

Steel Decarbonization in China:

Provincial Implementation Strategies and
the Path to Carbon Neutrality by 2060

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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.*

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 CO₂ penalty that paradoxically accelerates innovation, and (3) strategic piloting of breakthrough technologies including hydrogen-based direct reduction (H₂-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 H₂-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 H₂-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, CO₂ storage), creating viable markets for green steel products, and managing social transitions without instability. Technology pathways show provincial specialization: Hebei and Liaoning lead H₂-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 H₂-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 trajec-

tories. Success would validate hydrogen steelmaking at commercial scale (40-60 Mt H₂-DRI capacity by 2035), eliminate 500-700 Mt CO₂ 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

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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 CO₂ annually, representing roughly 15% of global industrial CO₂ 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_ChinaSteelPolicyDeepO 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 H₂-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 H₂-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 H₂-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 H₂-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, CO₂ 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.