Taiwan Steel Industry and Decarbonization Strategy: Innovation Leadership Constrained by Resource and Political Realities

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Abstract

This document examines Taiwan's steel industry within the unique context of a technologically advanced economy constrained by political isolation, limited natural resources, and critical dependencies on imported energy and raw materials. With annual crude steel production of approximately 19–22 million tonnes, Taiwan ranks as the world's 13th–15th largest producer and a significant exporter, shipping to over 130 countries. Dominated by China Steel Corporation (CSC)—accounting for approximately 50% of domestic capacity—and complemented by innovative electric arc furnace (EAF) producers like Tung Ho Steel, Taiwan's steel sector combines large-scale integrated production with pioneering urban mining and circular economy practices. The industry faces profound decarbonization challenges driven by Taiwan's 2050 net-zero commitment, yet constrained by insufficient government funding, limited renewable energy availability, and the technical complexity of transitioning blast furnace-basic oxygen furnace (BF-BOF) capacity. This analysis explores Taiwan's current steel landscape, nascent hydrogen-based steelmaking initiatives, carbon capture experiments, and the fundamental resource constraints that distinguish Taiwan's transition pathway from both larger Asian competitors and European counterparts. The Taiwan case illustrates how advanced technical capabilities and corporate ambition can be severely constrained by structural resource limitations and political context.

Contents

1 Strategic Context: Taiwan Steel in Global Perspective

1.1 Production Landscape and Industrial Structure

Taiwan has established itself as a significant mid-sized steel producer with distinctive characteristics:

Production Capacity and Output (2024):

- Crude steel production: 19–22 million tonnes annually
- Global ranking: 13th–15th largest steel producer
- Regional context: Major East Asian producer after China, Japan, South Korea
- Capacity utilization: Variable, approximately 70–80%
- Production growth: Increased 24% over decade 2009–2019

Technology Distribution:

- Integrated BF-BOF mills: ∼50–55% of capacity (dominated by CSC)
- Electric arc furnace (EAF): ∼45–50% of capacity
- Technology balance: Higher EAF share than most Asian peers except Thailand
- Urban mining leadership: Advanced scrap recovery and processing systems

Major Producers and Market Structure:

- **China Steel Corporation (CSC):** State-influenced integrated producer, ∼10 MT crude steel capacity, 50%+ domestic market share, largest company by shareholders
- **Tung Ho Steel Enterprise:** Leading EAF producer, 1.0 MT steelmaking capacity, innovation leader in direct rolling technology
- **Yieh United Steel Corporation (YUSCO):** Major specialty steel producer
- **Dragon Steel Corporation:** CSC subsidiary, integrated production
- **An Feng Steel, Yieh Loong:** Mid-sized EAF producers
- **Taiwan Steel Group (TSG) affiliates:** Multiple specialized producers

1.2 Economic and Strategic Significance

Employment and Economic Contribution:

- Direct employment: ∼90,000 workers in steel production
- Indirect employment: Tens of thousands in downstream processing, machining
- Value-added processing: Strong capabilities in specialty steels, precision products
- Export significance: Steel represented 3.6% of total exports by value (2018)
- Downstream integration: Supporting machine tools, construction, automotive sectors

Export Performance and Trade:

- 2017 ranking: World's 13th-largest steel exporter
- Export destinations: 130+ countries and territories
- Export volume (2018): One-sixth of China's, one-third of Japan's
- Regional focus: Proximate Asian neighbors for flat products
- Stainless steel exports: ∼500,000 tonnes (2018)
- US market: 300,000 tonnes pipe and tube products (2018)

Product Specialization:

- Hot-rolled and cold-rolled coils: Primary products from integrated mills
- Coated steel series: Color coils, electrical steel, galvanized products
- Specialty applications: High-forming steels for automotive, electronics
- Rebar and construction steel: EAF producers' primary focus
- Advanced products: Ultra-high strength rebar, threaded rebar innovations

1.3 Emissions Profile and Climate Challenge

Current Emissions Intensity:

- CSC reported emissions (2020): 19,579 kt CO_2e (Direct + Indirect)
- CSC share of Taiwan industrial emissions: 14% of total
- Dragon Steel: Ranks 4th in Taiwan's top 10 largest CO_2 emitters
- EAF producers benchmark: Tung Ho achieving low-emission direct rolling
- Technology advantage: Direct rolling eliminates reheating furnaces (equivalent to 68,631 tonnes CO_2 annual reduction per facility)

National Climate Commitments:

- Net-zero target: 2050 (announced April 2021 by President Tsai Ing-wen)
- Legal framework: Climate Change Response Act (February 2023, formerly Greenhouse Gas Reduction and Management Act)
- Pathway announcement: March 2022 "Taiwan's Pathway to Net-Zero Emissions in 2050"
- 12 Key Strategies: Including hydrogen energy, CCUS, resource recycling
- Carbon fee introduction: Dedicated revenues for low-carbon initiatives

Industry-Specific Challenges:

- CSC dominance: 14% of Taiwan industrial emissions from single company
- BF-BOF dependency: CSC's 10 MT capacity requires fundamental transformation
- Technology maturity gap: Hydrogen steelmaking, CCUS still early-stage
- Funding constraints: Limited government support compared to Japan, Germany, EU
- Time pressure: 2050 target requires revolutionary changes starting immediately

2 China Steel Corporation: The Dominant Player

2.1 Company Profile and Historical Development

Establishment and Evolution:

- Founded: December 1971, state-initiated industrial development project
- First blast furnace launch: June 27, 1977
- Phased development: Stage 1 (1977), Stage 2 (1982), Stage 3 (1988)
- Current infrastructure: Four blast furnaces operational
- Privatization history: State-owned (July 1, 1977), re-privatized (April 12, 1995)
- Current ownership: De facto state influence through significant government shareholding; chairman appointed by government
- Location: Kaohsiung, southern Taiwan

Production Capacity and Performance:

- Crude steel capacity: ∼10 million tonnes annually
- 2019 production: 15.23 million tonnes (CSC reported, may include subsidiaries)
- Market share: 50%+ of Taiwan's domestic steel market
- Geographic footprint: Largest integrated steel complex in Taiwan
- Product range: Plates, bars, wire rods, hot/cold rolled coils, electrical steel, galvanized products, Ti/Ni-base alloys
- Market split: 70% domestic, 30% exports

Corporate Recognition and Sustainability Performance:

- National Quality Award (1991, 17th): Executive Yuan recognition

- National Industrial Innovation Award (2009): MOEA recognition
- World Steel Association Leading Company Award (2013): Excellence in production maintenance, sustainable operations
- FTSE4Good Emerging Index: Constituent since 2017
- DJSI inclusion (2024): Both World Index and Emerging Markets Index
- World Steel Association Sustainability Champion (2024)
- Taiwan Institute for Sustainable Energy awards (ongoing): Multiple corporate sustainability recognitions

2.2 CSC Group Structure and Business Diversification

Subsidiary Ecosystem:

- Total subsidiaries: 22 reinvestment companies
- Business domains: (1) Steel production, (2) Engineering, (3) Industrial materials, (4) Logistics & investment, (5) Green energy
- Operational synergy: Maximizing group-wide coordination
- Strategic positioning: Diversification beyond traditional steelmaking

Strategic Priorities - Dual Cores:

- Core 1: High-value premium steel plant development
- Core 2: Green energy industry expansion
- Supporting transformations: (1) Digital transformation, (2) Low-carbon transformation, (3) Supply chain transformation
- Competitive enhancement: Strengthening business structure and resilience
- Industry leadership: Leading domestic steel sector in international competitiveness

2.3 CSC Decarbonization Strategy and Challenges

Net-Zero Commitment and Timeline:

- Target year: 2050 carbon neutrality
- Chairman Wong Chao-tung recognition (2021): Cannot sit on sidelines given CSC's 14% share of Taiwan industrial emissions
- Technology requirements: Revolutionary changes to time-honored BF-BOF processes
- Dual pathway approach: (1) Hydrogen-powered steelmaking, (2) Carbon capture and utilization

Hydrogen-Based Steelmaking Development:
Technical Requirements and Scale:

- Annual hydrogen demand: ∼1 million tonnes for complete transition
- Renewable electricity needed: 14 GW to produce required green hydrogen
- Scale comparison: Would require entire output of Taiwan's offshore wind parks
- Current status: Experimental blast furnace simulator at Kaohsiung facility
- Technology challenge: Hydrogen absorption of heat causing temperature drops, risking production halts
- Pilot scale: Three-meter-high blast furnace simulator testing hydrogen injection

Technical Leadership:

- Liu Shih-hsien: 67-year-old consultant, decades developing decarbonization solutions
- R&D focus: Hydrogen-fueled steel production technical solutions
- Process complexity: Managing heat balance, iron ore reduction kinetics

- Technology maturity: “Many technologies not yet mature, walking toward net-zero is very risky undertaking” (CSC President Wang Shyi-chin, 2024)

Carbon Capture, Utilization and Storage (CCUS):
Existing Infrastructure:

- Taiwan’s largest carbon capture facility: Operational at CSC
- Current capture rate: 0.4% of CSC’s annual emissions
- CO_2 utilization: Delivering captured carbon to Chang Chun Group for semiconductor chemical production
- Technology demonstration: Proof-of-concept for steel-petrochemical integration
- Scalability challenge: Massive infrastructure expansion needed for meaningful impact

Bridge Technology Role:

- Interim solution: While hydrogen infrastructure develops
- Circular economy integration: CO_2 as feedstock for chemical industry
- Revenue potential: Value-added utilization offsetting capture costs
- Limitation: Cannot achieve deep decarbonization alone

Financial and Resource Constraints:
Funding Inadequacy:

- Corporate resources: CSC cannot finance transition independently
- Government support shortfall: Taiwan earmarked only $125 million for hydrogen power (2023–2024 combined)
- CSC allocation: $75 million designated, only $10 million received (as of April 2024)
- International comparison: German government subsidized ThyssenKrupp with ∼20 billion; Japan’s Green Innovation Fund $1.5 billion
- Structural disadvantage: Taiwan’s support orders of magnitude below major competitors

Renewable Energy Bottleneck:

- Grid capacity limitations: Insufficient renewable energy development
- Offshore wind constraints: Total output inadequate for CSC’s hydrogen needs
- Policy coordination gap: Energy transition not aligned with industrial decarbonization requirements
- CPC Corporation constraints: Taiwan’s hydrogen development lead company also cash-strapped
- Infrastructure requirement: Hydrogen storage and distribution systems undeveloped

Strategic Foresight - Water Recycling Precedent:

- 2016 commitment: 100% recycled wastewater usage
- Drought resilience (2021): Plants operated normally during severe water shortages due to advance planning
- Lesson applied: Chairman Wong emphasizes similar foresight needed for hydrogen transition
- Long-term perspective: Planning for technologies that currently seem “far-fetched” given 2050 deadline

3 Electric Arc Furnace Sector and Innovation Leadership

3.1 Tung Ho Steel: EAF Technology Pioneer

Company Overview:

- Founded: 1987
- Primary technology: 100% EAF-based production
- Steelmaking capacity: 1.0 million tonnes annually
- Rolling mill capacity: 0.8 million tonnes annually
- Production focus: Rebar, H-beam steel, multi-purpose steel products
- Locations: Taoyuan Works (primary), Miaoli Works, Kaohsiung Works
- Combined H-beam capacity: 1.2+ million tonnes across facilities

Revolutionary Direct Rolling Technology:
Innovation Description:

- Process elimination: Removed reheating furnaces entirely at Taoyuan Works
- Direct rolling: Billet to finished product without intermediate reheating
- Energy consumption: Dramatically reduced vs. conventional rebar production
- Emission reduction: Approximately 68,631 tonnes CO_2 annually per facility
- Equivalence: Same as CO_2 absorbed by 176 Da'an Forest Parks
- Global impact: Technology imitated by rebar plants worldwide
- Industry milestone: "New milestone for steel industry in Taiwan"

Environmental Significance:

- Pollution elimination: No burning process emissions
- Heat energy savings: Substantial reduction in thermal energy requirements
- Low-pollution production: Near-zero emissions from eliminated reheating step
- Technology transfer: International adoption demonstrating viability

Environmental Product Certifications:

- EPD certification: First construction steel company in Taiwan achieving Environmental Product Declarations for all products
- UL certification: Passed for steel bars
- ISO 14025 compliance: Environmental performance quantification per international standards
- Climate response: Extension of global warming mitigation efforts
- Product lifecycle approach: Comprehensive environmental accounting
- Consumer information: Quantitative, comparable environmental performance data

Product Innovation and Diversification:

- Beyond traditional rebar: Expanding application ranges
- Threaded rebar (Screw rebar): Enhanced construction connections
- Compact rebar in coil: Handling and logistics advantages
- Ultra-high strength rebar: Advanced structural applications
- Downstream processing: Comprehensive product sales and services
- Quality emphasis: Higher construction quality, reduced labor time

3.2 Taiwan's Urban Mining Excellence

Scrap-Based Production Ecosystem:

- Circular economy leadership: Global recognition for scrap recovery systems
- Material sources: Industrial waste, electronic waste, construction demolition
- Quality scrap production: Advanced sorting and processing
- EAF feedstock: Supporting 45–50% of Taiwan's steel capacity

Taiwan Steel Union - Collaborative Innovation:

- Leadership: Tung Ho Steel founding member
- Structure: Competitors cooperating for joint scrap processing
- Scale: One of leading urban mining operations globally
- Throughput: Tens of thousands of tonnes recycled annually
- Emission reduction: Significant CO_2 avoidance through material recovery
- Model: Collaborative approach overcoming individual company limitations

Specialty Materials Recovery:
Beyond Steel Recycling:

- Zinc recovery: From industrial by-products and scrap
- Copper reclamation: High-value metal extraction
- Gallium and indium: Critical materials from electronic waste
- Technology partners: Solar Applied Materials Technology, CSC partners
- Value creation: Converting waste to high-purity specialty metals

Strategic Advantages:

- Raw material dependency reduction: Decreased reliance on imports
- Carbon emissions reduction: Avoiding primary production emissions
- Hazardous waste minimization: Environmental benefit from waste processing
- Economic value: Revenue from recovered specialty materials
- Supply chain resilience: Domestic material security

3.3 EAF Sector Competitive Advantages

Emissions Performance:

- Lower baseline: EAF inherently 70–80% lower emissions than BF-BOF
- Renewable electricity potential: Grid decarbonization directly reduces EAF emissions
- Flexibility: Easier adaptation to variable renewable energy
- Rapid response: Shorter capital cycles for technology upgrades

Economic and Technical Flexibility:

- Lower capital intensity: Smaller-scale investments possible
- Product specialization: Niche market responsiveness
- Technology adoption: Faster implementation of innovations
- Market dynamics: Agility in responding to demand fluctuations

4 National Policy Framework and Institutional Architecture

4.1 Taiwan's 2050 Net-Zero Pathway

Policy Development Timeline:

- January 1, 2021: President Tsai announces consultation for sustainable development methods
- April 22, 2021: Earth Day announcement of 2050 net-zero emissions goal
- October 10, 2021: National Day address on drawing roadmap with societal sectors
- November 7, 2021: COP26 Taiwan Day reiteration of commitment
- February 2021: Net-Zero Pathway Task Force established by Office of Energy and Carbon Reduction
- March 2022: Official publication of "Taiwan's Pathway to Net-Zero Emissions in 2050"
- December 2022: Action plan for 12 key strategies for net-zero transition

- February 15, 2023: Climate Change Response Act enacted (revised Greenhouse Gas Reduction and Management Act)
- January 2023: 2023–2026 plan outlining carbon reduction methods

Policy Architecture - Four Major Strategies:

1. **Energy Transition:** Renewable energy expansion, grid modernization, energy storage
2. **Industrial Transition:** Low-carbon manufacturing, circular economy, technology innovation
3. **Lifestyle Transition:** Green living, sustainable consumption, behavioral changes
4. **Social Transition:** Just transition, civic engagement, "leaving no one behind"

Two Governance Foundations:

1. **Technology R&D:** Innovation funding, research infrastructure, pilot projects
2. **Climate Legislation:** Legal framework, enforcement mechanisms, monitoring systems

Twelve Key Strategies:

- Wind and solar photovoltaic power
- Hydrogen energy
- Innovative energy (geothermal, ocean, bioenergy)
- Power systems and energy storage
- Energy saving and efficiency
- Carbon capture, utilization and storage (CCUS)
- Carbon-free and electric vehicles
- Resource recycling and zero waste
- Carbon sinks (forestry, ocean, land use)
- Green lifestyle
- Green finance
- Just transition

4.2 Climate Change Response Act (2023)

Key Legislative Elements:

- Structure: 7 chapters, 63 articles
- Net-zero target: 2050 emissions neutrality incorporated in law
- Authority establishment: Clear agency responsibilities and coordination
- Just transition chapter: Social equity and worker protection
- Emissions control: Enhanced reduction and incentive mechanisms
- Carbon fee system: Dedicated revenue streams for low-carbon initiatives
- Adaptation chapter: Climate resilience and preparedness
- Carbon footprint: Product labeling and management schemes
- Transparency: Information disclosure and citizen participation

Carbon Fee Implementation:

- Revenue dedication: Reinvestment in low-carbon technologies and initiatives
- Industry incentives: Supporting transformation investments
- Polluter-pays principle: Economic signals for emissions reduction
- Revenue recycling: Funding green industrial development

4.3 Institutional Coordination Mechanisms

Inter-Ministerial Coordination Group:

- Structure: Deputy ministers from climate policy-responsible ministries
- Functions: Division of labor coordination, information sharing
- Policy evaluation: Collaborative assessment of implementation

Consulting Units:

- **Academia Sinica:** Taiwan's premier academic research institution, scientific foundation for policy
- **Industrial Technology Research Institute (ITRI):** Applied research institution, technology development support
- Role: Professional advice, technical input, feasibility assessment

Key Government Ministries:

- **Ministry of Economic Affairs (MOEA):** Industrial policy, energy policy, economic transition
- **Ministry of Environment (MOENV):** Climate policy, emissions monitoring, environmental regulation
- **National Development Council:** Overall planning, policy coordination
- **Office of Energy and Carbon Reduction (Executive Yuan):** Cross-cutting coordination, net-zero pathway implementation

4.4 Hydrogen Energy Strategy

Key Strategic Action Plan: Hydrogen (2023):

- Launch: April 2023 by Executive Yuan
- Vision: Far-reaching goals and division of labor
- Critical gap: No corresponding funding plan specified
- CPC Corporation role: Leading hydrogen energy development
- CPC constraint: Cash-strapped, no subsidies received (as of April 2024)

Funding Reality vs. International Benchmarks:
Taiwan Hydrogen Investment (2023–2024):

- Total budget: $125 million combined
- CSC allocation: $75 million designated
- CSC received: $10 million (as of April 2024)
- CPC received: $0

International Comparison:

- Japan: $103 billion over 15 years (∼$6.9 billion annually) based on latest basic hydrogen strategy
- Germany: ∼20 billion for ThyssenKrupp hydrogen steelmaking alone
- Japan Green Innovation Fund: $1.5 billion for industry green transition
- Taiwan gap: Two orders of magnitude below comparable economies

Sector-Specific Initiatives:

- Steel sector priority: Recognized in 12 key strategies
- TSMC participation: World's largest chip foundry using green hydrogen in processes
- Corporate leadership: Eight major tech companies (ACER, AUO, ASUS, Delta Electronics, LiteOn, Pegatron, TSMC, Taiwan Microsoft) committed to 100% renewable energy (announced November 2021)
- Private sector driving: Companies moving ahead despite limited government support

5 Decarbonization Technology Pathways

5.1 Hydrogen-Based Direct Reduction (H2-DRI)

Technical Approach for Taiwan:

CSC Experimental Program:

- Blast furnace hydrogen injection: Testing partial replacement of coke
- Simulator facility: Three-meter-high apparatus at Kaohsiung
- Process parameters: Iron ore pellet reduction, hydrogen introduction from bottom
- Technical challenges: Heat absorption, temperature maintenance, reduction kinetics
- Risk assessment: "Very risky undertaking" given technology immaturity

Future DRI-EAF Pathway:

- Global standard: H2-DRI + EAF emerging as primary decarbonization route
- Taiwan application: Potential for new capacity, BF replacement
- Scale requirements: Industrial-scale DRI plants, EAF capacity expansion
- Integration needs: Hydrogen supply, electricity grid, downstream processing

Hydrogen Supply Challenges:

Production Requirements:

- CSC demand: 1 million tonnes H_2 annually for complete transition
- Electrolyzer capacity: 14 GW renewable electricity generation needed
- Taiwan constraint: Total offshore wind capacity insufficient
- Alternative sources: Onshore wind, solar, geothermal, hydropower
- Import option: Limited by island geography, storage infrastructure

Cost Competitiveness:

- Current green H_2: \$5,000–12,000 per tonne
- Target (2050): \$1,500 per tonne for commercial viability
- Cost reduction path: Electrolyzer efficiency, renewable energy costs, scale economies
- Timeline uncertainty: Achieving cost targets by 2050 not guaranteed

Infrastructure Development Needs:

- Production facilities: Large-scale electrolyzers, potentially offshore
- Storage systems: High-pressure tanks, underground storage, liquid hydrogen
- Distribution network: Pipelines, transportation systems to steel plants
- Safety infrastructure: Handling, monitoring, emergency response systems
- Grid integration: Managing variable renewable energy for H_2 production

5.2 Carbon Capture, Utilization and Storage (CCUS)

Current Implementation Status:

CSC CCUS Facility:

- Scale: Taiwan's largest carbon capture plant
- Capture capacity: 0.4% of CSC annual emissions currently
- Technology demonstration: Proof-of-concept operational
- Scalability challenge: 250-fold increase needed for comprehensive capture

Chang Chun Group Utilization:

- CO_2 delivery: Captured carbon piped to petrochemical partner

- Product: Chemical feedstocks for semiconductor industry
- Value chain integration: Steel-petrochemical-semiconductor linkage
- Economic model: Revenue from CO_2 utilization offsetting capture costs
- Replicability: Limited by utilization market size

Technology Pathway and Limitations:
Bridge Role:

- Interim solution: Reducing emissions while hydrogen infrastructure develops
- Retrofit potential: Applying to existing blast furnaces
- Incremental deployment: Gradual capacity increase over time
- Time-buying: Allowing continued BF operation during transition period

Fundamental Constraints:

- Energy penalty: CCUS systems consume 15–25% of plant energy
- Capture efficiency: Typically 80–90%, not 100%
- Storage capacity: Taiwan's geological storage potential uncertain
- Utilization limits: Market for CO_2-derived products finite
- Deep decarbonization: Insufficient for 95%+ emission reductions
- Cost trajectory: High capital and operating expenses likely persisting

5.3 Electric Arc Furnace Expansion and Grid Decarbonization

EAF Capacity Growth Potential:

- Current share: 45–50% of Taiwan capacity (higher than most Asian countries)
- Expansion opportunity: Additional scrap-based capacity
- Technology advantage: Existing expertise (Tung Ho, others)
- Capital efficiency: Lower investment than BF-BOF replacement
- Rapid deployment: Shorter construction timelines

Scrap Supply Dynamics:

- Urban mining leadership: Advanced collection and processing systems
- Domestic generation: Substantial scrap from manufacturing, construction, end-of-life products
- Quality control: Taiwan Steel Union innovations in sorting and upgrading
- Specialty materials recovery: Electronic waste as scrap source plus specialty metals
- Import potential: Supplementing domestic scrap with high-quality imports
- Export current practice: Some scrap exported; reversing flows would support EAF expansion

Grid Decarbonization Imperative:
Current Electricity Grid Challenges:

- Fossil fuel dependency: Substantial coal and natural gas generation
- Renewable energy constraints: Limited land area for large-scale solar, wind
- Offshore wind development: Ambitious targets but insufficient for industrial hydrogen needs
- Nuclear phase-out: Policy to exit nuclear power by 2025 (later extended)
- Grid stability: Managing intermittent renewable energy sources
- EAF emission linkage: Grid decarbonization directly impacts EAF steel carbon footprint

Renewable Energy Expansion Needs:

- Solar deployment: Maximizing rooftop, floating, and limited ground-mounted capacity
- Offshore wind acceleration: Current projects insufficient for hydrogen + EAF needs
- Geothermal potential: Underutilized resource given Taiwan's volcanic geology
- Energy storage: Battery systems, pumped hydro for grid stability
- Smart grid: Demand response, load balancing for variable renewable integration

5.4 Circular Economy and Material Efficiency

Taiwan's Circular Economy Excellence:

Policy Framework:

- Resource recycling: One of 12 key strategies in net-zero pathway
- Zero waste goal: Comprehensive waste minimization approach
- Extended producer responsibility: Product lifecycle management
- Industrial symbiosis: Waste-to-resource exchanges between industries

Steel Sector Applications:

- Slag utilization: Blast furnace and EAF slag in cement, construction
- Dust and sludge: Recovery of iron, zinc, other metals
- By-product gases: BFG, COG utilization for energy generation
- Water recycling: CSC's 100% wastewater recycling model
- Energy cascading: Waste heat recovery and utilization

Material Efficiency in End-Use Sectors:

- Construction optimization: Reduced steel intensity through design improvements
- Product longevity: Durability standards extending service life
- Remanufacturing: Component reuse in machinery, automotive sectors
- Design for disassembly: Facilitating future material recovery

6 Resource Constraints and Strategic Vulnerabilities

6.1 Energy Import Dependency

Fossil Fuel Import Reality:

- Coal imports: 100% dependency for coking coal (steelmaking) and thermal coal (power generation)
- Natural gas: 100% imported as LNG
- Oil: 100% imported petroleum products
- Energy security: Vulnerability to supply disruptions, price volatility
- Decarbonization imperative: Reducing fossil fuel imports while maintaining energy security

Renewable Energy Limitations:

- Land scarcity: Limited space for large-scale solar farms
- Offshore wind: Substantial potential but grid integration challenges
- Geothermal: Underdeveloped despite volcanic geology
- Hydropower: Limited expansion potential, environmental constraints
- Biomass: Competing uses, sustainability concerns
- Import potential: Green hydrogen, ammonia as future energy carriers

6.2 Raw Material Dependencies

Iron Ore Imports:

- CSC requirement: 100% imported iron ore for blast furnaces
- Supply sources: Australia, Brazil, other major exporters
- Price exposure: Global iron ore market volatility
- Shipping dependency: Vulnerable to maritime disruptions
- No domestic alternative: Zero iron ore resources in Taiwan

Alloying Elements and Specialty Materials:

- Nickel: Critical for stainless steel, imported
- Chromium, molybdenum, vanadium: All imported
- Rare earths: Imported for specialty steel applications
- Partial mitigation: Urban mining recovering some specialty materials

6.3 Geographic and Scale Constraints

Island Economy Limitations:

- Land area: 36,197 km^2, limiting industrial expansion
- Population density: Competing land uses (residential, agricultural, industrial)
- Transportation costs: Island logistics premium for imports and exports
- Regional integration: Limited pipeline connectivity (hydrogen, CO_2) vs. continental economies

Scale Disadvantages vs. Competitors:

- China: 1 billion+ tonnes annual production, economies of scale
- Japan: 90+ million tonnes, larger industrial base
- South Korea: 70+ million tonnes, POSCO as global leader
- Taiwan: 20 million tonnes, mid-sized producer
- Technology development: Smaller scale limiting pilot project economics
- Supply chain: Less bargaining power with equipment suppliers

7 Political Context and International Isolation

7.1 Cross-Strait Relations and Strategic Vulnerability

Geopolitical Complexity:

- Political status: Ambiguous international recognition (One China policy)
- Trade integration: Paradoxically high economic interdependence with China
- Security concerns: Military tensions, potential blockade scenarios
- Energy security: Maritime routes critical for fossil fuel, raw material imports
- Technology transfer: Political barriers to some international collaborations

Steel Trade with China:

- Export market: China significant destination for Taiwan steel products
- Import competition: Chinese overcapacity creating pricing pressures
- Trade barriers: Political tensions affecting market access
- Technology flow: Cross-strait investment and knowledge transfer

7.2 Limited International Participation

Exclusion from International Organizations:

- UN system: Not member of UN, UNFCCC, or most UN agencies
- Climate negotiations: Observer status only, limited voice in global agreements
- Technology partnerships: Political barriers to some multilateral initiatives
- Development finance: Limited access to some international funding mechanisms

Bilateral Relationships and Workarounds:

- US partnership: Strong economic and technology ties despite unofficial relations
- Japan cooperation: Deep industrial collaboration, technology transfer
- European engagement: Trade, research partnerships (though limited vs. sovereign states)
- APEC membership: Platform for regional economic engagement
- Private sector networks: Companies participating in international steel initiatives

7.3 Domestic Politics and Policy Continuity

Political Party Dynamics:

- Democratic Progressive Party (DPP): Currently governing, strong climate commitment
- Kuomintang (KMT): Opposition, different priorities and China relations approach
- Policy continuity risk: Potential shifts with electoral changes
- Net-zero commitment: Broad political consensus but implementation details debated

Public Opinion and Civil Society:

- Climate awareness: High public concern about climate change
- Just transition emphasis: Worker and community concerns about industrial transformation
- Environmental movements: Active civil society monitoring industrial emissions
- Energy policy debates: Nuclear power phase-out vs. renewable energy adequacy

8 Industry Perspectives and Corporate Strategies

8.1 CSC Strategic Positioning

Dual-Core Strategy Implementation:

- **Core 1 - High-Value Steel:** Shifting product mix toward premium grades
- Advanced high-strength steels for automotive
- Electrical steel for motors, transformers
- Specialty grades for electronics, precision applications
- **Core 2 - Green Energy:** Diversification beyond traditional steelmaking
- Renewable energy investments through subsidiaries
- Green energy materials and components
- Energy storage and grid services

Sustainability Integration:

- DJSI inclusion: Demonstrating ESG leadership
- Stakeholder engagement: Investor pressure for climate action
- Supply chain requirements: Downstream customers demanding low-carbon steel
- Brand positioning: Sustainability as competitive differentiation

Risk Management Approach:

- Technology hedging: Pursuing both hydrogen and CCUS pathways
- Phased transition: Incremental changes while developing breakthrough technologies
- Financial prudence: Balancing transformation investment with operational viability
- Government dialogue: Advocating for enhanced policy support

8.2 EAF Sector Competitive Strategy

Tung Ho and Peers:

- Technology leadership: Direct rolling innovation creating competitive advantage
- Environmental branding: EPD certifications differentiating products
- Niche market focus: Specialty rebar, high-strength products
- Collaborative innovation: Taiwan Steel Union model for shared challenges
- International recognition: Technology adoption globally validating approach

Market Positioning:

- Domestic construction: Serving Taiwan's infrastructure needs
- Export markets: Leveraging quality and environmental performance
- Green building: Supplying low-carbon steel for sustainable construction
- Customer education: Promoting environmental benefits of EAF steel

8.3 Industry Association Coordination

Taiwan Iron and Steel Industries Association (TISIA):

- Industry representation: Advocacy to government on policy needs
- Data collection: Industry statistics and benchmarking
- Technology sharing: Facilitating knowledge exchange among members
- International engagement: Representing Taiwan steel globally

Cross-Sector Collaboration:

- Downstream integration: Coordination with automotive, construction, machinery sectors
- Supply chain initiatives: Promoting low-carbon steel adoption
- Research partnerships: Collaboration with academic institutions
- Government consultation: Input to policy development processes

9 International Comparisons and Learning Opportunities

9.1 Similar-Scale Economies

South Korea Comparison:

- POSCO leadership: Global technology leader in hydrogen steelmaking
- Government support: Substantial public investment in green steel
- Scale advantage: 70 MT production vs. Taiwan's 20 MT
- Technology export: POSCO's FINEX, hydrogen DRI technologies
- Taiwan gap: Insufficient funding, political isolation limiting partnerships

Japan Lessons:

- Similar constraints: Island economy, resource import dependency
- Technology excellence: JFE, Nippon Steel leading hydrogen research
- Government support: $103 billion hydrogen strategy over 15 years
- NEDO funding: Public R&D support for breakthrough technologies
- Industry collaboration: Coordinated approach among competitors
- Taiwan parallel: Similar challenges but vastly different resource commitment

9.2 European Integrated Mills

ThyssenKrupp Model:

- H2-DRI investment: 2 billion direct reduction plant
- Government support: 20 billion total subsidies
- Technology pathway: Clear commitment to hydrogen route
- Timeline: Operational by late 2020s
- CSC comparison: Similar technology pathway, orders of magnitude less funding

ArcelorMittal and SSAB:

- Multiple pathways: Hydrogen, Smart Carbon, circular economy
- EU Innovation Fund: Large-scale demonstration project support
- CBAM protection: Carbon border adjustment ensuring competitiveness
- Regional coordination: EU-wide policy framework and funding
- Taiwan contrast: Isolated approach without multilateral support structure

9.3 Circular Economy Leaders

Netherlands and Belgium:

- Industrial symbiosis: Steel-chemical integration similar to CSC-Chang Chun model
- Port infrastructure: Hydrogen import terminals for steelmaking
- Geographic advantage: Continental connectivity Taiwan lacks
- Technology transfer: Potential partnerships for Taiwan

Singapore Urban Mining:

- Land-scarce analogy: Similar constraints to Taiwan
- High-value recovery: Electronics, specialty materials focus
- Regional hub: Serving Southeast Asian scrap processing needs
- Taiwan opportunity: Similar positioning for Northeast Asia

10 Future Scenarios and Strategic Pathways

10.1 Scenario 1: Technology Breakthrough and Enhanced Support (Optimistic)

Pathway Description:

- **2025–2030:** Government dramatically increases funding to $2–3 billion annually for industrial decarbonization, prioritizing steel sector
- CSC receives $15–20 billion for hydrogen infrastructure over decade
- Offshore wind accelerates to 20+ GW by 2035, enabling green hydrogen production
- First commercial-scale H2-DRI plant operational by 2033
- EAF sector expands to 60% of total capacity through new investments

2030–2040 Developments:

- CSC converts 2 of 4 blast furnaces to H2-DRI-EAF by 2038
- CCUS captures 50% of remaining BF emissions
- Taiwan becomes regional green steel technology hub
- Exports premium low-carbon steel to Japan, Korea, Southeast Asia
- 70% emissions reduction achieved by 2040

2040–2050 Completion:

- All BF capacity converted or retired
- Residual emissions offset through CCUS, carbon sinks
- Net-zero achieved by 2050
- Steel industry maintains 18–20 MT capacity
- Taiwan demonstrates island economy decarbonization model

Critical Success Factors:

- Political will: Sustained commitment across electoral cycles
- Funding mobilization: Public and private capital at sufficient scale
- Renewable energy: Overcoming land/grid constraints
- Technology maturation: Hydrogen costs declining to $1,500/tonne by 2040
- International cooperation: Overcoming political isolation for technology partnerships

10.2 Scenario 2: Incremental Progress with Constraints (Realistic)

Pathway Description:

- **2025–2030:** Government funding increases modestly to $500 million–$1 billion annually
- CSC receives $3–5 billion over decade, insufficient for complete transition
- Renewable energy reaches 12–15 GW by 2035, providing limited green hydrogen
- CCUS scales to 20–30% of BF emissions
- EAF expands to 55% of capacity

2030–2040 Developments:

- CSC converts 1 blast furnace to H2-DRI-EAF by 2038
- Other BFs continue with CCUS, efficiency improvements, hydrogen co-injection
- 50% emissions reduction achieved by 2040
- Capacity declines modestly to 18 MT due to competitiveness pressures
- Some market share lost to competitors with stronger decarbonization progress

2040–2050 Delayed Completion:

- Second BF conversion delayed to 2045–2048
- Significant CCUS dependency for residual emissions
- Net-zero achieved 2050–2055, potentially missing formal target
- Capacity stabilizes at 16–18 MT
- Competitive disadvantage vs. Korea, Japan in premium markets

Key Constraints:

- Funding limitations: Persistent gap vs. international benchmarks
- Energy constraints: Renewable energy development slower than needed
- Technology costs: Hydrogen remains expensive through 2040s
- Political challenges: Policy continuity issues, cross-strait tensions
- Economic pressures: Balancing transformation costs with competitiveness

10.3 Scenario 3: Managed Decline and Capacity Reduction (Pessimistic)

Pathway Description:

- **2025–2030:** Government funding remains inadequate at $100–300 million annually
- CSC struggles financially with carbon fee implementation, limited support
- Renewable energy stalls at 10 GW by 2035
- CBAM-equivalent trade barriers emerge in key export markets

- Competitiveness deteriorates vs. Korean, Japanese, Chinese producers

2030–2040 Contraction:

- CSC closes 2 blast furnaces without replacement (2032–2036)
- Capacity declines to 12–14 MT
- 40% emissions reduction achieved primarily through capacity reduction
- Market share loss in exports, increased imports for domestic consumption
- Employment declines, regional economic impacts in Kaohsiung

2040–2050 Residual Industry:

- Remaining BF closed by 2045
- EAF sector survives at 8–10 MT capacity
- Net-zero achieved through dramatic capacity reduction
- Taiwan becomes net steel importer for many products
- Loss of strategic industrial capability
- Downstream sectors (automotive, machinery) impacted by steel dependency

Triggering Factors:

- Policy failure: Insufficient climate policy support
- Financial constraints: Unable to mobilize transformation capital
- Technology disappointment: Hydrogen costs remain prohibitive
- Trade barriers: Export markets close to high-carbon steel
- Political instability: Cross-strait tensions disrupting economic planning

11 Recommendations and Policy Priorities

11.1 Immediate Actions (2025–2027)

Dramatically Scale Hydrogen Funding:

- Increase annual allocation from $125 million to $2–3 billion
- Prioritize CSC's hydrogen transition with $1.5–2 billion annually
- Ensure actual disbursement, not just budgetary allocation
- Establish dedicated Steel Decarbonization Fund modeled on Japan's Green Innovation Fund
- Create urgency matching 2050 deadline reality

Accelerate Renewable Energy Deployment:

- Streamline offshore wind permitting and grid connection
- Prioritize renewable electricity for industrial decarbonization
- Develop hydrogen production zones co-located with offshore wind
- Investigate green hydrogen imports as supplement to domestic production
- Reform electricity market for industrial green power procurement

Establish Clear Steel Decarbonization Roadmap:

- Binding sectoral targets aligned with 2050 net-zero goal
- Technology pathway guidance (H2-DRI, CCUS, EAF expansion)
- Phase-out timeline for conventional blast furnaces
- Investment incentives and risk mitigation mechanisms
- Coordination between MOEA, MOENV, MOF, CSC, private sector

11.2 Medium-Term Priorities (2027–2035)

CSC First H2-DRI Plant:

- Target: Operational by 2032–2033
- Capacity: 2–3 million tonnes annually (replacing one blast furnace)
- Funding: $4–6 billion capital investment, 60–80% government support
- Hydrogen supply: Dedicated green H_2 production or import terminal
- Technology partnership: Collaboration with Japan (JFE, Nippon Steel), Europe (ThyssenKrupp, SSAB), or Korea (POSCO)

EAF Sector Expansion:

- Target: 60% of Taiwan capacity by 2035
- New capacity: 4–5 million tonnes additional EAF
- Scrap supply: Enhanced collection, import augmentation, export restrictions
- Grid decarbonization: Ensuring EAF emission reductions through renewable electricity
- Technology diffusion: Tung Ho direct rolling model replicated industry-wide

CCUS Scale-Up:

- Target: 30–40% capture rate for remaining blast furnaces
- Utilization expansion: Additional petrochemical, chemical feedstock applications
- Storage exploration: Geological assessment for CO_2 sequestration
- Regional cooperation: Potential offshore storage shared with Japan, Korea
- Bridge technology: Enabling continued BF operation during H2 transition

Circular Economy Integration:

- Material efficiency standards: Reducing steel intensity in construction, manufacturing
- Extended producer responsibility: Steel-containing product takeback systems
- Industrial symbiosis expansion: Replicating CSC-Chang Chun model
- Urban mining excellence: Maintaining global leadership in scrap processing
- Product life extension: Design for durability and remanufacturing

11.3 Long-Term Vision (2035–2050)

Complete BF-BOF Phase-Out:

- Final two CSC blast furnaces converted to H2-DRI-EAF by 2045–2048
- Capacity maintenance: 18–20 million tonnes total (mix of DRI-EAF and scrap-EAF)
- Technology leadership: Taiwan as island economy decarbonization model
- Regional hub: Exporting low-carbon steel, technology, expertise

Hydrogen Economy Maturation:

- Domestic production: 15–20 GW renewable electricity for hydrogen
- Import infrastructure: Ammonia or liquid H_2 terminals supplementing domestic supply
- Cost competitiveness: Green hydrogen at $1,500–2,000 per tonne
- Cross-sector integration: Steel, chemicals, transportation sharing hydrogen infrastructure

Net-Zero Steel Sector:

- 95%+ emissions reduction from 2020 baseline
- Residual emissions: High-quality carbon offsets, nature-based solutions
- Circular economy: 70–80% scrap-based production where technically feasible
- Just transition: Workers retrained, Kaohsiung region economically diversified
- Competitiveness: Premium positioning in global low-carbon steel markets

11.4 Overcoming Political and Structural Constraints

International Cooperation Despite Isolation:

- Bilateral partnerships: Deepening collaboration with Japan, US, EU on technology transfer
- Private sector networks: CSC, Tung Ho participating in global steel initiatives
- Academic exchange: Taiwan universities partnering on decarbonization research
- Technology licensing: Accessing H2-DRI, CCUS, advanced EAF technologies
- Investment attraction: Foreign capital for green steel projects despite political constraints

Cross-Strait Pragmatism:

- Economic interdependence: Maintaining steel trade despite political tensions
- Technology exchange: Selective collaboration on climate technologies
- Supply chain resilience: Diversifying beyond China where strategically necessary
- Market access: Ensuring Chinese market remains open to Taiwan low-carbon steel

Domestic Consensus Building:

- Bipartisan climate commitment: Ensuring net-zero survives electoral changes
- Just transition emphasis: Addressing worker and community concerns proactively
- Public communication: Building societal understanding of transformation necessity
- Stakeholder engagement: Industry, labor, civil society co-creating solutions

12 Conclusions

Taiwan's steel industry occupies a unique position in the global decarbonization challenge. As a technologically advanced, mid-sized producer constrained by political isolation, limited natural resources, and critical import dependencies, Taiwan exemplifies both the possibilities and limitations facing island economies in industrial transformation.

Key Findings:

- **Corporate ambition vs. systemic constraints:** CSC and Tung Ho demonstrate world-class technical capabilities and genuine net-zero commitment, yet face insurmountable funding, energy, and political barriers without enhanced government support.
- **Funding gap as critical bottleneck:** Taiwan's $125 million annual hydrogen allocation (with only partial disbursement) contrasts catastrophically with Japan's $6.9 billion annually and Germany's 20 billion for single-company steelmaking transitions.
- **Island economy vulnerabilities:** 100% dependency on imported fossil fuels and iron ore, combined with limited land for renewable energy, creates structural disadvantages vs. continental competitors.
- **EAF and circular economy strengths:** Taiwan's 45–50% EAF share, Tung Ho's direct rolling innovation, and urban mining excellence provide competitive advantages and lower-cost decarbonization pathways.
- **Political isolation handicap:** Exclusion from international climate mechanisms, limited multilateral funding access, and cross-strait tensions constrain technology partnerships and policy coordination.
- **Technology readiness gap:** Despite CSC's experimental efforts, hydrogen steelmaking remains "very risky" with immature technologies, high costs, and uncertain timelines to commercial viability.

Strategic Imperatives:
Taiwan faces a stark choice between three pathways:

1. **Transformation Commitment:** Mobilizing $20–30 billion over 2025–2040 for hydrogen infrastructure, renewable energy, and steel decarbonization—enabling technology leadership and maintaining strategic industrial capability.
2. **Incremental Adaptation:** Modest increases in funding supporting partial transition, CCUS bridging, and gradual capacity adjustment—achieving 2050 goals but with competitive disadvantages and potential delays.
3. **Managed Decline:** Continued inadequate support leading to capacity closures, import dependency, and loss of strategic steel capability—technically achieving net-zero through de-industrialization.

The Path Forward:

The realistic scenario appears most likely given current trajectories. However, Taiwan possesses the technical excellence, corporate commitment, and societal support to pursue the optimistic pathway if political will and financial resources are mobilized. Key enablers include:

- **Immediate funding surge:** Increasing annual allocations 15–20× to match international benchmarks relative to GDP.
- **Renewable energy acceleration:** Prioritizing offshore wind, geothermal, and grid infrastructure for industrial decarbonization.
- **Technology partnerships:** Leveraging relationships with Japan, US, EU to access H2-DRI technologies despite political constraints.
- **EAF expansion:** Building on existing circular economy strengths for lower-cost, faster emission reductions.
- **Regional positioning:** Becoming Northeast Asian green steel hub, exporting low-carbon products and urban mining expertise.

A Call for Recognition and Support:

Taiwan's steel decarbonization challenge deserves international attention not only for its intrinsic importance but as a test case for how technologically advanced, resource-constrained economies navigate industrial transformation amid political complexity. Success would demonstrate that island economies can achieve ambitious climate goals without sacrificing strategic industrial capabilities. Failure would illustrate how structural constraints and political isolation can undermine even the most capable and committed actors.

For the global steel research community, Taiwan presents opportunities for collaboration on hydrogen steelmaking, urban mining, industrial symbiosis, and circular economy innovations. Supporting Taiwan's transition through knowledge sharing, technology partnerships, and recognition of its unique challenges serves broader objectives of demonstrating diverse pathways to sustainable steel production.

The window for Taiwan's steel transformation is narrowing. The decisions made in the coming 2–3 years will largely determine whether Taiwan navigates the optimistic, realistic, or pessimistic scenario. Given the technical excellence demonstrated by CSC, Tung Ho, and Taiwan's broader steel ecosystem, the primary barrier is not capability but resources and political will. Addressing this gap is essential for Taiwan's industrial future and its contribution to global climate objectives.

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