systems require modernization
- **Market Access**: Inland location (except Bayuquan) limits export potential

Assessment: Liaoning represents the strongest case for economically viable H2-DRI in China. If Ansteel Bayuquan achieves commercial success at competitive costs, it validates the hydrogen pathway for broader deployment. Success probability: 65-70% for achieving stated 2030 targets, higher than Hebei due to superior economics.

7.6 Guangdong Province: EAF Leader and Green Steel Market Pioneer

7.6.1 Distinctive Provincial Characteristics

Guangdong Province, China's most economically advanced region, exhibits a fundamentally different steel sector profile from the northern industrial heartlands:

Production Profile:

- Annual capacity: 40-45 Mt (approximately 4% of national total)
- Current technology: 45-50% BF-BOF, 50-55% EAF (highest EAF share nationally)
- Production centers: Guangzhou, Shaoguan, Shenzhen area
- Annual emissions: 70-80 Mt CO_2 (lowest intensity among major provinces)
- Emissions intensity: 1.75-1.80 t CO_2/t steel (vs 2.0-2.2 national average)

Economic and Market Context:

- Steel contribution to GDP: $< 3\%$ (lowest among major producing provinces)
- Economic structure: Dominated by high-tech manufacturing, electronics, services
- Market characteristics: High-value construction, automotive, appliance applications
- Environmental regulation: Strictest provincial standards outside Beijing-Tianjin-Hebei
- Green steel demand: Leading domestic market for certified low-carbon products

7.6.2 EAF Dominance and Scrap-Based Circular Economy

Guangdong's existing EAF leadership provides a foundation for further transformation:

Current EAF Infrastructure:

- Installed EAF capacity: 22-25 Mt (50-55% of provincial total)
- Average technology level: Modern, high-efficiency furnaces
- Primary feedstock: Scrap from manufacturing (electronics, automotive, construction)
- Scrap availability: 25-30 Mt annually (highest quality in China due to manufacturing base)

Scrap Supply Advantages:

1. **Manufacturing Scrap**:
   - Electronics manufacturing (Shenzhen, Dongguan): High-grade copper-bearing steel scrap
   - Automotive production: Clean manufacturing scrap with known chemistry
   - Appliance sector: Regular, predictable scrap generation
2. **Import Access**:
   - Proximity to Hong Kong facilitates scrap imports
   - Ports (Guangzhou, Shenzhen, Zhanjiang) handle international scrap trade
   - Southeast Asian scrap imports growing (Vietnam, Philippines, Thailand manufacturing)
3. **Quality Control**:
   - Advanced sorting and processing infrastructure
   - Highest scrap quality standards nationally
   - Closed-loop systems with major manufacturers

7.6.3 Green Steel Market Leadership

Guangdong is pioneering China's green steel premium market:

Demand-Side Drivers:

- **Real Estate Sector**: Green building certifications requiring low-carbon materials
- **Automotive OEMs**: Foreign joint ventures (Toyota, Honda, Nissan) with corporate carbon neutrality targets
- **Electronics Manufacturing**: Supply chain requirements from Apple, Samsung, other multinational buyers
- **Export-Oriented Manufacturing**: CBAM compliance driving green steel adoption
- **Government Procurement**: Guangdong provincial government mandating low-carbon steel in public projects

Green Steel Premium Capture:

- Current premium: RMB 200-400/t ($30-60/t) for certified low-carbon steel
- Acceptance rate: Approximately 30-40% of production sold at premium (highest nationally)
- Certification: Active EPD certification, ResponsibleSteel participation
- Market development: Guangdong steel companies partnering with end-users on carbon footprint reduction

7.6.4 Recent Developments and 2024-2025 Initiatives

Shaoguan Steel Group Transformation:

- One of Guangdong's largest integrated producers (8-10 Mt capacity)
- Announced major EAF expansion: Additional 3-4 Mt capacity by 2027
- Retiring aging BF-BOF capacity in urban Shaoguan location
- Investment: RMB 8-10 billion
- Target: Achieve 70% EAF share by 2028

Guangdong Province Steel Industry Development Plan (2024-2030): Key policy provisions:

1. **Capacity Target**: Net reduction to 35-38 Mt by 2030 (15-20% reduction)
2. **Technology Mandate**: Minimum 65-70% EAF share by 2030
3. **Emissions Intensity**: Target 1.2-1.3 t CO_2/t steel (vs current 1.75-1.80)
4. **Green Steel Certification**: 100% of production certified by 2028
5. **Renewable Electricity**: 80%+ renewable/nuclear electricity for EAF operations by 2030

Zhanjiang Steel Base Development (China Baowu subsidiary):

- Modern coastal integrated facility (10-12 Mt capacity)
- Among China's newest, most efficient BF-BOF operations
- Focus: Ultra-low emissions, preparing for CCUS and eventual H2-DRI integration
- Strategy: Maintain as high-efficiency BF facility serving export markets
- Long-term vision: Potential H2-DRI conversion post-2035 when technology mature

7.6.5 Renewable Energy Integration Strategy

Guangdong's electricity infrastructure supports aggressive EAF expansion:

Power Supply Characteristics:

- Nuclear power: 25+ GW capacity (Daya Bay, Yangjiang, Taishan plants)
- Offshore wind: Rapid expansion in South China Sea (target 20 GW by 2030)
- Imported hydropower: Yunnan and Guangxi hydroelectricity via ultra-high voltage
- Solar: Distributed generation and utility-scale (15+ GW by 2030)
- Grid reliability: Among China's most stable systems

Steel Sector Renewable Strategy:

- Target 2030: 25-30 TWh renewable/nuclear electricity for steel production
- Approach: Long-term PPAs with nuclear plants and offshore wind farms
- Cost: Competitive at RMB 0.35-0.45/kWh (lower than coal-fired electricity in northern provinces)
- Grid services: EAF operations providing demand response for grid balancing

7.6.6 Transformation Outcomes and National Significance

Projected Technology Evolution:

Table 15: Guangdong Province Steel Transformation 2024-2030

Technology	**2024**	**2027**	**2030**	**Emissions (t CO_2/t)**
BF-BOF (efficient)	48%	38%	30%	1.8-2.0
Scrap-EAF (grid)	30%	35%	20%	0.4-0.5
Scrap-EAF (renewable)	22%	27%	50%	0.1-0.15
Total Capacity (Mt)	**42**	**38**	**36**	–
Weighted Avg Intensity	**1.77**	**1.45**	**1.15**	–
Total Emissions (Mt CO_2)	**74.3**	**55.1**	**41.4**	–

National Significance:

- **Market Development**: Demonstrating viable green steel premium markets
- **Circular Economy Model**: Highest scrap utilization efficiency nationally
- **CBAM Readiness**: Leading position for EU export compliance
- **Technology Transfer**: Advanced EAF operations providing learning for other provinces
- **Policy Template**: Provincial regulations serving as model for other regions

Replicability: Guangdong's model most applicable to:

- Other economically advanced, manufacturing-intensive provinces (Zhejiang, Fujian)
- Regions with low steel dependency in GDP structure
- Areas with established green product markets and environmentally conscious consumers
- Coastal locations with renewable electricity access and scrap import potential

7.7 Inner Mongolia: The Renewable Energy Enabler

7.7.1 Strategic Role in National Steel Decarbonization

Inner Mongolia Autonomous Region occupies a unique position in China's steel transformation—not primarily as a major steel producer, but as the critical renewable energy supplier enabling decarbonization in major producing provinces.

Production Profile:

- Annual steel capacity: 25-30 Mt (approximately 2.5% of national total)
- Ranking: Mid-tier among provinces
- Current technology: 92% BF-BOF, 8% EAF (similar to Hebei)
- Major producers: Inner Mongolia Baotou Steel (Baosteel), regional smaller mills

Why Inner Mongolia Matters Beyond Steel Production: Inner Mongolia's significance lies in its transformative role as China's renewable energy powerhouse:

1. **Renewable Energy Resources**:

- Wind power potential: 150+ GW technically exploitable (among world's largest)
- Solar power potential: 100+ GW in Gobi Desert and grasslands
- Installed renewable capacity (2024): 85+ GW wind + solar (national leader)
- Target 2030: 200+ GW total renewable capacity

2. **Green Hydrogen Production Potential**:
    - Lowest-cost green hydrogen production region in China
    - Estimated 2030 green H_2 cost: RMB 7-9/kg ($1.00-1.30/kg)
    - Abundant land for electrolyzer facilities and solar/wind co-location
    - Water availability from Yellow River system (constraint requiring management)

3. **Geographic Positioning**:
    - Northern border with Russia (potential for international hydrogen trade)
    - Adjacent to major steel provinces: Hebei, Shanxi, Shaanxi
    - Ultra-high voltage transmission corridors to eastern China

7.7.2 Recent Developments: 2024-2025 Hydrogen Valley Initiatives

Inner Mongolia has emerged as the focal point for China's green hydrogen development, with major implications for steel decarbonization:

National Hydrogen Demonstration Zones:

- Ordos City: Designated as national hydrogen economy demonstration
- Baotou City: Industrial hydrogen application zone (including steel)
- Wuhai City: Hydrogen chemical integration zone
- Combined investment commitment: RMB 80-100 billion through 2030

Major Green Hydrogen Projects (2024-2025 Announcements):

1. **Inner Mongolia Energy Group - Ordos Green Hydrogen Project**:
    - Capacity: 30,000 tonnes green H_2/year (Phase 1, operational 2024)
    - Expansion target: 200,000 tonnes/year by 2028
    - Renewable integration: 1 GW solar + wind dedicated capacity
    - Applications: Industrial hydrogen, steel sector supply, chemical feedstock
    - Pipeline: 300 km pipeline to Hebei steel facilities (under construction)

2. **State Power Investment Corporation (SPIC) - Ulanqab Hydrogen Project**:
    - Capacity: 50,000 tonnes green H_2/year (targeting 2026 completion)
    - Technology: Alkaline and PEM electrolyzers (mixed portfolio)
    - Renewable source: 2 GW wind farms in Ulanqab grasslands
    - Strategic focus: Supply to Beijing-Tianjin-Hebei steel corridor
    - Cost target: RMB 8-10/kg at full operation

3. **China National Petroleum Corporation (CNPC) - Baotou Integrated Project**:

- Combining grey hydrogen retrofit with green hydrogen expansion
- Phase 1: 40,000 tonnes/year green H_2 (2025-2026)
- Integration with Baotou Steel for direct H2-DRI demonstration
- Long-term vision: 150,000 tonnes/year by 2030

Aggregate Impact:

- Total announced green H_2 capacity by 2030: 500,000-600,000 tonnes/year
- If achieved, sufficient to supply 8-12 Mt H2-DRI production nationally
- Critical mass for pipeline infrastructure economic viability
- Potential to drive hydrogen costs below RMB 10/kg threshold

7.7.3 Infrastructure Development: Hydrogen Pipeline Networks

The transformation of Inner Mongolia from energy supplier to hydrogen supplier requires unprecedented infrastructure:

Inner Mongolia-Hebei Hydrogen Corridor:

- **Route**: Ordos → Hohhot → Zhangjiakou → Tangshan/Shijiazhuang
- **Distance**: Approximately 800-1,000 km
- **Capacity**: Initial 200,000 tonnes H_2/year, expandable to 500,000 tonnes
- **Investment**: RMB 15-20 billion
- **Timeline**: First sections operational 2026, full completion 2028-2029
- **Technology**: Dedicated hydrogen pipeline (not repurposed natural gas)
- **Strategic importance**: Enables Hebei's steel decarbonization without local H_2 production

Additional Pipeline Networks (Proposed/Early Planning):

- Inner Mongolia → Shanxi (250 km, supporting Taiyuan steel cluster)
- Inner Mongolia → Shaanxi (400 km, Xi'an industrial corridor)
- Northern logistics network connecting to Russian border (long-term export potential)

Technical and Economic Challenges:

- **Hydrogen Embrittlement**: Pipeline material selection critical for long-term integrity
- **Compression Energy**: Significant electricity requirement for hydrogen transport
- **Economic Threshold**: Requires high utilization rates (70%+) for cost-effectiveness
- **Regulatory Framework**: Safety standards and operational protocols still developing
- **Coordination**: Multiple provinces, SOEs, and regulatory bodies must align

7.7.4 Local Steel Sector Transformation

While supporting other provinces' hydrogen needs, Inner Mongolia is also transforming its own steel sector:

Baotou Steel (Baosteel) Decarbonization:

- Production: 12-15 Mt annually
- Current technology: Conventional BF-BOF (rare earth steel specialty)
- Unique position: Proximity to Bayan Obo rare earth mine creates strategic value
- Transformation strategy:
  - Phase 1 (2025-2027): H2-DRI demonstration at 1-2 Mt scale
  - Phase 2 (2027-2030): Expand to 4-5 Mt H2-DRI capacity
  - Maintain 8-10 Mt specialized BF-BOF for rare earth steel integration
  - Target: 50% emissions reduction by 2030 vs 2024 baseline
- Competitive advantage: Lowest-cost green hydrogen access in China
- Product focus: High-value rare earth steel for advanced manufacturing

Regional Capacity Consolidation:

- Multiple small-scale producers (2-5 Mt capacity each) facing closure under 1.5:1 policy
- Provincial government encouraging consolidation into Baosteel
- Target: Reduce regional capacity from 28-30 Mt to 20-22 Mt by 2030
- Strategy: Quality over quantity, leveraging hydrogen cost advantage

7.7.5 Renewable Energy Integration and Grid Development

Inner Mongolia's renewable expansion must overcome significant technical challenges:

Current Grid Constraints:

- **Curtailment Problem**: 10-15% of wind/solar generation curtailed due to insufficient transmission
- **Distance to Demand Centers**: 1,000-1,500 km to major consumption areas
- **Seasonal Variability**: Winter heating demand conflicts with summer renewable peak

Grid Modernization Initiatives (2024-2030):

- **Ultra-High Voltage (UHV) Expansion**:
  - New ±800 kV DC transmission lines to Hebei, Shandong, Jiangsu
  - Capacity addition: 30-40 GW transmission capability
  - Investment: RMB 50-70 billion
- **Energy Storage Deployment**:
  - Pumped hydro storage: 3-5 GW capacity (mountainous regions)

  - Battery storage: 5-8 GWh (grid-scale lithium-ion)
  - Hydrogen storage: Using electrolyzers as "storage" via H_2 production

- **Smart Grid and Demand Response**:
  - Integration of industrial loads (electrolyzers, EAF steel) as flexible demand
  - Real-time pricing to incentivize consumption during renewable peaks
  - Grid forecasting and optimization systems

7.7.6 Inner Mongolia's Strategic Contribution to National Steel Decarbonization

Quantitative Impact Assessment:
If Inner Mongolia achieves its renewable hydrogen development targets:

Table 16: Inner Mongolia's Enabling Role in National Steel Decarbonization

Metric	2030 Target	National Impact
Green H_2 Production (tonnes/year)	500,000-600,000	Enables 8-12 Mt H2-DRI
H2-DRI Emissions Reduction	–	15-22 Mt CO_2/year
Renewable Electricity Export (TWh)	150-200	Supports 30-40 Mt EAF
EAF Emissions Reduction	–	45-60 Mt CO_2/year
Total Enabled Reduction	–	**60-82 Mt CO_2/year**
Share of National Steel Reduction Target	–	25-35%

Critical Success Factors:

1. **Cost Achievement**: Green H_2 must reach RMB 8-10/kg to enable competitive H2-DRI
2. **Infrastructure Completion**: Pipelines and UHV transmission must deliver on schedule
3. **Coordination**: Inner Mongolia, Hebei, and national authorities must align planning
4. **Water Resources**: Sustainable water management for electrolysis in arid region
5. **Policy Stability**: Long-term subsidies and support mechanisms during scale-up phase

Risks and Challenges:

- **Infrastructure Delays (High Risk)**: Complex, multi-province projects face coordination challenges
- **Water Scarcity (Medium Risk)**: Electrolysis water demand conflicts with agriculture
- **Economic Viability (Medium Risk)**: Hydrogen economics depend on continued policy support
- **Technological Risk (Low-Medium)**: Electrolyzer and pipeline technology mature but scaling untested

Assessment: Inner Mongolia represents a necessary but not sufficient condition for China's hydrogen steel pathway success. Provincial development is progressing faster than in most regions, but achieving 500,000+ tonnes/year green hydrogen by 2030 requires sustained policy commitment and infrastructure investment. Success probability: 55-60%.

7.8 Provincial Comparison and Strategic Insights

7.8.1 Divergent Pathways Synthesis

The provincial analyses reveal fundamentally different approaches to steel decarbonization across China:

Table 17: Provincial Steel Decarbonization Strategies Comparison

Province	Capacity (Mt)	Primary Pathway	2030 Target Reduction	Key Enabler	Critical Challenge
Hebei	250	H2-DRI (60%), CCUS (30%), EAF (10%)	33-38%	HBIS Zhangjiakou demo, political will	Hydrogen cost, infrastructure
Jiangsu	120	EAF (70%), H2-DRI (20%), CCUS (10%)	50-55%	Scrap availability, grid capacity	Scrap quality, capital
Shandong	82	Balanced: EAF (40%), CCUS (40%), H2-DRI (20%)	30-35%	Coastal location, diversified approach	Coordination complexity
Liaoning	63	H2-DRI (60%), CCUS (25%), EAF (15%)	30-35%	Lowest LCOS for H2-DRI	Rust belt economics
Guangdong	42	EAF (85-90%), efficient BF (10-15%)	40-45%	Green steel market, low GDP dependency	Limited scale impact
Inner Mongolia	28	H2-DRI (40%), BF-BOF (50%), EAF (10%)	25-30%	Renewable H_2 production	Water scarcity

7.8.2 Technology Pathway Suitability Matrix

Different provinces exhibit varying suitability for each major decarbonization technology:

Hydrogen DRI-EAF Suitability:

- **Most Suitable**: Liaoning (low electricity cost), Inner Mongolia (local H_2 production), Hebei (political priority + infrastructure investment)
- **Moderately Suitable**: Shandong (coastal, moderate costs), Shanxi (coal-to-hydrogen transition potential)
- **Less Suitable**: Jiangsu, Guangdong (superior scrap-EAF economics make H2-DRI less competitive)

Scrap-Based EAF Suitability:

- **Most Suitable**: Guangdong (existing leadership, scrap quality), Jiangsu (scrap availability, grid), Zhejiang (manufacturing base)
- **Moderately Suitable**: Shandong (growing scrap generation), Hebei (limited by scrap availability)
- **Less Suitable**: Shanxi, Inner Mongolia (limited scrap generation in resource-based economies)

CCUS on Blast Furnaces:

- **Most Suitable**: Shandong (Shengli Oilfield CO_2 storage), Liaoning (Liaohe Oilfield), offshore provinces with geological storage
- **Transitional Role**: All provinces for maintaining some BF capacity during transition
- **Long-term**: CCUS most economically viable as bridge technology, not endpoint

7.8.3 Critical Insights for National Policy

The provincial diversity reveals several critical insights for national-level policy design:

1. No One-Size-Fits-All Approach:

- Beijing's challenge: Allow provincial flexibility while ensuring national targets achieved
- Policy framework must accommodate different technology pathways
- Risk: Overly prescriptive national mandates may force suboptimal provincial choices
- Opportunity: Provincial experimentation can identify most effective approaches for different contexts

2. Infrastructure Coordination Critical:

- Inner Mongolia's hydrogen development depends on Hebei's demand commitment
- Hebei's transformation requires Inner Mongolia's renewable hydrogen supply
- Multi-province infrastructure (pipelines, UHV transmission) requires national-level coordination
- Current governance: Fragmented provincial planning with insufficient cross-provincial mechanisms

3. Cost Competitiveness Determines Success:

- Jiangsu's EAF pathway ($730-780/t LCOS) naturally competitive
- Liaoning's H2-DRI ($1,310/t LCOS) requires 40-45% cost reduction vs current
- Hebei's H2-DRI ($1,580/t LCOS) requires sustained subsidies or carbon pricing to achieve viability
- Implication: EAF pathways likely to progress faster than hydrogen routes absent major policy interventions

4. Scrap Availability as National Constraint:

- Ambitious EAF expansion across provinces (Jiangsu, Guangdong, Shandong) creates competition for limited scrap
- National scrap availability 2030: Projected 320-350 Mt
- Total EAF capacity if all provinces achieve targets: 350-400 Mt capacity requiring 315-360 Mt scrap at 90% utilization
- **Tension**: Near-complete scrap utilization required, limiting flexibility and quality selection
- **Resolution**: Hybrid DRI-scrap EAF operations, expanded scrap imports, improved collection efficiency

5. Just Transition Complexity Varies by Province:

- Hebei: Massive challenge (150,000-200,000 jobs at risk, 15-20% GDP dependency)
- Liaoning: Rust belt complication (aging workforce, limited alternative industries)
- Guangdong, Jiangsu: Manageable (diversified economies, growing sectors absorb displaced workers)
- National policy must provide differentiated support based on provincial socioeconomic capacity

8 Technology Deep Dive: Pathways to Near-Zero Emissions

8.1 Hydrogen Direct Reduced Iron (H2-DRI) Pathway

8.1.1 Technical Fundamentals and Process Description

Hydrogen direct reduced iron represents the most technically mature pathway to near-zero emission primary steelmaking:

Process Overview:

1. **Iron Ore Preparation**:
    - High-grade iron ore pellets (67%+ Fe content) required
    - Pelletization process: Fine ore → pellets (10-15 mm diameter)
    - Quality critical: Low gangue content, consistent chemistry
2. **Direct Reduction**:
    - Temperature: 850-1,050°C (below iron melting point of 1,538°C)
    - Reducing agent: Hydrogen gas (H_2) or H_2/CO mixture
    - Reaction: $Fe_2O_3 + 3H_2 \rightarrow 2Fe + 3H_2O$ (exothermic)
    - Technology: Shaft furnace (most common) or fluidized bed reactors
    - Duration: 4-8 hours residence time
    - Product: Direct Reduced Iron (DRI or "sponge iron") with 90-95% metallization
3. **Electric Arc Furnace Melting**:
    - DRI charged to EAF (can be mixed with scrap)
    - Electricity: 400-550 kWh per tonne steel
    - Temperature: 1,600-1,700°C for complete melting
    - Refining: Secondary metallurgy for chemistry adjustment
    - Casting: Continuous casting to slabs, billets, or blooms

Hydrogen Requirements:

- Approximately 50-60 kg H_2 per tonne of DRI produced
- For 1 tonne steel: 50-65 kg H_2 (depending on DRI vs scrap ratio)
- Quality requirements: 99.9%+ purity (avoiding catalyst poisoning)
- Supply options: Green (electrolysis), blue (natural gas + CCUS), grey (natural gas, no capture)

8.1.2 Emissions Profile and Carbon Footprint

The carbon footprint of H2-DRI steel depends critically on hydrogen source:

Green Hydrogen DRI-EAF (Renewable Electricity):

- H_2 production via electrolysis: 0.05-0.10 t CO_2/t DRI (upstream renewable electricity emissions)

- DRI production: Negligible direct emissions (only H_2O vapor)
- EAF melting: 0.05-0.10 t CO_2/t steel (renewable electricity upstream emissions)
- Auxiliary processes: 0.05-0.10 t CO_2/t steel (natural gas for pelletizing, lime, etc.)
- **Total: 0.15-0.30 t CO_2/t steel** (achieves IEA near-zero threshold of 0.4 t)

Natural Gas-Based DRI-EAF (without CCUS):

- H_2 from natural gas reforming: 0.50-0.70 t CO_2/t DRI
- DRI production: 0.10-0.15 t CO_2/t DRI (process emissions)
- EAF melting: 0.15-0.25 t CO_2/t steel (grid electricity)
- Auxiliary: 0.05-0.10 t CO_2/t steel
- **Total: 0.80-1.20 t CO_2/t steel** (45-60% reduction vs conventional BF-BOF)

Conventional BF-BOF (Baseline):

- **Total: 1.8-2.2 t CO_2/t steel** (China average approximately 2.0-2.1 t)

8.1.3 Economic Analysis: Levelised Cost of Steel

The economics of H2-DRI are dominated by hydrogen costs:

Cost Structure for Green H2-DRI-EAF (2030 Projections, Liaoning - Best Case China):

Table 18: H2-DRI-EAF Cost Breakdown (Liaoning, 2030 Projection)

Cost Component	Value	Share (%)
Capital Costs (annualized):		
DRI plant	\$180/t	14%
EAF and casting	\$120/t	9%
Hydrogen production (allocated)	\$150/t	11%
Capital Subtotal	**\$450/t**	**34%**
Operating Costs:		
Iron ore pellets	\$180/t	14%
Hydrogen (60 kg @ \$1.40/kg)	\$350/t	27%
Electricity for EAF	\$90/t	7%
Labor and maintenance	\$120/t	9%
Other inputs	\$120/t	9%
Operating Subtotal	**\$860/t**	**66%**
Total LCOS	**\$1,310/t**	**100%**

Sensitivity to Hydrogen Cost:

- At H_2 = \$1.00/kg (RMB 7/kg): LCOS = \$1,160/t (green steel competitive)
- At H_2 = \$1.40/kg (RMB 10/kg): LCOS = \$1,310/t (requires subsidies or carbon pricing)
- At H_2 = \$2.00/kg (RMB 14/kg): LCOS = \$1,670/t (not commercially viable without massive support)
- **Critical Threshold**: H_2 must reach \$1.00-1.40/kg for economic viability

Comparison with Conventional BF-BOF:

- Conventional BF-BOF LCOS: $550-650/t (China average, without carbon pricing)
- Green H2-DRI premium: $660-760/t (**120-140% premium**)
- Required carbon price for parity: $300-380/t CO_2 (current China ETS: $12-16/t CO_2)
- **Gap to close: 20-30x increase in carbon pricing, or equivalent subsidies**

8.1.4 Implementation Status in China

HBIS Zhangjiakou - Leading Demonstration:

- Status: Phase 1 operational (1.2 Mt/year), as analyzed in Hebei section
- Current hydrogen: Grey H_2 from coke oven gas (transitional)
- Key learnings: Process stability, product quality validation, operational optimization
- Challenges identified: Hot DRI transport logistics, hydrogen purity management, EAF integration
- Next phases: Scale to 5-8 Mt, transition to green hydrogen

Ansteel Bayuquan - Cost-Competitive Route:

- Status: Under construction, targeting 2026-2027 first production
- Capacity: 1.5-2.0 Mt initial, expandable to 4-5 Mt
- Strategic advantage: Liaoning's low electricity costs
- Hydrogen strategy: Phased transition grey → blue → green
- Significance: Proving commercial viability in best-case cost environment

Other Announced Projects (Various Stages):

- Shandong Steel: Small-scale pilots (0.5-1.0 Mt each)
- Baotou Steel: Local H_2 integration (1-2 Mt)
- China Baowu: Technology scouting, potential deployment post-2027
- Aggregate pipeline: 10-15 Mt capacity by 2030 if all projects proceed

8.1.5 Critical Success Factors and Barriers

Technical Challenges:

1. **Hydrogen Purity and Handling**:
    - Requires 99.9%+ purity to avoid operational issues
    - Hydrogen embrittlement of equipment and pipelines
    - Safety protocols for large-scale H_2 storage and transport
    - Workforce training for hydrogen safety

2. **Hot DRI Transport**:
   - DRI is pyrophoric (spontaneously combusts) when exposed to air
   - Optimal: Hot DRI direct charging to EAF (requires close physical proximity)
   - Alternative: Cold DRI with protective atmosphere (higher energy penalty)
   - Logistics constraint: Limits flexibility in facility siting
3. **Iron Ore Quality**:
   - Requires higher-grade ore than conventional BF (67%+ vs 62%+ Fe)
   - Limited global supply of premium DR-grade pellets
   - Potential supply bottleneck as H2-DRI scales globally

Economic Barriers:

1. **Hydrogen Cost Imperative**:
   - Must achieve $1.00-1.40/kg for competitiveness
   - Current green H_2: $2.50-4.00/kg (China, 2024)
   - Requires 60-75% cost reduction
   - Timeline uncertain: Optimistic 2028-2030, conservative 2032-2035
2. **Capital Intensity**:
   - H2-DRI-EAF requires $900-1,200/t capacity investment
   - Conventional BF-BOF: $300-450/t capacity (for greenfield)
   - **2.5-3x capital requirement**
   - Brownfield retrofit: Can reduce capital needs but limited applicability
3. **Stranded Asset Risk**:
   - Natural gas-based DRI (transitional) may become stranded as carbon costs rise
   - Grey hydrogen facilities face regulatory phase-out risk
   - Uncertainty discourages investment without long-term policy guarantees

Infrastructure Dependencies:

- Hydrogen production capacity must scale 50-100x current levels
- Pipeline networks require 5-10 year development timelines
- Renewable electricity expansion must pace electrolyzer deployment
- Multi-sector coordination (energy, steel, transport) complex

Assessment: H2-DRI represents the most credible pathway to near-zero emission primary steelmaking, but faces formidable economic and infrastructure barriers. China's demonstrations (HBIS, Ansteel) are progressing, but achieving competitive economics by 2030 requires 55-65% probability, and national scaling to 20-30 Mt capacity requires sustained policy support and favorable hydrogen cost trajectory. The technology is viable; the economics remain challenging.

Challenge: Maintaining transformation pressure through:

- Economic downturns that reduce steel demand and profitability
- Leadership transitions at provincial and national levels
- Competing policy priorities (economic growth, employment, technological sovereignty)
- Social unrest from job losses and regional economic decline

Current Status:

- Strong commitment at highest levels (Xi Jinping's carbon neutrality pledge)
- Steel decarbonization explicitly included in 14th and 15th FYP documents
- October 2025 policy intensification demonstrates sustained commitment
- However: 2024 economic slowdown led to temporary relaxation of output controls

Sustainability Probability (60-65%):

- **Favorable Factors**:
  - Climate commitments tied to international credibility and leadership
  - Air quality improvements directly benefit politically powerful urban populations
  - State capacity for long-term planning and policy consistency
  - Integration with broader technological sovereignty goals (hydrogen economy, renewable energy)
- **Risk Factors**:
  - Economic growth slowdown reduces tolerance for industrial restructuring pain
  - Provincial governments prioritize local GDP and employment over national environmental goals
  - Steel industry lobbying power remains substantial
  - Social stability concerns could trigger policy reversal if unemployment surges

Critical Junctures:

- 2026-2027: First wave of major capacity closures tests social stability
- 2028: 15th FYP mid-term evaluation assesses progress and adjusts targets
- 2030: Emissions peak deadline creates political accountability moment
- 2032-2035: Sustained commitment needed despite likely economic cycles

8.1.6 Factor 5: Just Transition Program Delivery (Weight: 10%)

Scale of Employment Challenge:

Table 19: Employment Impact by Province (2024-2030)

Province	Current Jobs	At Risk	% Loss
Hebei	600,000-800,000	150,000-200,000	25-30%
Jiangsu	180,000-220,000	45,000-60,000	25-27%
Shandong	180,000-200,000	40,000-55,000	22-27%
Liaoning	120,000-140,000	30,000-40,000	25-28%
Other provinces	450,000-550,000	90,000-145,000	20-26%
National Total	**1.53-1.91 million**	**355,000-500,000**	**23-26%**

Required Program Components:

1. **Active Labor Market Programs**:
   - Skills retraining for renewable energy, hydrogen infrastructure, advanced manufacturing sectors
   - Job placement services and mobility assistance
   - Wage insurance to maintain 80-90% of previous income during transition
   - Duration: 18-36 months per worker
   - Cost: RMB 50,000-80,000 per worker = RMB 17.8-40 billion nationally
2. **Early Retirement Options**:
   - Workers age 55+ (men) or 50+ (women) eligible for early retirement
   - Pension top-up to prevent income loss
   - Estimated 40-45% of displaced workers eligible
   - Cost: RMB 100,000-150,000 per worker = RMB 14.2-33.8 billion
3. **Regional Economic Diversification**:
   - Investment in alternative industries: renewable energy manufacturing, logistics, advanced materials
   - Special economic zones in steel-dependent cities
   - Infrastructure projects to create temporary employment
   - Cost: RMB 30-50 billion over 5-7 years
4. **Social Safety Net Strengthening**:
   - Enhanced unemployment insurance
   - Healthcare continuation for displaced workers
   - Housing support in regions with declining property values
   - Cost: RMB 10-20 billion

Total Program Cost: RMB 72-143.8 billion ($10-20 billion) nationally
Success Probability (55-60%):

- **Favorable Factors**:
  - China has experience with large-scale industrial workforce transitions (coal sector restructuring 2016-2020)
  - State capacity to mobilize resources and coordinate programs
  - Financial resources available (though requiring political prioritization)
  - Precedent of generous support packages preventing social unrest
- **Challenge Factors**:
  - Scale exceeds previous transitions (coal restructuring affected 1.3 million workers over 4 years; steel transition affects similar numbers in more compressed timeframe)
  - Regional concentration creates localized economic crises
  - Alternative employment opportunities limited in steel-dependent cities
  - Aging workforce (average age 45-50) faces retraining challenges
  - Success requires 60-70% re-employment within 24 months—historically difficult threshold

Consequence of Failure:

- Social unrest in Hebei, Liaoning, Shanxi steel cities
- Political pressure to slow or reverse capacity reduction
- Potential for entire transformation program to stall or collapse
- Historical precedent: France's 1970s-80s steel crisis delayed restructuring for a decade due to social resistance

8.1.7 Factor 6: Green Steel Market Creation (Weight: 10%)

Demand Requirements:

To justify investment in higher-cost green steel production, viable markets must absorb 40-50 Mt by 2030 and 150-200 Mt by 2040.

Market Segments:

1. **Government Procurement Mandates**:
   - Infrastructure projects (high-speed rail, bridges, public buildings)
   - Potential: 15-20 Mt/year by 2030
   - Policy status: Informal preferences exist; formal mandates under development
   - Challenge: Government projects price-sensitive; requires subsidy or mandate
2. **Automotive Sector**:
   - Leading OEMs (Great Wall Motors, Geely, BYD, NIO, Chery) announcing sustainability commitments
   - Premium EV brands willing to pay green steel premium for brand differentiation
   - Potential: 12-18 Mt/year by 2030 (20-25% of automotive steel demand)
   - Status: Pilots and partnerships emerging (HBIS-Great Wall Motors, Baowu-Tesla China)

   - Challenge: Cost premium must remain below 10-15% to maintain competitiveness

3. **Appliances and Electronics**:
   - Export-oriented manufacturers facing EU CBAM pressure
   - Consumer goods brands emphasizing sustainability
   - Potential: 5-8 Mt/year by 2030
   - Status: Early adoption by premium brands (Midea, Haier in pilot programs)

4. **Construction Sector**:
   - Green building certifications incentivizing low-carbon materials
   - Commercial and high-end residential projects
   - Potential: 8-12 Mt/year by 2030
   - Challenge: Highly price-competitive sector; requires strong policy push

5. **Export Markets (CBAM-Driven)**:
   - EU Carbon Border Adjustment Mechanism (CBAM) creates export incentive
   - Potential: 5-10 Mt/year exports by 2030
   - Status: CBAM implementation 2026-2034 creates growing premium for low-carbon steel
   - Challenge: Certification and verification requirements; competition from EU producers

Total Market Potential 2030: 45-68 Mt (sufficient to absorb green steel production)
Pricing Dynamics:

- **Current Green Steel Premium**: 15-25% above conventional steel
- **Acceptable Premium (Market Research)**: 5-10% for most industrial applications
- **Required Cost Reduction**: Green steel production costs must decline 10-15% through scale economies and technology learning
- **Alternative**: Carbon pricing of RMB 100-150/tonne CO_2 makes green and conventional steel price-competitive

Success Probability (60-70%):
Market creation probability relatively high due to:

- Government ability to mandate procurement
- Export pressure from CBAM
- Growing corporate sustainability commitments
- China's integrated supply chain enabling coordination

However, sustained market depends on:

- Green steel cost competitiveness improving
- Policy consistency maintaining demand pressure
- International standards recognizing Chinese green steel certifications
- Domestic carbon pricing providing economic signal

8.2 Integrated Probability Assessment

Combining the six critical success factors with assigned weights:

Table 20: Integrated Success Factor Assessment

Factor	Weight	Probability	Weighted
Hydrogen Cost Trajectory	30%	50-60%	15-18%
HBIS Zhangjiakou Scaling	20%	60-65%	12-13%
Infrastructure Development	15%	55-60%	8.25-9%
Political Will Sustainability	15%	60-65%	9-9.75%
Just Transition Delivery	10%	55-60%	5.5-6%
Green Steel Market Creation	10%	60-70%	6-7%
Overall Success Probability	**100%**	–	**55.75-62.75%**

Interpretation: Approximately 56-63% probability of achieving "Managed Transformation" scenario (50-60% national emissions reduction by 2040, technology mix transition, but with delays and higher costs than optimistic projections).

9 Scenario Analysis: Three Pathways to 2040

9.1 Scenario 1: Green Steel Pioneer (Probability: 20-25%)

9.1.1 Defining Characteristics

- Hydrogen costs reach RMB 8-10/kg by 2028-2029 (vs target 2030)
- HBIS Zhangjiakou scales to 10 Mt by 2030 with operational stability
- Political will sustained through economic cycles
- Just transition programs achieve 70%+ re-employment rates
- Green steel market develops robustly with 10-15% premiums accepted

9.1.2 Quantitative Outcomes (2040)

Table 21: Green Steel Pioneer Scenario Outcomes

Metric	2024 Baseline	2040 Outcome
Total Steel Capacity (Mt)	1,100-1,150	900-950
H_2-DRI Capacity (Mt)	1-2	300-350 (33-37%)
EAF Capacity (Mt)	140-160	400-450 (44-47%)
BF-BOF (conventional) (Mt)	950-1,000	150-200 (16-21%)
BF-BOF with CCUS (Mt)	Minimal	50-100 (5-11%)
Annual Emissions (Mt CO_2)	2,100-2,200	650-800
Emissions Reduction	–	**62-70%**
Green Hydrogen Production (Mt)	0.06-0.08	4.5-5.5
Renewable Energy (GW)	1,200 (total)	500-600 (steel-dedicated)
Investment (RMB trillion)	–	2.8-3.5

9.1.3 Technology Leadership Outcomes

- China establishes global leadership in H_2-DRI technology
- Technology export potential: licensing shaft furnace designs, electrolyzer manufacturing, integrated steel-hydrogen systems
- Domestic supply chain: world's largest hydrogen infrastructure, electrolyzer production capacity 30-40 GW/year
- Cost position: Green steel production at parity or 5% premium vs global conventional steel by 2040

9.1.4 Critical Enablers

This scenario requires:

1. Breakthrough in electrolyzer costs: $300-350/kW by 2030 (vs current $800/kW)
2. Inner Mongolia hydrogen production and pipeline infrastructure operational by 2028
3. Zero major social unrest events during 2026-2030 capacity reduction phase
4. Sustained GDP growth 4-5% annually maintaining political space for transformation
5. CBAM and international green steel standards create strong export incentives

9.1.5 Global Implications

Success of this scenario would:

- Eliminate 1,300-1,450 Mt CO_2 annually from global steel emissions (35-40% of 2024 global steel sector emissions)
- Validate hydrogen steelmaking economics, accelerating global adoption
- Position China as green industrial technology leader, analogous to solar PV dominance
- Create competitive pressure on European, Japanese, Korean steelmakers to accelerate transformation
- Demonstrate feasibility of deep industrial decarbonization, strengthening Paris Agreement credibility

9.2 Scenario 2: Managed Transformation (Probability: 50-55%)

9.2.1 Defining Characteristics

- Hydrogen costs reach RMB 10-12/kg by 2030-2032 (2-3 year delay)
- HBIS Zhangjiakou scales to 6-8 Mt by 2030 with some operational challenges
- Political will sustained but with periodic relaxations during economic downturns
- Just transition programs achieve 55-65% re-employment, requiring enhanced support
- Green steel market develops but requires policy mandates and subsidies

9.3 Scenario 2: Managed Transformation (Probability: 50-55%)

9.3.1 Defining Characteristics

- Hydrogen costs reach RMB 10-12/kg by 2030-2032 (2-3 year delay)
- HBIS Zhangjiakou scales to 6-8 Mt by 2030 with some operational challenges
- Political will sustained but with periodic relaxations during economic downturns
- Just transition programs achieve 55-65% re-employment, requiring enhanced support
- Green steel market develops but requires policy mandates and subsidies

9.3.2 Quantitative Outcomes (2040)

Table 22: Managed Transformation Scenario Outcomes

Metric	2024 Baseline	2040 Outcome
Total Steel Capacity (Mt)	1,100-1,150	950-1,000
H_2-DRI Capacity (Mt)	1-2	180-220 (18-22%)
EAF Capacity (Mt)	140-160	350-400 (35-40%)
BF-BOF (conventional) (Mt)	950-1,000	250-320 (25-32%)
BF-BOF with CCUS (Mt)	Minimal	150-200 (15-20%)
Annual Emissions (Mt CO_2)	2,100-2,200	850-1,050
Emissions Reduction	–	**52-60%**
Green Hydrogen Production (Mt)	0.06-0.08	2.8-3.5
Renewable Energy (GW)	1,200 (total)	350-450 (steel-dedicated)
Investment (RMB trillion)	–	2.2-2.8

9.3.3 Implementation Characteristics

- Delays in hydrogen infrastructure (pipelines, electrolyzers) of 2-4 years
- Periodic policy relaxation during economic downturns (2026-2027, 2032-2033)
- Higher-than-expected subsidies required for green steel market development
- Social tensions in Hebei and Liaoning requiring additional transition funding
- Technology learning occurs but at slower pace than optimal

9.3.4 Global Implications

- China achieves substantial emissions reduction but misses most ambitious targets
- Global steel emissions decline by 1,000-1,200 Mt CO_2/year (significant but insufficient for Paris alignment)
- Hydrogen steelmaking proven viable but not yet cost-competitive without support
- China maintains steel production leadership but without clear technology export advantage
- EU and other regions face continued competitive pressure from Chinese conventional steel

9.4 Scenario 3: Troubled Transition (Probability: 20-25%)

9.4.1 Defining Characteristics

- Hydrogen costs remain at RMB 15-18/kg through 2035 (technology and scale failures)
- HBIS Zhangjiakou limited to 3-4 Mt with persistent operational issues
- Political will fractures during economic downturn (2026-2028)
- Just transition programs achieve <50% re-employment, triggering social unrest
- Green steel market fails to develop beyond niche applications

9.4.2 Quantitative Outcomes (2040)

Table 23: Troubled Transition Scenario Outcomes

Metric	2024 Baseline	2040 Outcome
Total Steel Capacity (Mt)	1,100-1,150	1,000-1,100
H_2-DRI Capacity (Mt)	1-2	40-60 (4-6%)
EAF Capacity (Mt)	140-160	250-300 (25-27%)
BF-BOF (conventional) (Mt)	950-1,000	550-650 (55-59%)
BF-BOF with CCUS (Mt)	Minimal	100-150 (10-14%)
Annual Emissions (Mt CO_2)	2,100-2,200	1,200-1,450
Emissions Reduction	–	**34-43%**
Green Hydrogen Production (Mt)	0.06-0.08	0.8-1.2
Renewable Energy (GW)	1,200 (total)	150-200 (steel-dedicated)
Investment (RMB trillion)	–	1.5-2.0

9.4.3 Critical Failure Points

1. **2026-2027 Economic Downturn**: Steel demand drops 15-20%, triggering policy relaxation and capacity replacement delays
2. **2028 Social Unrest**: Hebei steel cities experience protests over unemployment, forcing restructuring pause
3. **2030 Hydrogen Cost Reality**: Failure to achieve cost targets undermines investment confidence
4. **2032 Political Transition**: New leadership prioritizes economic stability over environmental goals
5. **2034 Infrastructure Gaps**: Hydrogen pipeline and renewable transmission projects significantly delayed

9.4.4 Global Implications

- China's steel emissions remain world's largest, undermining global climate goals
- Paris Agreement 1.5°C target becomes mathematically unattainable
- EU CBAM creates trade tensions without driving meaningful emissions reduction

- Global hydrogen economy development delayed by 5-10 years
- China loses technological leadership opportunity to EU or other regions

10 Conclusions and Strategic Recommendations

10.1 Key Findings Summary

10.1.1 Policy Effectiveness Assessment

China's October 2025 capacity replacement policy represents the world's most ambitious steel decarbonization framework:

- **Strengths**: Clear quantitative targets, enforceable mechanisms, technology incentives, regional differentiation
- **Weaknesses**: Economic rigidity, provincial implementation challenges, infrastructure dependencies
- **Comparative Advantage**: More predictable than market-based mechanisms (EU ETS), more comprehensive than voluntary approaches (Japan)
- **Implementation Probability**: 55-63% success probability for "Managed Transformation" scenario

10.1.2 Provincial Differentiation Insights

The analysis reveals four distinct provincial models:

1. **Hebei**: Hydrogen-centered pathway driven by environmental emergency and political pressure
2. **Jiangsu**: EAF-centered pathway leveraging scrap availability and economic diversification
3. **Shandong**: Balanced approach with technology diversification and coastal advantages
4. **Liaoning**: Cost-competitive hydrogen pathway exploiting renewable energy advantages

10.1.3 Technology Economics Reality Check

- **EAF Pathway**: Economically viable today ($730-780/t LCOS), limited by scrap availability and quality
- **H2-DRI Pathway**: Technically viable but economically challenged ($1,310-1,580/t LCOS), requires hydrogen cost breakthrough
- **CCUS Pathway**: Transitional solution, economically viable at carbon prices >$80/t CO_2, limited by storage infrastructure
- **Critical Threshold**: Green hydrogen must reach $1.00-1.40/kg for H2-DRI competitiveness

10.2 Strategic Recommendations

10.2.1 For Chinese Policymakers

1. **Enhance Policy Certainty**
    - Establish 15-year capacity replacement roadmap with clear annual targets
    - Create carbon contract for difference (CCfD) mechanism to de-risk hydrogen investments
    - Implement graduated carbon pricing reaching RMB 200-300/t CO_2 by 2035
2. **Accelerate Infrastructure Development**
    - Designate steel-hydrogen corridors as national strategic infrastructure
    - Fast-track Inner Mongolia-Hebei hydrogen pipeline (2028 completion critical)
    - Coordinate renewable energy deployment with steel sector demand centers
3. **Strengthen Just Transition Programs**
    - Establish RMB 100 billion national steel transition fund
    - Create regional economic diversification zones in steel-dependent cities
    - Implement wage insurance and retraining programs with 24-month coverage
4. **Develop Green Steel Markets**
    - Mandate green steel in all government infrastructure projects (20% by 2028, 50% by 2035)
    - Create green steel certification aligned with international standards
    - Establish CBAM revenue recycling to support domestic green steel production

10.2.2 For International Stakeholders

1. **European Union and CBAM Implementation**
    - Recognize Chinese green steel certifications to avoid trade barriers
    - Create technology cooperation frameworks for hydrogen steel development
    - Use CBAM revenues to support global steel decarbonization fund
2. **International Financial Institutions**
    - Develop transition finance instruments tailored to Chinese steel sector
    - Support just transition programs through technical assistance and funding
    - Create risk-sharing facilities for first-mover hydrogen steel projects
3. **Global Steel Companies**
    - Monitor Chinese technology developments for potential licensing opportunities
    - Develop partnerships with Chinese leaders (HBIS, Baowu) on hydrogen steel
    - Prepare for competitive pressure from scaled Chinese green steel production post-2030
4. **Research Institutions and MIFUS Framework**
    - Establish international monitoring of Chinese provincial implementation
    - Create technology learning sharing mechanisms across regions
    - Develop standardized methodologies for green steel accounting and verification

10.2.3 For University of Udine and MIFUS Project

1. **Research Priorities**
   - Monitor HBIS Zhangjiakou operational performance and scaling challenges
   - Track provincial implementation differences and lessons learned
   - Analyze cross-provincial infrastructure development and coordination
   - Assess social impact and just transition program effectiveness
2. **Educational Integration**
   - Develop case studies on Chinese provincial decarbonization strategies
   - Create comparative analysis frameworks (China vs EU vs Japan approaches)
   - Incorporate real-time policy developments into course materials
   - Establish student exchange programs with Chinese metallurgy universities
3. **International Collaboration**
   - Partner with Chinese research institutions on technology assessment
   - Participate in international standard development for green steel
   - Create EU-China steel decarbonization knowledge exchange platform
   - Develop joint proposals for Horizon Europe and Chinese funding programs

10.3 Final Assessment: Global Implications

China's steel decarbonization represents the critical determinant of global industrial emissions trajectories:

10.3.1 Success Scenario Implications

If China achieves "Managed Transformation" or "Green Steel Pioneer" outcomes:

- **Global Climate Impact**: 1,000-1,450 Mt CO_2/year reduction (3-4% of global emissions)
- **Technology Validation**: Hydrogen steelmaking proven at commercial scale
- **Economic Transformation**: Green steel becomes benchmark, reshaping global markets
- **Geopolitical Realignment**: China establishes clean technology leadership
- **Paris Agreement Viability**: Industrial decarbonization proven feasible

10.3.2 Failure Scenario Implications

If China experiences "Troubled Transition":

- **Climate Consequences**: Paris Agreement goals become unattainable
- **Economic Costs**: Stranded assets, trade conflicts, delayed energy transition
- **Technological Delay**: Global hydrogen economy development setback
- **Political Consequences**: Erosion of multilateral climate cooperation
- **Social Impact**: Continued air pollution health burdens in China and globally

10.3.3 The Italian and European Perspective

For Italy and the EU, China's steel transformation presents both challenges and opportunities:

- **Competitive Threat**: Potential Chinese green steel exports at scale post-2030
- **Technology Opportunity**: Partnerships in hydrogen infrastructure and steel technology
- **Policy Learning**: Chinese capacity replacement mechanisms offer lessons for EU industrial policy
- **Strategic Imperative**: Accelerate EU steel transformation to maintain competitiveness
- **Collaborative Potential**: Joint development of international standards and certification

10.4 Concluding Remarks

China's provincial steel decarbonization represents the largest industrial transformation in human history. The analysis presented in this document demonstrates both the extraordinary ambition of China's approach and the formidable challenges facing implementation.

The October 2025 policy framework, provincial differentiation strategy, and technology pathway development collectively represent a comprehensive response to the steel decarbonization challenge. However, success remains contingent on multiple interdependent factors: hydrogen cost reductions, infrastructure development, political will sustainability, just transition management, and market creation.

The MIFUS project, through this analysis and ongoing monitoring, provides a critical independent assessment of this globally consequential transformation. The University of Udine's role in documenting, analyzing, and contextualizing China's steel decarbonization contributes to global understanding of industrial climate action.

As the 2026-2030 implementation period commences, the world will witness whether China can transform its massive steel sector while maintaining economic competitiveness and social stability. The outcome will determine not only China's environmental future but the viability of global industrial decarbonization and climate stability.

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- **China Iron and Steel Association (CISA)**: http://www.chinaisa.org.cn
- **HBIS Group Official Website**: http://www.hbisco.com
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International Organizations

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- **World Steel Association**: https://worldsteel.org
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