Steel Decarbonization in Liaoning Province, China:
China's Hydrogen Metallurgy Pioneer and
Northeast Industrial Transformation Model

MIFUS: A Global Journey Through Steel Decarbonization

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Abstract

Liaoning Province, China's fourth-largest steel producer with 60-65 million tonnes annual capacity, represents a unique case study in steel decarbonization: the province combines Northeast China's industrial heritage with pioneering hydrogen metallurgy technology and possesses the nation's lowest Levelized Cost of Steel (LCOS) for green production routes. Home to Ansteel Group – the world's third-largest producer and operator of the world's first green hydrogen demonstration project for steel (Bayuquan, 10,000 tonnes capacity) – Liaoning is positioned as China's hydrogen steel technology hub. This paper analyzes Liaoning's transformation within the MIFUS framework, examining parallels with Germany's hydrogen-focused strategy while highlighting critical differences: China's 1.5:1 capacity replacement policy framework, centralized state direction versus German federal-state coordination, and Liaoning's structural cost advantages in renewable energy access and industrial infrastructure. With China implementing the most stringent capacity replacement ratio globally and the EU's Carbon Border Adjustment Mechanism (CBAM) creating competitive pressure, Liaoning's success in scaling hydrogen direct reduced iron (H2-DRI) from demonstration (10,000 tonnes) to commercial scale (target: 20 million tonnes by 2030) will determine whether hydrogen-based steelmaking can achieve cost parity with conventional blast furnace-basic oxygen furnace (BF-BOF) production. The analysis contextualizes Liaoning's transformation against Germany's challenges (hydrogen costs exceeding €9/kg, electricity cost crises), China's October 2024 national policy revolution, and the broader question: can a traditional rust belt province reinvent itself as a green steel leader?

Keywords: Steel decarbonization, Liaoning Province, hydrogen DRI-EAF, Ansteel, China steel policy, 1.5:1 capacity replacement, green steel, Bayuquan demonstration, Northeast China transformation, MIFUS

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1 Introduction: Liaoning's Strategic Position in China's Steel Transformation

1.1 The MIFUS Framework and Study Objectives

This paper is part of the MIFUS initiative (A Global Journey Through Steel Decarbonization), providing detailed provincial-level analysis that complements:

- Global overview documents (A_Global.pdf, B_GlobalAppendix.pdf)
- China's transformative October 2024 policies and 1.5:1 capacity replacement framework (ChinaGovOct.pdf, C_ChinaSteelPolicyDeep01.pdf, ZF_ChinaSteelDecarb.pdf)
- Germany's hydrogen steel transformation challenges and opportunities (H_Germany.pdf)
- European Union policy context (J_EuropeanUnion.pdf)

This study provides direct comparison between Liaoning Province and Germany – both pursuing hydrogen-based steel decarbonization but operating under fundamentally different policy, economic, and institutional frameworks.

1.2 Why Liaoning Province?

Liaoning occupies a unique strategic position in China's steel decarbonization:

Scale and Significance:

- Fourth-largest steel producing province: 60-65 Mt annually (6-7% of China's 1,018 Mt)
- Fourth-highest provincial capacity: 68-70 Mt installed
- Home to Ansteel Group: 59.55 Mt production (2024), world's #3 producer
- Critical mass sufficient for national policy demonstration

Technology Leadership:

- World's first green hydrogen steel demonstration: Ansteel Bayuquan (10,000 tonnes capacity)
- Lowest Levelized Cost of Steel (LCOS) across all Chinese provinces for H2-DRI route
- Strong industrial base, skilled workforce, established infrastructure
- Robust grid connections facilitating renewable energy integration

Strategic Role:

- National hydrogen metallurgy technology hub designation
- Model for Northeast China's industrial transformation (rust belt modernization)
- Export center for hydrogen steel technology and operational expertise
- Test case for whether H2-DRI can achieve commercial viability in Chinese context

1.3 Parallel with Germany, Contrast with National Policy

Germany Parallels:

- Both pursuing hydrogen-based steel production as primary decarbonization pathway
- Both feature major integrated producers (Ansteel vs ThyssenKrupp, Salzgitter)
- Both face challenge of scaling hydrogen demonstrations to multi-million tonne capacity
- Both operate in regions with significant renewable energy potential
- Both must manage just transition for large steel-dependent workforces

Critical Differences from Germany:

- **Policy Framework:** China's centralized 1.5:1 capacity replacement vs Germany's federal-state negotiation with 50-55% subsidies
- **Cost Structure:** Liaoning's projected H2 cost \$2-3/kg vs Germany's current €9-14.50/kg
- **Electricity Costs:** China's industrial power <\$0.06/kWh vs Germany's €0.05-0.08/kWh (with volatility causing 45.6% EAF output drops)
- **Market Dynamics:** Domestic-focused Chinese market vs Germany's export dependence and 25% US tariffs
- **Timeline:** China's aggressive 2025-2030 transformation vs Germany's 2027-2045 gradual approach

Within Chinese Context:

- Liaoning represents hydrogen-DRI pathway vs Jiangsu's EAF leadership and Hebei's mixed approach
- Lower GDP dependence on steel (vs Hebei's 15-20%) enabling more aggressive transformation
- Northeast China's economic challenges create urgency for industrial modernization
- Coastal provinces' advantage (easier to cut supply given lower steel GDP contribution) partially applies

1.4 The Transformation Imperative

Liaoning's steel sector confronts converging pressures:

1. **National Policy Mandate:**

- 1.5:1 capacity replacement policy: 1.5 tonnes retired per 1 tonne new capacity
- Ultra-low emissions compliance: 80% of Chinese capacity by 2025
- China's 2060 carbon neutrality commitment
- October 2024 freeze on new BF-BOF approvals (only EAF and green technologies approved)

2. **Economic Restructuring:**

- Northeast China's rust belt transformation necessity

- Competition from coastal provinces with lower production costs
- Opportunity to capture green steel premium markets (domestic and export)
- CBAM compliance requirements for European exports (full implementation January 2026)

3. Technological Opportunity:

- Lowest LCOS advantage: $50-100/tonne better than national average for H2-DRI
- Proven demonstration project ready for commercial scaling
- Strong renewable energy resources (wind, solar) in Northeast China
- Established industrial infrastructure reducing capital requirements

4. Social Imperatives:

- 200,000+ direct steel sector jobs requiring protection and evolution
- Single-industry cities (Anshan, Benxi) requiring economic diversification
- Skilled workforce ready for retraining in advanced metallurgy
- Opportunity to reverse decades of Northeast China population decline

2 Production Landscape and Technology Mix

2.1 Current Production Capacity (2024)

Table 1: Liaoning Steel Production by Technology (2024)

Technology	Volume (Mt)	Share (%)	Emissions Intensity (t CO_2/t steel)
BOF/BF-BOF	54-58	88-92%	2.2
Electric Arc Furnace (EAF)	5-7	8-12%	0.4 (grid average)
H2-DRI Demonstration	0.01	<0.1%	0.1 (green hydrogen)
Total Crude Steel	**60-65**	**100%**	**2.0-2.1**
Pig Iron Production	50-54	–	–

Key Observations:

- Liaoning remains heavily dependent on conventional BF-BOF (88-92%), similar to Hebei but higher than Jiangsu (82%)
- EAF share (8-12%) below national average (10-15%) but growing
- Capacity utilization: 88-93% (relatively healthy compared to Hebei's 88-90%)
- H2-DRI demonstration operational since 2023, world's first green hydrogen project for steel
- Provincial emissions: 130-145 Mt CO_2 annually (2.0-2.1 t per tonne steel)

Comparison with Germany:

- Germany's BF-BOF share: 71% vs Liaoning's 90% – Liaoning more dependent on conventional route
- Germany's EAF: 29% vs Liaoning's 10% – Germany further along EAF transition
- However: Liaoning's H2-DRI demonstration operational, Germany's still in planning/tendering
- Scale advantage: Liaoning's 60-65 Mt comparable to major German producers individually but concentrated in single province

2.2 Major Steel Producers

Liaoning's production is highly concentrated, dominated by state-owned enterprises:

2.2.1 1. Ansteel Group Corporation Limited

Basic Profile:

- Headquarters: Anshan, Liaoning Province
- 2024 Production: 59.55 million tonnes (world rank #3)
- Ownership: State-owned enterprise (central government)
- History: One of China's oldest steel manufacturers, founded 1948
- Market Position: 90-95% of Liaoning's provincial production

Production Facilities:

- Anshan Iron and Steel Complex: Main integrated facility, 40+ Mt capacity
- Bayuquan Steelworks: Coastal facility, site of hydrogen demonstration project
- Benxi subsidiary: Additional 15-20 Mt capacity
- Multiple finishing and specialty steel facilities

Product Portfolio:

- Automotive steel: Major supplier to Chinese OEMs
- Construction steel: Rebar, structural sections
- Railway steel: High-speed rail components
- Heavy plate: Shipbuilding, offshore engineering
- Special grades: Silicon steel, tool steel, stainless

2.2.2 2. Benxi Steel Group

Profile:

- Location: Benxi City, Liaoning
- Capacity: 15-20 Mt annually
- Ownership: Provincial state-owned enterprise
- Relationship: Closely coordinated with Ansteel (potential merger discussions)
- Specialization: Heavy plate, special steels

2.2.3 3. Smaller Provincial Producers

- Combined capacity: 3-5 Mt
- Focus: Regional construction steel, rebar
- Status: Consolidation targets under 1.5:1 policy
- Role: Local supply for provincial infrastructure

2.3 Production Technology Evolution

Historical Trajectory (2020-2024):

- 2020: 68 Mt total capacity, 95% BF-BOF
- 2021: Capacity reduction initiatives begin, 65 Mt
- 2022: Ansteel carbon neutrality targets announced
- 2023: Bayuquan H2-DRI demonstration commissioned (10,000 tonnes)
- 2024: 60-65 Mt production, 10% EAF share achieved

Technology Demonstration Milestones:

- **2023: Bayuquan Green Hydrogen Project**
  - World's first green hydrogen steel demonstration
  - Capacity: 10,000 tonnes annually
  - Technology: H2-DRI (hydrogen direct reduced iron)
  - Hydrogen source: On-site electrolysis with renewable electricity
  - Electrolyzer: 10 MW capacity
  - Operations: Continuous since Q2 2023
  - Performance: 85,021 tonnes CO_2 reduction annually per tonne capacity
- **Ultra-Low Emissions Compliance:**
  - Ansteel facilities: 80% compliant by 2025 (national target)
  - PM, SO_2, NO_x emissions: 90% reduction vs 2015 baseline
  - Investment: RMB 15 billion in environmental infrastructure

3 Decarbonization Strategy and Major Projects

3.1 Provincial Transformation Framework

Liaoning's Strategic Positioning:

Unlike Hebei (aggressive capacity reduction) or Jiangsu (EAF transition), Liaoning's strategy emphasizes *technology leadership and demonstration*:

- **Scale hydrogen DRI from demonstration to commercial deployment**
- **Export technology and operational knowledge** to other provinces and international markets
- **Leverage lowest LCOS advantage** to achieve cost-competitive green steel first
- **Moderate capacity reduction** (10 Mt net by 2030) focused on technology substitution rather than absolute cuts

1.5:1 Policy Implementation in Liaoning:

Table 2: Liaoning 1.5:1 Policy Impact Projections (2025-2030)

Metric	2025 Baseline	2027 Target	2030 Target	Change (Mt)	Change (%)
Total Capacity	65	60	55	-10	-15%
BF-BOF Retired	–	12	30	-30	–
New H2-DRI	–	5	20	+20	–
New EAF	–	3	10	+10	–
Net New Capacity	–	8	30	+30	–
Technology Mix:					
BF-BOF	90%	73%	45%	–	–
H2-DRI	<1%	8%	36%	–	–
EAF	10%	19%	19%	–	–

3.2 Ansteel's Hydrogen Leadership: The Bayuquan Model

3.2.1 Current Demonstration Project

Bayuquan Green Hydrogen Steel Demonstration:

Technical Specifications:

- **Location:** Bayuquan Steelworks, coastal Liaoning
- **Capacity:** 10,000 tonnes H2-DRI annually
- **Electrolyzer:** 10 MW alkaline electrolysis
- **Hydrogen Production:** 800-1,000 tonnes H_2/year
- **Renewable Energy:** Wind power from provincial grid
- **DRI Technology:** Shaft furnace with 100% hydrogen reduction
- **EAF Integration:** DRI melted in existing 120-tonne EAF

Performance and Learning (2023-2024):

- **Operational Uptime:** 85-90% (excellent for demonstration)
- **Hydrogen Consumption:** 55-58 kg H_2 per tonne DRI (within international benchmarks)
- **Product Quality:** Equivalent to conventional blast furnace iron
- **Emissions:** 0.1 tonnes CO_2 per tonne steel (95% reduction vs BF-BOF)
- **Cost (2024):** $850-950/tonne (uncompetitive at current scale)
- **Lessons Learned:**
  - Intermittency management: Battery storage critical for stable operations
  - Hydrogen purity: 99.9% required for optimal DRI quality
  - Workforce training: 18-month program for hydrogen safety and operations
  - Equipment reliability: Specialized valves and piping for H_2 service

3.2.2 Commercial Scale-Up Plan (2025-2030)

Phase 1 (2025-2027): 500,000 Tonnes

Project Specifications:

- Scale Bayuquan from 10,000 t to 500,000 t capacity
- Investment: RMB 8-10 billion ($1.1-1.4 billion)
- Electrolyzer capacity: 500 MW (50x demonstration scale)
- Hydrogen production: 40,000-50,000 tonnes H_2/year
- New DRI furnaces: 2 x 250,000 tonne units
- EAF expansion: 2 x 250 tonne ultra-high power furnaces

Infrastructure Requirements:

- **Renewable Electricity:** 1.5-2 TWh/year dedicated wind power
  - New offshore wind farms: 300-400 MW capacity
  - Grid connection upgrades: 500 kV transmission
  - Battery storage: 200 MWh for intermittency management
- **Hydrogen Infrastructure:**
  - On-site storage: 50 tonnes compressed H_2 (safety buffer)
  - Pipeline: 5 km intra-facility network
  - Backup: Natural gas with steam methane reforming + CCUS (bridge strategy)
- **Water Supply:** 5-7 million tonnes/year for electrolysis (seawater desalination)

Phase 2 (2027-2030): 5-8 Million Tonnes

Provincial-Scale Deployment:

- Deploy 3-5 commercial H2-DRI facilities across Liaoning
- Individual facility capacity: 1.5-2 Mt each
- Total provincial H2-DRI capacity: 5-8 Mt by 2030
- Locations:
  - Bayuquan expansion: 2 Mt total (Phase 1 + Phase 2)
  - Anshan main complex: 2 Mt (retrofit existing site)
  - Benxi: 1.5 Mt (new greenfield or retirement replacement)
  - Dalian region: 1.5 Mt (potential joint venture or new entrant)

Capital Requirements:

- Total investment: RMB 60-80 billion ($8.3-11.1 billion)
- Breakdown:
  - H2-DRI facilities: RMB 40-50 billion ($650-800/tonne capacity)
  - Electrolyzer and H_2 production: RMB 15-20 billion

  - Renewable energy (offshore wind, solar): RMB 10-15 billion
  - Grid and infrastructure: RMB 5-8 billion
- Financing model:
  - Ansteel internal resources: 40-45%
  - Government subsidies (central + provincial): 30-35%
  - Green bonds and policy banks: 20-25%

3.3 Supporting Projects and Infrastructure

3.3.1 1. Renewable Energy Development

Provincial Renewable Resources:

Liaoning possesses significant renewable potential:

- **Offshore Wind:** Bohai Bay, Yellow Sea coastline
  - Potential capacity: 15-20 GW
  - Average capacity factor: 40-45%
  - Proximity to Bayuquan and coastal steel facilities
- **Onshore Wind:** Northern and western Liaoning
  - Existing capacity: 8 GW
  - Additional potential: 5-8 GW
  - Average capacity factor: 25-30%
- **Solar PV:** Distributed and utility-scale
  - Existing capacity: 3-4 GW
  - Potential: 10-15 GW additional
  - Average capacity factor: 15-18%

Development Targets (2025-2030):

- **2025:** 12 GW renewable (current baseline)
- **2027:** 18 GW (6 GW additions, supporting 500,000 t H2-DRI)
- **2030:** 25-30 GW (supporting 5-8 Mt H2-DRI + broader decarbonization)

3.3.2 2. Hydrogen Production and Distribution

Electrolyzer Deployment Plan:

- 2024 baseline: 10 MW (Bayuquan demonstration)
- 2027 target: 500-600 MW
- 2030 target: 3-4 GW
- Technology preference: Alkaline electrolysis (proven, lower cost) transitioning to PEM (higher efficiency, flexibility)

Hydrogen Cost Trajectory:

- 2024 (demonstration scale): $6-8/kg
- 2027 (500,000 t scale): $3.5-4.5/kg
- 2030 (5-8 Mt scale): $2-3/kg (target)
- 2035+ (full commercial): $1.5-2/kg

Compare with Germany:

- Germany current (2025): €9.35/kg (March 2025 tender), peaked €14.50/kg (Dec 2024)
- Germany 2030 target: €4.50/kg (industry requirement for viability)
- Liaoning advantage: Cheaper renewable electricity and established industrial integration

Pipeline and Storage Infrastructure:

- Intra-facility pipelines: 50-80 km total by 2030
- Inter-facility connections: 100-150 km linking Anshan-Bayuquan-Benxi triangle
- Storage capacity: 500-800 tonnes compressed H_2 (operational buffer)
- Safety standards: Comply with international codes for H_2 service

3.3.3 3. Electric Arc Furnace Expansion

While hydrogen DRI is the headline strategy, Liaoning also plans EAF expansion:

Scrap-Based EAF Development:

- Current EAF capacity: 5-7 Mt (10% of provincial total)
- 2030 target: 10-12 Mt (19% share)
- Growth drivers:
  - Increased scrap availability from Northeast China industrial base
  - Lower capital cost ($300-500/t) vs H2-DRI ($650-800/t)
  - Flexibility: scrap-based EAF as complement to DRI-EAF
- Hybrid approach: Some EAF facilities designed for DRI-scrap blends (60% DRI + 40% scrap)

3.3.4 4. Carbon Capture, Utilization, and Storage (CCUS)

Role in Liaoning Strategy:

CCUS is *secondary* to hydrogen DRI but still relevant:

- Target facilities: Newest BF capacity (10-15 years asset life remaining)
- Scale: 10-15 Mt steel capacity with CCUS by 2030
- CO_2 capture: 15-25 Mt/year
- Storage: Offshore geological formations in Bohai Bay
- Cost: RMB 200-400 per tonne capacity retrofit

Technology Development:

- Ansteel partnering with national research institutes
- Pilot scale: 100,000 t CO_2/year at Anshan facility (planned 2026)
- Commercial deployment: 2028-2030

4 Infrastructure Dependencies and Challenges

4.1 Hydrogen Infrastructure: The Critical Path

4.1.1 Production Capacity Requirements

For 5-8 Mt H2-DRI capacity by 2030, Liaoning requires:

- **Hydrogen demand:** 300,000-450,000 tonnes H_2/year
  - Assumption: 55-60 kg H_2 per tonne DRI
- **Electrolyzer capacity:** 3-4 GW
  - Assumption: 50-55 kWh per kg H_2, 4,000-5,000 hours annual operation
- **Renewable electricity:** 15-20 TWh/year dedicated to hydrogen production
  - Context: Liaoning's total electricity consumption 250-280 TWh/year
  - Steel's hydrogen share: 6-8% of provincial electricity by 2030

4.1.2 Timeline and Phasing

Table 3: Liaoning Hydrogen Infrastructure Development Timeline

Metric	2025	2027	2030	2035
H2-DRI Capacity (Mt)	0.01	0.5	5-8	20-25
H_2 Demand (kt/year)	0.6	30	300-450	1,200-1,500
Electrolyzer (GW)	0.01	0.5	3-4	12-15
Renewable (GW)	12	18	25-30	40-50
H_2 Cost ($/kg)	6-8	3.5-4.5	2-3	1.5-2

4.1.3 Infrastructure Bottlenecks and Risks

Key Challenges:

1. **Electrolyzer Manufacturing:**
   - Global capacity constraints for GW-scale units
   - Chinese manufacturers scaling rapidly but quality concerns
   - Lead times: 18-24 months for large installations
   - Mitigation: Early procurement, multiple supplier strategy
2. **Grid Integration:**
   - Renewable intermittency requires flexible electrolyzer operations
   - Grid stability concerns with large-scale electrolysis loads
   - Investment needed: $800M-1.2B in grid reinforcement
   - Solution: Battery storage (200-400 MWh) + demand response
3. **Pipeline Safety:**
   - Hydrogen embrittlement of steel pipelines

- Leak detection and safety systems
- Regulatory framework under development
- International standards compliance (ISO/TC 197)

4. **Water Supply:**
   - 9 kg water per kg H_2 production
   - 3-4 million tonnes water/year needed by 2030
   - Coastal facilities: seawater desalination
   - Inland facilities: water recycling and municipal supply

4.2 Electricity Infrastructure and Costs

4.2.1 Current Electricity Landscape

Liaoning Provincial Grid:

- Total installed capacity: 50-55 GW
- Current mix:
  - Coal: 60-65%
  - Nuclear: 15-18%
  - Wind: 15-18%
  - Solar: 5-8%
  - Hydro: 2-3%
- Grid connection: Northeast China regional grid, connections to North China
- Industrial electricity price: RMB 0.40-0.55/kWh ($0.055-0.075/kWh)

Comparison with Germany:

- **Cost advantage:** Liaoning $0.055-0.075/kWh vs Germany €0.05-0.08/kWh ($0.055-0.088)
- **But:** Germany's December 2024 spike caused 45.6% EAF output drop
- **Stability:** China's grid more stable but renewable integration lags
- **Carbon intensity:** Liaoning grid (0.6-0.7 kg CO_2/kWh) vs Germany (0.35-0.45 kg/kWh)

4.2.2 Renewable Energy Expansion Requirements

Steel Sector Electricity Demand (2030):

- H2-DRI hydrogen production: 15-20 TWh
- EAF operations (10-12 Mt): 6-7 TWh
- Auxiliary systems: 2-3 TWh
- Total steel sector: 23-30 TWh (vs current 15-18 TWh)
- Share of provincial total: 9-11% (up from 6-7%)

Renewable Capacity Additions Needed:

- Wind (offshore): 5-7 GW new capacity
- Wind (onshore): 3-4 GW new capacity
- Solar PV: 5-7 GW new capacity
- Total additions: 13-18 GW (2025-2030)
- Investment required: RMB 80-120 billion ($11-17 billion)

4.3 Raw Material Dependencies

4.3.1 Iron Ore Supply

Current Supply Chain:

- Liaoning domestic ore: Low-grade (20-30% Fe), declining reserves
- Primary imports: Australia (60%), Brazil (30%), others (10%)
- Port infrastructure: Dalian, Yingkou major ore terminals
- Annual requirements: 90-100 Mt iron ore for 60-65 Mt steel production

DRI-Grade Ore Requirements:

- Quality needed: >67% Fe content (vs 62% standard for BF)
- Premium: $10-20/tonne above standard ore
- Supply sources: Australia (high-grade hematite), Brazil (pellet feed)
- 2030 requirement: 12-15 Mt DRI-grade ore for 5-8 Mt H2-DRI capacity

4.3.2 Scrap Steel Availability

Northeast China Scrap Market:

- Current generation: 15-20 Mt/year (Liaoning + adjacent provinces)
- Quality: Mixed, significant industrial scrap from machinery sector
- Competition: Growing EAF capacity in Jiangsu, Hebei, Guangdong
- Price volatility: RMB 2,000-3,500/tonne ($280-490)

Development Strategy:

- Improve collection networks in cities (automotive, appliances)
- Processing centers: Automated sorting and upgrading facilities
- Target: 25-30 Mt/year provincial supply by 2030
- Imports: Supplement from Japan, South Korea (5-8 Mt/year)

Table 4: Liaoning BF-BOF Steel Production Costs (2024 estimates)

Cost Component	RMB/tonne	Share (%)
Iron ore	850-950	25-28%
Metallurgical coal/coke	700-850	21-25%
Energy (electricity, gas)	400-550	12-16%
Labor	250-350	7-10%
Other materials	200-300	6-9%
Depreciation	180-250	5-7%
CO_2 costs (national ETS)	80-150	2-4%
Other overhead	300-400	9-12%
Total ($415-535/tonne)	**2,960-3,800**	**100%**

Table 5: Liaoning H2-DRI-EAF Cost Structure (Projections)

Cost Component	2027 (RMB/t)	2030 (RMB/t)	2035 (RMB/t)
Iron ore (DRI-grade)	1,000-1,100	950-1,050	900-1,000
Green hydrogen	1,600-2,000	900-1,200	600-850
Electricity (EAF)	350-450	300-400	280-350
Labor	200-280	180-250	170-240
Other materials	150-220	140-200	130-190
Depreciation (higher CAPEX)	400-550	350-480	300-420
CO_2 costs	20-40	10-30	5-20
Other overhead	250-350	220-310	200-280
Total (USD)	**3,970-4,990 $555-700**	**3,050-3,920 $425-550**	**2,585-3,350 $360-470**

5 Economic and Competitive Challenges

5.1 Cost Competitiveness Analysis

5.1.1 Current BF-BOF Production Costs (2024)

5.1.2 H2-DRI-EAF Cost Projections

Key Insights:

- At H_2 cost of $3.5-4.5/kg (2027): Green steel costs $555-700/tonne (30-35% premium)
- At H_2 cost of $2-3/kg (2030): Green steel costs $425-550/tonne (2-10% premium)
- At H_2 cost of $1.5-2/kg (2035): Green steel achieves cost parity with BF-BOF
- Critical threshold: $H_2 < \$3$/kg for commercially viable green steel

Liaoning's LCOS Advantage:
Liaoning has lowest Levelized Cost of Steel (LCOS) in China for H2-DRI:

- **Liaoning LCOS (2030):** $640-730/tonne
- **National average LCOS (2030):** $740-830/tonne

- **Advantage:** $50-100/tonne (~12% lower)
- **Drivers:**
  - Lower renewable electricity costs (abundant wind resources)
  - Existing industrial infrastructure reduces capital needs
  - Skilled workforce lowers operational costs
  - Grid infrastructure already robust

5.2 Market Demand and Positioning

5.2.1 Domestic Market

Northeast China Steel Demand:

- Current consumption: 80-90 Mt/year (Liaoning, Jilin, Heilongjiang)
- Liaoning share: 40-45 Mt (local + exports)
- Main sectors:
  - Automotive: 25-30% (declining with industry shift to coastal provinces)
  - Construction: 30-35% (stable, infrastructure modernization)
  - Machinery/equipment: 20-25% (Northeast industrial base)
  - Shipbuilding: 5-10% (Dalian shipyards)
  - Railway: 5-8% (high-speed rail expansion)

Regional Challenges:

- Northeast China economic slowdown (population decline, industrial migration)
- Automotive production shifting to coastal regions (Shanghai, Guangdong)
- Competition from Hebei steel (lower costs, proximity to Beijing-Tianjin)
- Opportunity: Green steel premium for quality-focused customers

5.2.2 Export Markets

Current Exports:

- Volume: 5-8 Mt/year (8-12% of production)
- Destinations: South Korea, Japan, Southeast Asia, Europe
- Products: Specialty steel, heavy plate, railway steel
- Challenge: CBAM implementation January 2026

CBAM Impact Analysis:
Strategic Response:

- Prioritize H2-DRI production for EU export markets
- Environmental Product Declaration (EPD) certification for all export grades
- Market segmentation: Green steel premium products vs conventional domestic
- Partnerships with European buyers (automotive OEMs, construction)

Table 6: CBAM Impact on Liaoning Steel Exports to EU

Scenario	Current BF-BOF	2027 Mixed	2030 H2-DRI
Emissions (t CO_2/t steel)	2.0-2.1	1.3-1.5	0.3-0.5
EU ETS price (/t CO_2)	80-100	80-100	80-100
CBAM tariff (/t steel)	160-210	104-150	24-50
CBAM tariff ($/t steel)	**$175-230**	**$115-165**	**$26-55**
Competitive position	Uncompetitive	Moderate	Competitive

5.3 Competitive Position within China

5.3.1 Provincial Competition

Table 7: Liaoning vs Other Major Steel Provinces (Competitive Analysis)

Factor	Liaoning	Hebei	Jiangsu	Shandong
Production (Mt)	60-65	225-250	119-121	76-80
Technology focus	H2-DRI leader	Mixed (H2/CCUS)	EAF leader	Balanced
LCOS advantage	Lowest	High	Moderate	Moderate
Market position	Northeast, export	Beijing-Tianjin, national	East China, premium	Coastal, balanced
Key advantage	Technology, renewables	Scale	EAF infra, scrap	Ports, recent investment
Challenge	Demand decline	Environmental pressure	Competition	Asset age

Liaoning's Competitive Strategy:

1. **Technology Leadership:** First-mover advantage in H2-DRI, export knowledge
2. **Premium Positioning:** Green steel certification, quality over volume
3. **Cost Advantage:** Leverage lowest LCOS to capture margins
4. **Niche Markets:** Specialty steel, high-performance grades
5. **International Partnerships:** Technology licensing, joint ventures

6 Policy and Regulatory Framework

6.1 National Policy: China's 1.5:1 Capacity Replacement

6.1.1 Policy Framework Overview

Core Mechanism:

- **Standard ratio:** 1.5 tonnes old capacity retired per 1 tonne new capacity added
- **M&A exception:** 1.25:1 for mergers completed after June 2021

- **Equal-capacity exceptions (1:1):**
  1. On-site equipment upgrades and modernization
  2. High-end specialty steel using advanced smelting
  3. Projects in Qinghai and Xizang (remote provinces)

Liaoning-Specific Implications:

- Ansteel H2-DRI projects qualify for **on-site upgrade** exception (1:1 ratio)
  - Rationale: Modernization of existing sites, advanced technology
  - Impact: Can replace 20 Mt BF with 20 Mt H2-DRI (no net capacity loss)
- Additional greenfield H2-DRI: Subject to 1.5:1 ratio
  - Example: 10 Mt new greenfield requires 15 Mt retirement
- Provincial flexibility: Liaoning can balance on-site + greenfield to manage net capacity

6.1.2 Implementation in Liaoning

Phase 1 (2025-2027): Foundation

- Retire 12 Mt oldest BF capacity (3-4 facilities, 40+ years old)
- Commission 8 Mt new capacity:
  - 5 Mt H2-DRI (qualifying for 1:1 on-site exception)
  - 3 Mt EAF (standard 1.5:1 ratio, requires 4.5 Mt retirement)
- Net capacity: 65 Mt → 60 Mt (-5 Mt, -7.7%)

Phase 2 (2027-2030): Acceleration

- Retire additional 18 Mt BF capacity
- Commission 30 Mt total new capacity since 2025:
  - 20 Mt H2-DRI (mix of 1:1 and 1.5:1 projects)
  - 10 Mt EAF
- Net capacity: 60 Mt → 55 Mt (-5 Mt additional, -8.3%)
- Cumulative 2025-2030: -10 Mt (-15.4% from baseline)

6.2 Provincial Government Support

6.2.1 Liaoning Provincial Industrial Policy

Strategic Priorities:

- **Revitalization of Northeast:** Central government campaign to modernize rust belt
- **Green transformation:** Environmental quality improvement mandate
- **Technology leadership:** Position Liaoning as innovation hub
- **Employment preservation:** Just transition for steel workforce

Financial Support Mechanisms:

- **Provincial subsidies:** RMB 15-20 billion (2025-2030)
  - H2-DRI capital cost support: 15-20% of project costs
  - Renewable energy connection: Grid infrastructure upgrades
  - Worker retraining programs: RMB 2-3 billion
- **Tax incentives:**
  - VAT rebates for green steel production equipment
  - Corporate income tax reduction (first 5 years of H2-DRI operations)
  - Property tax exemption for renewable energy facilities
- **Land and permitting:**
  - Fast-track approvals for hydrogen and renewable projects
  - Industrial land at preferential rates
  - Environmental impact assessment streamlining

6.2.2 Central Government Programs

National Support for Liaoning:

- **Technology demonstration funding:** RMB 5-8 billion
  - Bayuquan scale-up: Priority national project status
  - R&D grants for hydrogen metallurgy innovation
- **Policy bank lending:** Preferential rates from China Development Bank
  - RMB 30-40 billion low-interest loans for decarbonization projects
  - Terms: 15-20 year tenor, 2-3% annual interest
- **Hydrogen infrastructure:** National hydrogen pipeline network
  - Liaoning connection planned 2027-2028
  - Import corridor from Inner Mongolia (renewable H_2) or Russia (potential)

6.3 Comparison with Germany's Policy Framework

Key Observations:

- **China/Liaoning advantages:**
  - Faster decision-making and implementation
  - Integrated infrastructure planning (hydrogen, renewables, grid)
  - Lower costs (H_2, electricity, capital)
  - Mandatory compliance ensures transformation proceeds
- **Germany advantages:**
  - Higher public subsidy share (lower private risk)
  - More developed environmental governance

Table 8: Policy Framework Comparison: Liaoning vs Germany

Element	Liaoning/China	Germany
Capacity control	Mandatory 1.5:1 replacement, centrally enforced	Voluntary transformation with subsidies
Public funding	30-35% of costs (central + provincial)	50-55% of costs (federal + EU)
Total public investment	RMB 45-60B ($6-8B) for 5-8 Mt H2-DRI	€6.9B for 5+ Mt H2-DRI (Germany-wide)
Hydrogen support	Direct infrastructure investment, state-directed supply	Carbon Contracts for Difference (CCfD), tenders
Renewable energy	State-directed capacity additions, grid priority	Market-based PPAs, slow grid expansion
Carbon pricing	National ETS (~RMB 80-100/t CO_2)	EU ETS (€60-100/t CO_2)
Trade protection	Domestic market focus, CBAM response	CBAM implementation, US tariff concerns
Decision-making	Centralized (MIIT, NDRC, provinces coordinate)	Federal-state negotiation, slower consensus
Timeline	Aggressive: 2025-2030 transformation	Gradual: 2027-2045 transformation

  - Stronger worker protections and just transition programs
  - Technology partnerships with European ecosystem

- **Convergence:**
  - Both face hydrogen cost challenges as critical bottleneck
  - Both require massive renewable energy expansion
  - Both pursuing H2-DRI as primary pathway (vs EAF in other regions)
  - Both must manage significant workforce transitions

7 Environmental Impact and Emissions Reduction

7.1 Current Emissions Profile (2024)

Table 9: Liaoning Steel Sector Emissions (2024 estimates)

Source	Mt CO_2/year	Share (%)	Intensity (t CO_2/t steel)
BF-BOF Production	118-128	90-92%	2.0-2.2
EAF Production	2-3	2-3%	0.4 (grid avg)
H2-DRI Demonstration	<0.01	<0.1%	0.1
Total Direct (Scope 1)	**120-131**	**92-95%**	**1.9-2.0**
Indirect (electricity, Scope 2)	8-10	6-8%	0.13-0.15
Total (Scope 1+2)	**128-141**	**100%**	**2.0-2.2**

Context:

- Liaoning steel emissions: 128-141 Mt CO_2/year
- Provincial total emissions: 500-550 Mt CO_2/year (all sectors)

- Steel's share: 25-28% of Liaoning's total greenhouse gas emissions
- National context: 2-3% of China's total CO_2 emissions

7.2 Decarbonization Pathway and Targets

7.2.1 Short-Term (2025-2030)

Planned Emissions Reductions:

Table 10: Liaoning Steel Emissions Trajectory (2025-2030)

Year	Production (Mt)	Technology Mix (BF/H2/EAF)	Total Emissions (Mt CO_2)	Intensity (t CO_2/t)
2025	63	90/0.5/9.5%	125-135	2.0-2.1
2027	60	73/8/19%	100-110	1.7-1.8
2030	55	45/36/19%	70-80	1.3-1.5
Reduction (2025-2030)	**-8 Mt (-13%)**	–	**-50 to -60 Mt (-40 to -47%)**	**-35%**

Emissions Reduction Drivers:

- **Capacity reduction:** -8 Mt production (13% decrease) → -15 Mt CO_2 reduction
- **H2-DRI deployment:** 20 Mt capacity @ 0.1 t CO_2/t → saves 42 Mt CO_2 vs BF
- **EAF expansion:** 10 Mt capacity @ 0.4 vs 2.2 → saves 9 Mt CO_2
- **Total 2030 reduction:** 50-60 Mt CO_2 (40-47% vs 2025 baseline)

7.2.2 Medium-Term (2030-2040)

Transformation Acceleration:

- Target production: 50 Mt (further capacity optimization)
- Technology mix: 20% BF-BOF with CCUS, 60% H2-DRI, 20% EAF
- Emissions: 25-35 Mt CO_2/year
- Intensity: 0.5-0.7 t CO_2 per tonne steel
- Reduction vs 2025: 75-80%

7.2.3 Long-Term (2040-2060)

Carbon Neutrality Pathway:

- Target production: 45-50 Mt (stabilized)
- Technology mix: 0-5% BF-BOF with CCUS, 75-80% H2-DRI, 20-25% EAF
- Emissions: 5-10 Mt CO_2/year (near-zero)
- Intensity: 0.1-0.2 t CO_2 per tonne steel
- Residual emissions: Offset through forestry, CCUS, or carbon credits
- Achievement: 2055-2060 (aligned with national carbon neutrality 2060 target)

7.3 Co-Benefits of Decarbonization

7.3.1 Air Quality Improvements

Beyond CO_2 reduction, H2-DRI-EAF eliminates conventional pollutants:

Table 11: Air Pollutant Reduction from Steel Decarbonization

Pollutant	Current (2024) (tonnes/year)	2030 Target (tonnes/year)	Reduction
SO_2 (Sulfur Oxides)	80,000-100,000	15,000-25,000	75-85%
NO_x (Nitrogen Oxides)	60,000-80,000	10,000-18,000	75-83%
$PM_{2.5}$ (Particulate Matter)	25,000-35,000	5,000-8,000	77-84%
PM_{10}	40,000-55,000	8,000-12,000	78-85%

Health Benefits:

- Improved air quality in Anshan, Benxi (steel cities)
- Reduced respiratory and cardiovascular disease burden
- Estimated health cost savings: RMB 500M-1B/year ($70-140M)
- Extended life expectancy: 6-12 months for residents of steel cities

7.3.2 Resource Efficiency

- **Water consumption:** 30-40% reduction
  - No coal washing, less cooling water for BF operations
  - However: Water needed for electrolysis (9 kg per kg H_2)
  - Net reduction through efficiency and recycling
- **Land use:** Closure of coking plants frees 5,000-8,000 hectares
  - Urban redevelopment opportunities in Anshan
  - Industrial park conversion to commercial/residential
- **Waste reduction:**
  - Elimination of blast furnace slag: -15 Mt/year
  - Reduced hazardous waste: -500,000 t/year
  - However: DRI process creates different by-products requiring management
- **Material circularity:**
  - Increased scrap recycling
  - By-product utilization (oxygen from electrolysis, waste heat)
  - Closed-loop systems with automotive and machinery sectors

Table 12: Liaoning Steel Sector Employment (2024 estimates)

Category	**Number of Jobs**	**Share of Provincial Employment**
Direct Production (Ansteel, Benxi)	180,000-200,000	1.0-1.1%
Supply Chain	80,000-100,000	0.4-0.5%
- Raw materials, logistics	35,000-45,000	
- Equipment, maintenance	25,000-30,000	
- Services (consulting, finance)	20,000-25,000	
Downstream Users	400,000-500,000	2.2-2.7%
- Automotive	120,000-150,000	
- Construction	100,000-130,000	
- Machinery/equipment	150,000-180,000	
- Other manufacturing	30,000-40,000	
Total Steel-Dependent	**660,000-800,000**	**3.6-4.3%**

8 Social and Employment Dimensions

8.1 Employment Impact Analysis

8.1.1 Current Employment Structure (2024)

Context:

- Liaoning total employment: 18-19 million
- Steel sector: 3.6-4.3% of provincial jobs
- Concentration in Anshan (50,000+ direct), Benxi (25,000+ direct), and surrounding industrial regions
- Average age: 45-48 years (aging workforce, experience retention challenge)
- Skill profile: 60% production/operations, 25% technical/maintenance, 15% administrative

8.1.2 Transformation Impact on Employment

Projected Changes (2025-2030):

Table 13: Employment Impact of Steel Decarbonization in Liaoning

Category	**2024 Baseline**	**2030 Projection**	**Net Change**
BF-BOF Operations	120,000-135,000	60,000-70,000	-50,000-65,000
H2-DRI Operations	200-300	15,000-20,000	+14,700-19,700
EAF Operations	25,000-30,000	35,000-40,000	+5,000-15,000
Hydrogen Production	50-100	3,000-4,000	+2,900-3,900
Renewable Energy	500-1,000	8,000-12,000	+7,000-11,500
Total Direct	**180,000-200,000**	**165,000-185,000**	**-15,000**

Key Employment Trends:

- **Net job reduction:** 15,000 direct positions (-8%) but higher-skilled roles

- **Skill transformation:** Metallurgical engineers → hydrogen specialists, electrolyzer technicians, renewable energy operators
- **Geographic redistribution:** Shift from inland Anshan to coastal Bayuquan for hydrogen facilities
- **Wage impact:** 15-25% higher wages for hydrogen and renewable energy roles

8.2 Just Transition and Workforce Development

8.2.1 Workforce Retraining Programs

Provincial Retraining Initiative:

- **Budget:** RMB 2-3 billion ($280-420 million) 2025-2030
- **Target:** 40,000-50,000 workers retrained for new technologies
- **Implementation:** Partnership between Ansteel, provincial technical colleges, national research institutes

Key Training Programs:

- **Hydrogen Safety and Operations:** 6-month certification (5,000 workers annually)
- **Electrolyzer Maintenance:** 12-month specialist program (1,000 workers annually)
- **Renewable Energy Integration:** 9-month technical program (2,000 workers annually)
- **Digital Skills:** Automation, process control, data analytics (3,000 workers annually)

8.2.2 Social Protection Measures

Early Retirement and Transition Packages:

- Workers aged 55+: Voluntary retirement with 80-100% salary continuation until pension eligibility
- Workers aged 45-55: Retraining priority with job guarantee in new facilities
- Workers under 45: Comprehensive retraining with wage protection during transition

Regional Economic Diversification:

- **Anshan Technology Park:** Conversion of former steel lands to advanced manufacturing
- **Bayuquan Hydrogen Hub:** New industrial cluster attracting equipment manufacturers
- **Benxi Special Steel Center:** Focus on high-value specialty steel production

8.3 Community and Regional Development

8.3.1 Steel City Transformation

Anshan: From Steel City to Technology Hub

- Population: 3.3 million (city), 7.5 million (metropolitan)
- Current dependence: 25-30% of municipal GDP from steel
- Transformation strategy:

  - Repurpose 1,500 hectares of industrial land for technology parks
  - Develop advanced materials research institute
  - Attract hydrogen equipment manufacturing (compressors, electrolyzers)
- Target: Reduce steel GDP share to 15% by 2030 while maintaining employment

Bayuquan: Emerging Hydrogen Capital

- Strategic advantage: Coastal location, new infrastructure
- Development focus: Hydrogen production, storage, and export facilities
- Target: 10,000 new jobs in hydrogen economy by 2030
- Infrastructure: New technical college specializing in hydrogen technologies

9 Comparative Analysis: Liaoning vs. Germany

9.1 Strategic Parallels and Divergences

Table 14: Comparative Analysis: Liaoning vs. Germany Steel Decarbonization

Dimension	Liaoning Province, China	Germany
Policy Approach	Centralized mandate, 1.5:1 replacement, state-directed investment	Federal-state coordination, subsidies (50-55%), market mechanisms
Primary Technology	Hydrogen DRI-EAF (world's first demonstration operational)	Hydrogen DRI-EAF (multiple projects planned, none operational)
Hydrogen Cost (2025)	\$6-8/kg (demonstration), target \$2-3/kg (2030)	€9.35/kg (March 2025 tender), peaked €14.50/kg
Electricity Cost	\$0.055-0.075/kWh (stable, government regulated)	€0.05-0.08/kWh (volatile, caused 45.6% EAF output drop)
Scale and Timeline	60-65 Mt current, target 5-8 Mt H2-DRI by 2030 (aggressive)	40 Mt current, target 5+ Mt H2-DRI by 2030-2045 (gradual)
Public Funding	30-35% of project costs (central + provincial)	50-55% of project costs (federal + EU)
Workforce Transition	State-managed retraining, job guarantees, regional diversification	Social partnership model, codetermination, extensive retraining
Market Orientation	Domestic focus, CBAM response, technology export opportunity	Export dependence (25% US tariffs), EU market alignment
Renewable Integration	State-directed capacity additions, grid priority	Market-based PPAs, slower grid expansion, planning challenges

9.2 Critical Success Factors

9.2.1 Liaoning's Advantages

Structural Strengths:

- **Cost Leadership:** Lowest LCOS in China for H2-DRI pathway
- **First-Mover Advantage:** Operational demonstration project providing valuable learning
- **Policy Consistency:** Central government backing with clear regulatory framework
- **Infrastructure Foundation:** Established industrial base reducing capital requirements
- **Scale Economics:** Large production volumes enabling rapid technology diffusion

Comparative Advantages vs. Germany:

- 60-70% lower hydrogen production costs at scale
- 20-30% lower electricity costs with greater stability
- Faster decision-making and implementation timelines
- Integrated renewable energy planning and deployment

9.2.2 Persistent Challenges

Technical and Operational Risks:

- Scaling hydrogen technology from demonstration (10,000 t) to commercial (5-8 Mt)
- Grid integration of intermittent renewable energy for electrolysis
- Hydrogen embrittlement and materials compatibility in existing infrastructure
- Workforce skill transformation at unprecedented scale and speed

Economic Vulnerabilities:

- Northeast China economic decline and population outflow
- Competition from lower-cost provinces (Hebei, Jiangsu)
- Global iron ore price volatility affecting DRI economics
- CBAM implementation timeline and compliance costs

10 Conclusion and Policy Implications

10.1 Key Findings

10.1.1 Liaoning's Strategic Position

Liaoning Province represents a critical test case for hydrogen-based steel decarbonization globally:

- **Technology Pioneer:** World's first operational green hydrogen steel demonstration provides invaluable operational data and learning curves

- **Cost Benchmark:** Lowest Levelized Cost of Steel (LCOS) for H2-DRI in China creates competitive advantage
- **Policy Laboratory:** Implementation of China's stringent 1.5:1 capacity replacement policy under real-world conditions
- **Regional Transformation Model:** Potential blueprint for rust belt industrial modernization combining decarbonization with economic revitalization

10.1.2 Comparative Insights

The Liaoning-Germany comparison reveals fundamental differences in decarbonization approaches:

- **China's centralized model** enables faster implementation but requires careful workforce transition management
- **Germany's subsidy-heavy approach** reduces private risk but faces hydrogen cost and electricity volatility challenges
- **Liaoning's cost advantages** (hydrogen, electricity, infrastructure) could make it the first region to achieve cost-competitive green steel at scale
- Both regions face the common challenge of scaling hydrogen production and managing renewable energy integration

10.2 Broader Implications

10.2.1 For Global Steel Decarbonization

Technology Validation:

- Liaoning's H2-DRI demonstration provides critical proof-of-concept for hydrogen-based steelmaking
- Success could accelerate global adoption, while failure might shift focus to alternative pathways (CCUS, bioenergy)
- Operational data from Bayuquan will inform technology choices and investment decisions worldwide

Economic Viability:

- Liaoning's target of $2-3/kg hydrogen by 2030 represents the threshold for green steel competitiveness
- Achievement would demonstrate that hydrogen steel can compete with conventional BF-BOF without permanent subsidies
- Cost reduction learning curves from Liaoning could benefit global deployment

10.2.2 For International Climate Policy

CBAM and Trade Implications:

- Successful Liaoning transformation could position Chinese steel as CBAM-compliant for EU markets
- Technology export potential: Chinese H2-DRI expertise and equipment could become competitive export

- Green steel standards and certification: Liaoning's experience will inform international standard development

Developing Country Relevance:

- Liaoning's state-led, infrastructure-heavy approach may be more replicable in emerging economies than Germany's market-based model
- Integration of industrial policy with climate goals provides template for other industrializing regions
- Just transition lessons from Northeast China's rust belt transformation applicable to other regions facing industrial decline

10.3 Recommendations

10.3.1 For Chinese Policymakers

- **Maintain Policy Consistency:** Ensure 1.5:1 capacity replacement enforcement while providing flexibility for technology demonstration
- **Accelerate Hydrogen Infrastructure:** Invest in regional hydrogen pipelines and storage to reduce costs
- **Strengthen Workforce Transition:** Expand retraining programs and regional economic diversification initiatives
- **International Certification:** Develop robust green steel certification aligned with international standards for CBAM compliance

10.3.2 For International Stakeholders

- **Technology Monitoring:** Closely track Liaoning's H2-DRI scale-up for operational learning and cost data
- **Partnership Opportunities:** Explore joint ventures and technology cooperation with Ansteel and Chinese equipment manufacturers
- **Policy Learning:** Study China's capacity replacement mechanism as potential model for other regions
- **Standard Alignment:** Engage with Chinese stakeholders on harmonizing green steel certification and emissions accounting

10.3.3 For Industry Participants

- **Technology Investment:** Focus on electrolyzer efficiency, hydrogen-compatible materials, and renewable integration solutions
- **Workforce Development:** Develop comprehensive retraining programs combining traditional steel skills with new energy technologies
- **Market Positioning:** Prepare for segmented steel markets with green premiums and CBAM-driven cost structures
- **Supply Chain Collaboration:** Work with iron ore suppliers on DRI-grade quality standards and logistics optimization

10.4 Concluding Remarks

Liaoning Province stands at the forefront of the global steel industry's most ambitious decarbonization experiment. As the world's first operational green hydrogen steel demonstration scales toward commercial viability, it represents not just a technological transformation but a comprehensive reimagining of traditional industrial regions in the low-carbon era.

The province's unique combination of scale (60-65 Mt production), technology leadership (operational H2-DRI demonstration), policy framework (1.5:1 capacity replacement), and cost advantages (lowest LCOS in China) positions it as a critical test case for whether hydrogen-based steelmaking can achieve both environmental sustainability and economic competitiveness.

The parallel transformation efforts in Germany highlight alternative approaches to the same fundamental challenge, with contrasting strengths (higher subsidies, social partnership) and weaknesses (hydrogen costs, electricity volatility). The comparative success of these two models will shape global steel decarbonization pathways for decades to come.

Liaoning's journey from traditional rust belt province to potential green steel leader embodies the broader challenge facing heavy industry worldwide: navigating the complex intersection of technological innovation, economic competitiveness, social equity, and environmental responsibility. Its success or failure will provide critical lessons for industrial regions globally seeking to maintain their economic foundation while achieving deep decarbonization.

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