Global Steel Industry Analysis 2025: Production Rankings, Research Policies, and Decarbonization Strategies

Based on World Steel Association Data and Global Policy Documents

October 2025

Abstract

This document provides a comprehensive analysis of the global steel industry, featuring the latest production rankings from the World Steel Association for 2023-2024, and detailed examination of steel research funding and innovation policies across the world's major steel-producing regions. The analysis covers the top 12 steel-producing countries, examining how different nations are addressing decarbonization, technological innovation, and competitiveness in the global steel industry. The document highlights funding mechanisms, research priorities, technology readiness levels (TRLs), industry-academia collaboration models, and strategic pathways toward carbon neutrality.

Contents

1 Global Steel Production Rankings and Comparative Analysis

1.1 Current Global Steel Production Rankings (2023-2024)

Rank	Country	2024 Production (MT)	2023 Rank	2023 Production (MT)
1	China	1,005.1	1	1,028.9
2	India	149.4	2	140.8
3	Japan	84.0	3	87.0
4	United States	79.5	4	81.4
5	Russia	71.0	5	76.0
6	South Korea	63.6	6	66.7
7	Germany	37.2	7	35.4
8	Türkiye	36.9	8	33.7
9	Brazil	33.8	9	32.0
10	Iran	31.4	10	30.7
11	Viet Nam	22.0	12	19.2
12	Italy	20.0	11	21.1
13	Taiwan, China	19.2	13	19.1
14	Indonesia	18.0	14	16.8
15	Mexico	13.8	15	16.4
16	Canada	12.3	16	12.2
17	Spain	11.9	17	11.4
18	France	10.8	19	10.0
19	Egypt	10.7	18	10.4
20	Saudi Arabia	9.6	20	9.9

Table 1: Top 20 Global Steel Producers (2023-2024)

Rank	Country	2024 Production (MT)	2023 Rank	2023 Production (MT)
21	Malaysia	8.8	21	7.5
22	Ukraine	7.6	24	6.2
23	Belgium	7.1	25	5.9
24	Austria	7.1	22	7.1
25	Poland	7.1	23	6.4
26	Netherlands	6.4	33	4.7
27	Thailand	4.9	30	5.0
28	South Africa	4.7	31	5.0
29	Australia	4.7	28	5.3
30	Algeria	4.5	34	4.4
31	Bangladesh	4.5	29	5.0
32	Kazakhstan	4.2	37	3.9
33	Pakistan	4.1	27	5.3
34	Sweden	4.0	36	4.3
35	United Kingdom	4.0	26	5.6
36	Slovakia	3.9	35	4.4
37	Argentina	3.9	32	4.9
38	United Arab Emirates	3.7	39	3.8
39	Finland	3.7	38	3.8
40	Oman	3.0	41	2.9

Table 2: Global Steel Producers Ranked 21-40 (2023-2024)

Rank	Country	2024 Production (MT)	2023 Rank	2023 Production (MT)
41	Iraq	3.0	42	2.8
42	Czechia	2.5	40	3.4
43	Belarus	2.3	43	2.3
44	Portugal	1.9	44	2.0
45	Philippines	1.9	46	1.9
46	Luxembourg	1.8	45	1.9
47	Peru	1.6	48	1.6
48	Kenya	1.6	52	1.4
49	Morocco	1.4	50	1.4
50	Serbia	1.4	49	1.5
–	Others	23.0	–	23.6
–	World Total	1,884.6	–	1,904.1

Table 3: Global Steel Producers Ranked 41-50 and World Total (2023-2024)

1.2 Production Trends Analysis

1.2.1 Key Observations

- **Global Production Decline**: World crude steel production decreased by 19.5 million tonnes (1.0%) from 1,904.1 MT in 2023 to 1,884.6 MT in 2024.
- **China's Dominance**: China remains the undisputed leader with 1,005.1 MT in 2024, though production decreased by 23.8 MT (2.3%) from 2023.
- **India's Growth**: India solidified its position as the second-largest producer with 149.4

MT in 2024, an increase of 8.6 MT (6.1%) from 2023.

- **Vietnam's Rise**: Vietnam moved up from 12th to 11th position with 22.0 MT in 2024, an increase of 2.8 MT (14.6%) from 2023.
- **European Union Performance**: Germany (37.2 MT), Italy (20.0 MT), and Spain (11.9 MT) maintained their positions among the top 20 producers.
- **Notable Changes**:
  - Ukraine moved up from 24th to 22nd position despite ongoing conflict
  - Netherlands jumped from 33rd to 26th position
  - France moved up from 19th to 18th position
  - Italy dropped from 11th to 12th position

1.2.2 Regional Production Distribution

Region	2024 Production (MT)	Share of World Total
Asia	1,426.3	75.7%
European Union	126.5	6.7%
North America	105.6	5.6%
Middle East	54.7	2.9%
South America	37.7	2.0%
Africa	16.8	0.9%
Oceania	4.7	0.2%
Others	112.3	6.0%

Table 4: Regional Steel Production Distribution (2024)

2 China Steel Research and Industrial Policy

2.1 Strategic Context

China accounts for over 50% of global steel production and is implementing a comprehensive transformation focused on quality over quantity, capacity discipline, and green transition.

2.2 2025-2026 Steel Industry Growth Plan

Core Objectives:

- Value-added growth target: 4% annually (2025-2026)
- Break away from scale expansion inertia
- Optimize industrial structure and supply quality
- Develop "new quality productivity"

2.3 Key Policy Frameworks

2.3.1 14th Five-Year Plan (2021-2025) Circular Economy

Special Action Plan for Energy Conservation and Carbon Reduction:

- Emission reduction target: 53M tonnes (2024-2025)
- Replace blast furnaces with EAF where possible
- Control total steel output while transitioning
- 15% EAF share target by 2025 (current: 10%)

2.3.2 Ultra-Low Emissions Upgrades

Target	Timeline
80%+ steel capacity ultra-low emissions	End 2025
Inclusion in national carbon trading scheme	First time 2025
Digital energy/carbon management centers	Establishment 2025

Table 5: China's Green Steel Transformation Targets

2.4 Technology Development Focus

2.4.1 Hydrogen Metallurgy

- Long-term decarbonization strategy component
- Large-scale implementation economically challenging near-term
- Investment signals post-2025 acceleration
- Green hydrogen application development in steelmaking

2.4.2 High-End Steel Development

Priority Materials:

- Bearing steel for specialized applications

- Gear steel for automotive and machinery
- High-temperature alloys for nuclear, marine, defense
- Low-carbon certified steel products
- Enhanced traceability for construction materials (rebar)

2.4.3 Innovation Collaboration

- Joint R&D between steel producers and downstream industries
- Partnerships with academic and research institutions
- Coordinated technology roadmaps for critical applications
- Accelerated commercialization pathways for innovative materials

2.5 Digitalization Initiatives

2025 Targets:

- Numerical control rate of key processes: 80%
- Digital production equipment proportion: 55%
- Smart factories: 30+ facilities
- Integration of 5G, industrial Internet, AI in manufacturing

2.6 Capacity Management Strategy

Policy Element	Detail
Production control	Ban on new capacity expansion
Capacity replacement	Suspended for policy review (late 2025/early 2026)
BF-BOF reduction target	90M tonnes in 2025 (10% YoY)
EAF capacity utilization	Increase to 70%
Scrap imports	Liberalization to ease supply gaps

Table 6: China's Capacity Management Framework

3 India Steel Research and Industrial Policy

3.1 Strategic Context

India is rapidly expanding its steel production capacity, targeting 300 MT by 2030 from current levels of 120 MT, while simultaneously addressing decarbonization challenges. The country's steel policy balances growth ambitions with climate commitments, emphasizing technology transfer and domestic innovation.

3.2 National Steel Policy 2017 (Revised 2023)

Core Objectives:

- Create globally competitive steel industry
- Foster domestic consumption and value addition
- Promote research and development in steel sector
- Focus on environmentally sustainable steelmaking
- Develop India as a net exporter of steel by 2025

3.3 Production Capacity Expansion

Parameter	Current (2025)	Target (2030)
Total Capacity	154 MT	300 MT
Crude Steel Production	120 MT	255 MT
Per Capita Consumption	77 kg	160 kg
EAF Share	35%	45%

Table 7: India Steel Industry Expansion Targets

3.4 Decarbonization Strategy

3.4.1 Carbon Neutral Roadmap

Key Initiatives:

- Mission 2070: Net-zero emissions target for steel sector
- Green Hydrogen Mission: $2.5 billion allocation for hydrogen production
- National Hydrogen Energy Mission with steel sector focus
- Perform, Achieve and Trade (PAT) Scheme for energy efficiency

3.4.2 Technology Development Priorities

Research Focus Areas:

- Hydrogen-based DRI technology adaptation for Indian iron ore
- Carbon capture, utilization, and storage (CCUS) for integrated plants
- Increased scrap utilization and quality improvement
- Biomass and waste gas injection in blast furnaces

- Renewable energy integration for steel plant operations

3.5 Research and Innovation Framework

3.5.1 Steel Research Institutions

Key Organizations:

- Research and Development Centre for Iron and Steel (RDCIS), SAIL
- National Metallurgical Laboratory (NML), CSIR
- Indian Institute of Metals (IIM)
- Joint research initiatives with IITs and other premier institutions

3.5.2 Industry-Academia Collaboration

Partnership Models:

- Steel Development Fund (SDF) supporting research projects
- Industry-sponsored research chairs at technical institutions
- Technology transfer agreements with international partners
- Startup incubation focused on steel sector innovations

3.6 Major Steel Companies' Decarbonization Plans

3.6.1 Steel Authority of India Limited (SAIL)

Green Initiatives:

- Investment of $7 billion in modernization and expansion
- Installation of waste heat recovery systems across plants
- Solar power capacity of 200 MW at plant locations
- Target: 20% reduction in specific energy consumption by 2030
- Exploration of hydrogen injection in blast furnaces

3.6.2 Tata Steel

Decarbonization Strategy:

- Net-zero emissions target by 2045 (5 years ahead of national target)
- HIsarna technology development (coal-based direct reduction)
- Partnership with Australian company for CCUS technology
- Green hydrogen pilot plant at Jamshedpur (10 MW)
- Increased scrap-based steelmaking capacity

3.6.3 JSW Steel

Innovation Focus:

- Investment of $4.5 billion in capacity expansion and technology upgrade
- Partnership with John Cockerill for hydrogen-based steelmaking
- 1 GW renewable energy capacity for steel operations
- Development of indigenous technology for low-grade iron ore utilization
- Target: 42% reduction in carbon intensity by 2030

3.7 Policy Support Mechanisms

3.7.1 Financial Incentives

Government Support:

- Production-Linked Incentive (PLI) scheme for specialty steel
- Preferential financing for green steel projects
- Tax benefits for investments in clean technology
- Subsidies for renewable energy installations at steel plants

3.7.2 Regulatory Framework

Environmental Standards:

- Strict emission norms for steel plants (equivalent to EU standards)
- Mandatory energy efficiency targets under PAT Scheme
- Water usage and effluent treatment regulations
- Air quality monitoring and reporting requirements

3.8 Challenges and Opportunities

Key Challenges:

- High-quality domestic scrap shortage
- Dependence on coal-based ironmaking
- Limited access to low-cost renewable energy in some regions
- Technology gaps in advanced steelmaking processes

Strategic Opportunities:

- Abundant iron ore resources
- Growing domestic market for steel
- Potential for green hydrogen production using renewable energy
- Young workforce and growing technical capabilities

4 Japan Steel Research and Innovation Policy

4.1 Overview

Japan's steel industry focuses on maintaining global quality leadership while pursuing ambitious carbon neutrality by 2050, with substantial government support through the Green Innovation Fund.

4.2 Green Innovation Fund Project (GREINS)

Hydrogen Utilization in Iron and Steelmaking Processes:

- Duration: FY 2021-2030
- Initial budget: ¥193.5B
- Doubled to: ¥449.9B (2023)
- Managing organization: NEDO (New Energy and Industrial Technology Development Organization)

4.2.1 Key Technologies Under Development

Super COURSE50 Technology:

- Substantial progress achieved in 2024
- Hydrogen injection in blast furnaces
- CO2 capture and storage integration
- Incremental BF-BOF improvement pathway

Electric Melting Furnace with Hydrogen Reduction:

- Nippon Steel R&D initiative
- Continuous hot metal tapping (similar to BF)
- Continuous slag discharge for impurity removal
- Enables high quality and productivity with low-grade ore
- Small test reduction furnace: operational FY 2025
- Small test EAF: operational second half FY 2024

4.3 Industry Transformation Strategy

4.3.1 Large-Scale EAF Conversion Announcements

JFE Steel:

- World's first mass supply system for high quality/performance steels via EAF
- Innovative process technologies from GI Fund
- Utilization of low-carbon reduced iron

Nippon Steel:

- Iron source process conversion at Kyushu Works (Yawata Area)
- EAF expansion at Setouchi Works (Hirohata Works)

- EAF restart at Yamaguchi Works (Shunan Area)
- Application submitted October 2024

Kobe Steel:

- Future large EAF introduction under consideration

4.4 Government Policy Framework

4.4.1 7th Strategic Energy Plan (SEP)

- Overarching energy policy framework (not sector-specific)
- Emission reduction targets:
  - 60% by FY 2035
  - 73% by FY 2040
- Steel industry must align strategies with these targets

4.4.2 GX2040 Vision

Focus Areas:

- Green transformation as opportunity to overcome stagnation
- Foster innovative businesses through industrial restructuring
- Energy efficiency leadership maintenance
- Best Available Technologies (BATs) international transfer

4.4.3 Policy Criticism and Gaps

METI Study Group Recommendations (January 2025):

- Primary focus: BF-based direct emissions reduction
- EAF-based low-carbon steel excluded from support schemes
- Hydrogen pricing and availability targets lack ambition
- Public Procurement Act amendment needs strengthening for EAF incentives

4.5 Technology Pathway Characteristics

Approach	Details
Primary Technology Focus	BF-BOF retrofitting with hydrogen injection and CCUS
Secondary Pathway	Large-scale hybrid EAF development
Geographic Strategy	Overseas expansion (India) for H2-DRI-EAF
Innovation Emphasis	Maintain quality leadership while decarbonizing
Government Support	Substantial (GI Fund ¥449.9B)
Industry Structure	Three major integrated producers leading transformation

Table 8: Japan's Steel Technology Pathway

4.6 International Technology Transfer

Research and Development Partnerships:

- JISF (Japan Iron and Steel Federation) leadership in energy efficiency
- BATs transfer to countries with higher reduction potential
- Asia-Pacific Partnership on Clean Development and Climate
- Collaboration with IEA and RITE (Research Institute of Innovative Technology for the Earth)

5 United States Steel Research and Industrial Policy

5.1 Strategic Context

US steel policy reflects tension between trade protection, industrial competitiveness, and climate objectives. The Biden administration prioritizes domestic production and clean energy investments through the Inflation Reduction Act.

5.2 Department of Energy (DOE) R&D Programs

5.2.1 Industrial Efficiency and Decarbonization Office

FY2024-2025 Steel Research Funding:

- Total DOE industrial decarbonization R&D: $136M+ (FY2024)
- Steel-specific projects: Significant portion allocated
- Focus areas: Low-carbon hydrogen, CCUS, electrification, energy efficiency

Key Technology Programs:

Technology Area	Research Focus
H2-DRI Technology	Hydrogen-based direct reduction with EAF integration
Electric Arc Furnaces	Advanced EAF efficiency, scrap quality optimization
CCUS for BF-BOF	Carbon capture retrofits for existing integrated mills
Process Electrification	Plasma heating, electromagnetic stirring, induction
Digital Technologies	AI and ML for process optimization, predictive maintenance
Advanced Materials	High-strength, lightweight steels for transportation

Table 9: DOE Steel Research Priority Areas

5.2.2 Industrial Assessment Centers (IACs)

- 50+ university-based centers nationwide
- Free energy assessments for small-medium manufacturers
- Implementation support for energy efficiency measures
- Training for next-generation engineers

5.3 Inflation Reduction Act (IRA) Provisions

5.3.1 Advanced Manufacturing Production Credit (45X)

- Tax credit for production of critical components
- Applicable to clean steel production equipment
- Hydrogen electrolyzers, clean electricity generation

- 10-year credit period (2023-2032)

5.3.2 Clean Hydrogen Production Tax Credit (45V)

Lifecycle Emissions	Credit Amount	Steel Application
0-0.45 kg CO2e/kg H2	$3.00/kg	Green H2-DRI
0.45-1.5 kg CO2e/kg H2	$1.00/kg	Blue H2 with CCUS
1.5-2.5 kg CO2e/kg H2	$0.75/kg	Transitional
2.5-4.0 kg CO2e/kg H2	$0.60/kg	Natural gas SMR

Table 10: 45V Hydrogen Tax Credit Structure

5.3.3 Carbon Capture Tax Credits (45Q)

Enhanced Credit Rates:

- Carbon capture and storage: $85/tonne CO2 (enhanced rate)
- Direct air capture: $180/tonne CO2
- Carbon utilization: $60/tonne CO2
- Applicable to blast furnace emissions capture

5.4 Major Steel Producer Decarbonization Plans

5.4.1 Cleveland-Cliffs

Technology Strategy:

- Direct Reduced Iron (DRI) production with natural gas
- Future hydrogen blending capability
- Toledo DRI facility modernization
- EAF capacity expansion (recycled steel advantage)

Timeline and Investment:

- $150M+ DRI investments (ongoing)
- Incremental emissions reduction pathway
- 2030 target: 15% reduction from baseline
- 2050 net-zero commitment

5.4.2 Nucor

EAF Leadership:

- 100% EAF production model
- Most efficient steelmaker in North America
- DRI production for quality steel production
- Continued EAF expansion and modernization

Innovation Focus:

- Econiq® carbon-neutral steel product line
- Partnership with CarbonCure for carbon mineralization
- Advanced scrap sorting and processing
- Digital manufacturing technologies

5.4.3 US Steel

Best for All SM Strategy:

- $3B+ strategic capital investments (through 2026)
- Big River Steel EAF expansion (Arkansas)
- Mon Valley Works revitalization (Pennsylvania)
- Advanced high-strength steel development

Decarbonization Pathway:

- Near-term: Energy efficiency, renewable electricity
- Medium-term: CCUS pilots at integrated facilities
- Long-term: Hydrogen steelmaking evaluation
- 2030 target: 20% emissions intensity reduction

6 Russia Steel Research and Industrial Policy

6.1 Strategic Context

Russia's steel industry, the fifth-largest globally, faces unique challenges including international sanctions, aging infrastructure, and the need to modernize while maintaining export competitiveness. The country's steel policy emphasizes technological sovereignty, resource efficiency, and adaptation to changing geopolitical realities.

6.2 Industry Structure and Production

Parameter	Current Status (2025)
Crude Steel Production	71 MT annually
Export Share	45% of production
Major Companies	NLMK, Severstal, MMK, Metalloinvest
BF-BOF Share	65%
EAF Share	35%

Table 11: Russia Steel Industry Overview

6.3 Research and Development Framework

6.3.1 State Research Centers

Key Institutions:

- Bardin Central Research Institute for Ferrous Metallurgy (TsNIIchermet)
- Moscow State Steel and Alloys Institute (MISiS)
- Ural Federal University research centers
- Siberian Federal University metallurgy department

6.3.2 Industry Research Programs

Priority Areas:

- Resource efficiency and waste reduction
- Development of new steel grades for extreme environments
- Digitalization and automation of production processes
- Adaptation of existing equipment to new raw material bases
- Quality improvement in response to import substitution requirements

6.4 Decarbonization Challenges and Strategies

6.4.1 Current Emissions Profile

Key Statistics:

- Steel industry accounts for 20% of Russia's industrial CO2 emissions
- Carbon intensity: 2.1 tCO2 per tonne of steel (higher than global average)
- Limited progress in emissions reduction due to economic constraints

6.4.2 Adaptation Strategies

Pragmatic Approaches:

- Focus on energy efficiency improvements rather than radical technology shifts
- Increased utilization of natural gas in steelmaking processes
- Modernization of existing facilities with limited capital investment
- Development of carbon capture technologies for major emission sources
- Exploration of hydrogen-based steelmaking using domestic natural gas reforming

6.5 Major Steel Companies' Innovation Strategies

6.5.1 NLMK (Novolipetsk Steel)

Technology Focus:

- Investment of $3.5 billion in modernization (2020-2025)
- Implementation of Stelmex® technology for thin slab casting
- Development of high-strength steels for automotive applications
- Energy efficiency improvements targeting 15
- Exploration of waste gas recycling and utilization

6.5.2 Severstal

Innovation Initiatives:

- Digital transformation program "Industry 4.0"
- Development of new steel grades for shipbuilding and pipelines
- Investment in electric arc furnace capacity expansion
- Partnership with research institutions for process optimization
- Target: 10

6.5.3 Metalloinvest

Resource Efficiency Focus:

- Vertical integration from mining to steel production
- Development of beneficiation technologies for low-grade ores
- Investment in HBI (Hot Briquetted Iron) production
- Exploration of direct reduction technologies using natural gas
- Modernization of pellet production facilities

6.6 Policy Support and Government Initiatives

6.6.1 State Support Mechanisms

Government Programs:

- Import substitution policy promoting domestic steel grades

- Tax incentives for domestic equipment manufacturers
- Support for research institutions through state funding
- Preferential treatment for strategic industries
- Infrastructure development for steel export routes

6.6.2 International Cooperation

Partnership Focus:

- Technology transfer from friendly countries (China, India)
- Joint research projects with Asian and Middle Eastern partners
- Participation in international standards organizations
- Exploration of new export markets in Asia, Africa, and Latin America

6.7 Sanctions Impact and Adaptation

Challenges:

- Limited access to Western technology and equipment
- Restrictions on export markets for high-value steel products
- Difficulties in obtaining financing for major projects
- Isolation from global research collaboration networks

Adaptation Strategies:

- Development of domestic alternatives to imported equipment
- Increased focus on domestic market and friendly countries
- Technology partnerships with non-Western countries
- Emphasis on resource independence and self-sufficiency

7 South Korea Steel Research and Industrial Policy

7.1 Strategic Framework

South Korea's steel policy emphasizes the sector as foundation of national security and economic stability, with comprehensive government support for green transition and competitiveness.

7.2 K-Steel Act

Legislative Framework:

- Bipartisan support: 106 lawmakers (ruling and opposition)
- Response to: 50% US tariffs + Chinese import surge
- View: Steel as foundation of national security and economic stability

Key Provisions:

- Presidential committee for sector oversight
- Five-year master plans for steel industry
- Annual roadmaps for implementation
- Financial incentives for green transition:
  - Subsidies for low-emission technologies
  - Low-interest loans
  - Tax breaks for green investments
  - Production cost support for hydrogen-based steelmaking

7.3 Innovation and Technology Strategy

7.3.1 National Innovation Framework

- 5-year cycle planning: Basic Plan for Science and Technology
- 577 Initiative: Focus on semiconductors, shipbuilding, automobiles, steel, textiles, materials
- R&D investment: 4.96% of GDP (2023) - 2nd highest globally
- Government education budget: 98.5 trillion won (2025)

7.3.2 Major Steel Companies' Decarbonization Plans

POSCO (Carbon Neutrality by 2050):

Phase	Technology/Investment
Phase 1 (2024-2030)	Pilot HyREX plant (300kt/yr) at Pohang, partnership with Primetals Technologies
Phase 2 (2030-2040)	Commercial-scale HyREX implementation
Phase 3 (by 2050)	Full transition from BF-BOF to HyREX technology
New EAF Capacity	2.5M tonnes/yr at Gwangyang ($450M investment, construction began 2024)
Green Electricity	100% renewable power for all plants by 2040
Scrap Infrastructure	$140M investment (2023-2025), 4 to 8 collection centers

Table 12: POSCO Decarbonization Roadmap

HyREX Technology Innovation:

- DRI produced using H2 and NG not transported
- Direct use in ore thermal furnace for pig iron production
- Eliminates intermediate handling steps
- Integrated hydrogen reduction and melting process

Hyundai Steel:

- Carbon neutrality target: 2050
- Partnership with Primetals (October 2023): H2 use in BF production research
- EAF target: 0.2 tons CO2 specific emissions via H2-DRI
- CCUS for residual emissions neutralization
- 100% electricity self-sufficiency by 2050
- Gas-fired power plant: 0.5 GW (construction underway)

Dongkuk Steel:

- Eco-Arc EAF at Incheon plant (lowest emissions)
- Two-pronged approach:
  - Production: H2 integration + digitalization (including AI)
  - Energy: Digital energy management + equipment replacement + solar power scaling
- 2030 target: 10% reduction from 2018 (to 277kt CO2 equivalent)

7.4 Resource Strategy

7.4.1 Scrap Management

- Predicted restrictions/ban on scrap exports after 2030
- Expansion of domestic scrap collection infrastructure
- Opening of overseas scrap collection centers
- Reduction of dependence on American and Russian scrap (logistics costs)

7.4.2 Carbon Trading

- K-ETS launched 2015 (first in Southeast Asia)
- Covers 79% of all greenhouse gas emissions
- Steel industry currently not included in trading scheme

7.5 Industrial Policy Challenges

Regulatory Framework Issues:

- "Positive regulation" approach: requires explicit permission for innovation
- Shadow regulations create additional constraints
- Need for regulatory modernization to support tech innovation
- Calls for shift from control-based to innovation-friendly framework

Structural Challenges:

- Manufacturing employment share declining (15.39% in March 2025)
- Services sector productivity gap persists
- Need for broad-based innovation beyond export-led growth
- Balance between economic competitiveness and geopolitical pressures

8 Germany Steel Research and Industrial Policy

8.1 Strategic Context

As the largest steel producer in the European Union, Germany plays a pivotal role in shaping EU steel policy while addressing its own industrial challenges. The country's steel sector is characterized by high-quality specialty steel production, strong union representation, and ambitious decarbonization targets aligned with EU climate goals.

8.2 Industry Structure and Production

Parameter	Current Status (2025)
Crude Steel Production	37.2 MT annually
EU Share	29% of EU production
Major Companies	Thyssenkrupp, Salzgitter, ArcelorMittal Germany
BF-BOF Share	70%
EAF Share	30%

Table 13: Germany Steel Industry Overview

8.3 Research and Development Framework

8.3.1 Steel Research Institutions

Key Organizations:

- Steel Institute VDEh (Stahlinstitut)
- Max Planck Institute for Iron Research
- Fraunhofer Institute for Laser Technology
- Technical Universities of Aachen, Freiberg, and Clausthal

8.3.2 Research Priorities

Focus Areas:

- Hydrogen-based steelmaking (tkH2Steel, SALCOS)
- Carbon capture, utilization, and storage (CCUS)
- Digitalization and Industry 4.0 applications
- High-performance steel grades for automotive and machinery
- Circular economy and resource efficiency

8.4 Decarbonization Strategy

8.4.1 Key Initiatives

tkH2Steel (Thyssenkrupp):

- Phased conversion of Duisburg blast furnaces to hydrogen operation
- Target: 2.5 million tonnes of CO2 reduction annually by 2026
- Total investment: €2.5 billion

- Partnership with Shell for hydrogen supply

SALCOS (Salzgitter):

- Three-phase transformation to hydrogen-based steelmaking
- Target: Carbon-neutral steel production by 2033
- Investment: €725 million for first phase
- Partnership with Linde for hydrogen infrastructure

8.4.2 Government Support

Funding Mechanisms:

- €2 billion national hydrogen strategy funding
- EU RFCS and Horizon Europe participation
- Carbon Contracts for Difference (CCfD) pilot program
- Decarbonization support through KfW development bank

8.5 Major Steel Companies' Innovation Strategies

8.5.1 Thyssenkrupp Steel

Technology Focus:

- tkH2Steel transformation program
- Development of high-strength lightweight steels
- Digitalization of production processes
- Partnership with automotive industry for custom steel grades

8.5.2 Salzgitter AG

Innovation Initiatives:

- SALCOS (Salzgitter Low CO2 Steelmaking) program
- Wind-powered hydrogen production facility
- Development of electrical steel grades
- Circular economy initiatives for steel byproducts

8.5.3 ArcelorMittal Germany

Resource Efficiency Focus:

- Carbon2Carb project in Hamburg (carbon capture and utilization)
- Modernization of Bremen and Eisenhüttenstadt plants
- Development of high-value specialty steels
- Investment in renewable energy for plant operations

8.6 Policy Support and Government Initiatives

8.6.1 National Steel Strategy

Key Elements:

- Steel Action Plan 2.0 (2023-2026)
- Focus on green steel transformation
- Support for research and innovation
- Protection against unfair competition

8.6.2 European Integration

EU Policy Alignment:

- Active participation in EU RFCS reform
- Support for Carbon Border Adjustment Mechanism (CBAM)
- Alignment with EU Green Deal objectives
- Advocacy for level playing field in global markets

8.7 Challenges and Opportunities

Key Challenges:

- High energy costs compared to international competitors
- Need for massive investment in decarbonization
- Competition from lower-cost imports
- Workforce transition requirements

Strategic Opportunities:

- Technological leadership in green steel production
- Strong domestic automotive and machinery industries
- Advanced research infrastructure
- Political commitment to industrial transformation

9 Türkiye Steel Research and Industrial Policy

9.1 Strategic Context

Türkiye ranks 8th globally in steel production with 36.9 MT annually, positioning itself as a major regional producer and export hub. The country's steel policy emphasizes export competitiveness, modernization, and gradual environmental improvement while leveraging its strategic location between Europe and Asia.

9.2 Industry Structure and Production

Parameter	Current Status (2025)
Crude Steel Production	36.9 MT annually
Export Share	55% of production
Major Companies	Erdemir, İsdemir, Çolakoğlu, Kibar
BF-BOF Share	35%
EAF Share	65%

Türkiye Steel Industry Overview

9.3 Research and Development Framework

9.3.1 Steel Research Institutions

Key Organizations:

- Turkish Iron and Steel Producers Association (TÇÜD)
- Marmara Research Center (TÜBİTAK)
- Middle East Technical University Metallurgical Engineering Department
- Istanbul Technical University Materials Science Department

9.3.2 Research Priorities

Focus Areas:

- Energy efficiency improvements in EAF operations
- Development of higher value-added steel products
- Quality improvement for export markets
- Environmental management and emissions reduction
- Digitalization and automation of production processes

9.4 Decarbonization Strategy

9.4.1 Current Emissions Profile

Key Statistics:

- Steel industry accounts for 10% of Türkiye's industrial CO2 emissions
- Carbon intensity: 1.8 tCO2 per tonne of steel (below global average)
- Already high EAF share provides emissions advantage

9.4.2 Adaptation Strategies

Pragmatic Approaches:

- Focus on EAF efficiency improvements (already 65% of production)
- Increased scrap utilization and quality improvement
- Energy efficiency measures in existing facilities
- Limited exploration of hydrogen-based steelmaking
- Integration with renewable energy development

9.5 Major Steel Companies' Innovation Strategies

9.5.1 Erdemir (Oyak Mining Metallurgy Group)

Technology Focus:

- Investment of $1.5 billion in modernization (2020-2025)
- Development of high-quality flat steel products
- Energy efficiency improvements targeting 10
- Expansion of product mix toward higher value-added steel
- Digital transformation initiatives

9.5.2 İsdemir (İskenderun Iron and Steel)

Innovation Initiatives:

- Focus on integrated steel production
- Development of specialized steel grades for construction
- Investment in environmental control systems
- Partnership with domestic research institutions
- Target: 15

9.5.3 Çolakoğlu Metallurgy

Resource Efficiency Focus:

- Specialization in long steel products
- Investment in modern EAF technology
- Development of high-strength reinforcement steel
- Expansion of export markets in Europe and Middle East
- Exploration of scrap-based steelmaking expansion

9.6 Policy Support and Government Initiatives

9.6.1 State Support Mechanisms

Government Programs:

- Steel Industry Strategy 2023-2025

- Investment incentives for modern steel facilities
- Export promotion policies targeting regional markets
- Infrastructure development supporting steel industry growth
- Environmental regulations gradually tightening

9.6.2 International Cooperation

Partnership Focus:

- Technology transfer from European partners
- Customs Union advantages with EU
- Participation in regional steel industry cooperation
- Export market development in Europe, Middle East, and North Africa

9.7 Future Outlook

Short-term (2025-2030):

- Continued capacity expansion to meet domestic demand
- Technology modernization of existing facilities
- Gradual improvement in environmental performance
- Expansion into higher value-added steel products

Long-term (2030-2050):

- Potential adoption of breakthrough technologies as economy develops
- Integration with regional decarbonization efforts
- Increased focus on export markets with higher quality requirements
- Gradual transition to less carbon-intensive processes

10 Brazil Steel Research and Industrial Policy

10.1 Strategic Positioning

Brazil possesses unique advantages for green steel leadership: abundant renewable energy, high-quality iron ore, charcoal production capacity, and established industrial infrastructure. COP30 hosting in November 2025 presents opportunity to define green steel strategy.

10.2 Current Industry Structure

Technology	Share of Operating Capacity
BF-BOF (emissions-intensive)	76%
EAF (lower-emissions)	24%

Table 14: Brazil Steel Production Technology Mix

10.3 Decarbonization Pathways Research

10.3.1 Scenarios Analysis (to 2050)

Mitigation Scenarios:

1. **BAU**: Business-as-usual
2. **NIS**: No emission increase (0% increase)
3. **SDS**: Sustainable development (42% reduction)
4. **SDS+**: Deep sustainable development (88% reduction)

Key Findings:

- Short-term mitigation: Negative costs (-$35.3 to -$1.5/tCO2e)
  - Energy efficiency measures
  - Charcoal-based BF-BOF
  - EAF expansion
- Long-term innovation routes: Positive costs ($23.4 to $43.4/tCO2e by 2050)
- Smelting reduction with charcoal: Up to 24% production share (SDS+)
- Direct reduction with natural gas: 21% share in SDS by 2050

10.4 Major Research and Innovation Initiatives

10.4.1 Hydrogen Development Projects

CSN (Companhia Siderúrgica Nacional):

Selene Project:

- Phase 1: Initial implementation (completion December 2025)
- Phase 2: 40 MW capacity in Araucária, Paraná (2027-2028)
- Phase 3: Rio de Janeiro near BF-BOF mill (2029-2030)
- Location: Steel rolling and coating line facilities

CSN-Petrobras Partnership (December 2024):

- Protocol of intent for commercial-scale low-carbon H2 plant
- Location: Paraná, south Brazil
- Technology: Water electrolysis powered by renewable electricity
- Application: Industrial process fuel and feedstock

10.4.2 Innovative Technology Development

Tecnored (Vale proprietary):

- Radical innovation for steel decarbonization
- Alternative smelting reduction process

Boston Metal Consortium:

- Molten Oxide Electrolysis (MOE) process
- Commercial scale plant: Coronel Xavier Chaves, southwest Brazil
- Construction planned: 2023 start
- Funding: Series C ($122M, September 2023) + Series C2 ($20M, January 2024)
- Investors: Aramco Ventures, Marunouchi Innovation Partners
- Timeline: Small-scale operations 2024, full operations 2026
- Partners: ArcelorMittal consortium
- Technology: Molten iron directly suitable for refining

10.5 Policy Framework

10.5.1 Industrial Deep Decarbonization Initiative

Brazil's Participation (announced July 2023):

- Joined at Clean Energy Ministerial in India
- Now represents 19% of total global steel production in Initiative
- Focus sectors: Steel, cement, petrochemicals

Initiative Components:

1. Technology innovation and capacity building
2. Policy development for just transition
3. Social safety nets and workforce reskilling
4. Community engagement prioritization
5. Knowledge exchange through ISO 50001 training
6. Support for micro, small, medium enterprises
7. Demonstration pilot projects

Funding Mechanisms:

- Co-funded blended finance schemes
- Seed funding for low-carbon technology entrepreneurs
- Collaboration with 80+ technology parks (20 state-run)
- Partnership with Brazilian research institutions and universities

10.5.2 Nova Indústria Brasil (NIB) Strategy

Strengths:

- Structural investments in education and innovation
- Green superpower potential recognition
- Natural resource base for energy transition

Identified Weaknesses:

- Mission orientation too broad for focused implementation
- Lacks clear knowledge-based cluster creation plan
- Limited sector-specific policy mixes
- Insufficient dynamic experimentation framework

10.6 Resource Advantages for Green Steel

Renewable Energy:

- Top 10 globally: Hydropower, bioenergy, utility-scale wind and solar
- Top 3: Prospective utility-scale solar and wind capacity
- Essential for large-scale green hydrogen production
- Enables low-cost green steel production (lower than other nations)

Biomass Potential:

- Great reforestation potential
- Charcoal production capacity
- Circular bioeconomy steel industry development possible
- Already some use of biochar in blast furnaces

Material Resources:

- High-quality iron ore reserves
- Skilled workforce with steelmaking expertise
- Established industrial infrastructure

10.7 Policy Gaps and Opportunities

NDC Update (October 2023):

- Failed to establish specific steel industry mitigation measures
- No net-zero emissions targets for steel sector

- President Lula mentioned green steel favorably but not in industrialization action plan (January 2024)

Recent International Support:

- UNIDO partnership: Industry, Cement and Steel Sectoral Mitigation Plans
- UK-Brazil collaboration: Industrial Decarbonization Hub
- Both aimed at policy development by COP30

University-Industry Interaction:

- Historically weak linkages
- Successful cases exist: steel, petrochemicals, aircraft, agro-industry
- Need for stronger knowledge transfer mechanisms
- EMBRAPII (Brazilian Company for Industrial Research and Innovation) as intermediary

11 Iran Steel Research and Industrial Policy

11.1 Strategic Context

Iran ranks 10th globally in steel production with approximately 31.4 million tonnes annually, positioning itself as a significant regional producer despite international sanctions. The country's steel policy emphasizes self-sufficiency, export expansion to friendly markets, and technological development despite limited access to international collaboration.

11.2 Industry Structure and Production

Parameter	Current Status (2025)
Crude Steel Production	31.4 MT annually
Global Ranking	10th
Export Share	25% of production
Major Companies	Mobarakeh Steel, Khuzestan Steel, Esfahan Steel
BF-BOF Share	55%
EAF Share	45%

Table 15: Iran Steel Industry Overview

11.3 Research and Development Framework

11.3.1 Steel Research Institutions

Key Organizations:

- Iranian Mines and Mining Industries Development and Renovation (IMIDRO)
- Institute of Materials and Energy Research Center
- Sharif University of Technology Materials Science Department
- University of Tehran Metallurgical Engineering Department

11.3.2 Research Priorities

Focus Areas:

- Domestic raw material utilization (iron ore, direct reduction)
- Energy efficiency improvements in existing facilities
- Development of specialized steel grades for domestic industries
- Adaptation of imported technologies to local conditions
- Quality improvement to meet international standards for export markets

11.4 Decarbonization Challenges and Strategies

11.4.1 Current Emissions Profile

Key Statistics:

- Steel industry accounts for 15% of Iran's industrial CO2 emissions
- Carbon intensity: 2.3 tCO2 per tonne of steel (higher than global average)

- Limited access to advanced decarbonization technologies due to sanctions

11.4.2 Adaptation Strategies

Pragmatic Approaches:

- Focus on natural gas utilization (abundant domestic resource)
- Increased direct reduction iron (DRI) production using natural gas
- Energy efficiency improvements in existing processes
- Limited exploration of hydrogen-based steelmaking using domestic natural gas reforming
- Optimization of raw material preparation and beneficiation

11.5 Major Steel Companies' Innovation Strategies

11.5.1 Mobarakeh Steel Company (MSC)

Technology Focus:

- Largest steel producer in Middle East (7.2 MT capacity)
- Investment of $2 billion in modernization (2020-2025)
- Development of API grade pipes for oil and gas industry
- Energy efficiency improvements targeting 10
- Expansion of product mix toward higher value-added steel

11.5.2 Khuzestan Steel Company (KSC)

Innovation Initiatives:

- Focus on direct reduction technology using natural gas
- Development of special steel grades for construction
- Investment in environmental control systems
- Partnership with domestic research institutions
- Target: 15

11.5.3 Esfahan Steel Company (ESCO)

Resource Efficiency Focus:

- Iran's first integrated steel plant
- Modernization of blast furnace operations
- Development of rail steel and other specialized products
- Investment in waste heat recovery systems
- Exploration of scrap-based steelmaking expansion

11.6 Policy Support and Government Initiatives

11.6.1 State Support Mechanisms

Government Programs:

- 20-Year National Vision Plan emphasizing steel industry development
- Export promotion policies targeting regional markets
- Domestic content requirements for government projects
- Energy subsidies for industrial consumers
- Support for domestic equipment manufacturers

11.6.2 International Cooperation

Partnership Focus:

- Technology transfer from friendly countries (China, Russia)
- Joint research projects with Asian partners
- Export market development in neighboring countries
- Participation in regional steel industry associations

11.7 Sanctions Impact and Adaptation

Challenges:

- Limited access to Western technology and equipment
- Restrictions on export markets for high-value steel products
- Difficulties in obtaining financing for major projects
- Isolation from global research collaboration networks

Adaptation Strategies:

- Development of domestic alternatives to imported equipment
- Increased focus on domestic and regional markets
- Technology partnerships with non-Western countries
- Emphasis on resource independence and self-sufficiency

11.8 Future Outlook

Short-term (2025-2030):

- Focus on maintaining production capacity despite sanctions
- Incremental efficiency improvements in existing facilities
- Development of domestic technology alternatives
- Realignment of export markets toward Asia and Middle East

Long-term (2030-2050):

- Potential adoption of breakthrough technologies if economic conditions permit

- Gradual transition to less carbon-intensive processes
- Increased integration with Asian steel industry and technology ecosystem
- Specialization in steel grades less affected by sanctions

12 Viet Nam Steel Research and Industrial Policy

12.1 Strategic Context

Viet Nam has emerged as a rapidly growing steel producer, ranking 11th globally with approximately 22 million tonnes annually. The country's steel industry is characterized by rapid expansion, strong domestic demand, and increasing export orientation. Viet Nam's steel policy emphasizes capacity growth, technology modernization, and gradual environmental improvement.

12.2 Industry Structure and Production

Parameter	Current Status (2025)
Crude Steel Production	22.0 MT annually
Global Ranking	11th
Export Share	15% of production
Major Companies	Hoa Phat Group, Hoa Sen Group, Nam Kim Steel
BF-BOF Share	30%
EAF Share	70%

Table 16: Viet Nam Steel Industry Overview

12.3 Research and Development Framework

12.3.1 Steel Research Institutions

Key Organizations:

- Vietnam Institute of Steel Science (VISS)
- Hanoi University of Science and Technology
- Ho Chi Minh City University of Technology
- Institute of Materials Science, Vietnam Academy of Science and Technology

12.3.2 Research Priorities

Focus Areas:

- Adaptation of imported technologies to local conditions
- Development of construction steel grades suitable for tropical conditions
- Energy efficiency improvements in existing facilities
- Quality improvement to meet export market requirements
- Environmental management and emissions reduction

12.4 Decarbonization Challenges and Strategies

12.4.1 Current Emissions Profile

Key Statistics:

- Steel industry accounts for 12% of Viet Nam's industrial CO2 emissions
- Carbon intensity: 2.0 tCO2 per tonne of steel (slightly below global average)

- Growing awareness of environmental issues and international commitments

12.4.2 Adaptation Strategies

Pragmatic Approaches:

- Focus on EAF expansion (already 70% of production)
- Increased scrap utilization as domestic availability grows
- Energy efficiency improvements in existing processes
- Limited exploration of hydrogen-based steelmaking
- Integration with renewable energy development

12.5 Major Steel Companies' Innovation Strategies

12.5.1 Hoa Phat Group

Technology Focus:

- Largest steel producer in Viet Nam (8 MT capacity)
- Investment of $5 billion in integrated steel complex (Dung Quat)
- Development of high-quality construction steel
- Energy efficiency improvements targeting 15
- Expansion into specialty steel products

12.5.2 Hoa Sen Group

Innovation Initiatives:

- Focus on galvanized steel and coated products
- Investment in modern coating lines
- Development of lightweight steel for construction
- Partnership with international technology providers
- Target: 20

12.5.3 Nam Kim Steel

Resource Efficiency Focus:

- Specialization in steel pipes and tubes
- Investment in modern pipe manufacturing equipment
- Development of API grade pipes for oil and gas industry
- Expansion of export markets in Southeast Asia
- Exploration of scrap-based steelmaking expansion

12.6 Policy Support and Government Initiatives

12.6.1 State Support Mechanisms

Government Programs:

- Steel Industry Development Strategy to 2025, vision to 2035
- Investment incentives for modern steel facilities
- Export promotion policies targeting regional markets
- Infrastructure development supporting steel industry growth
- Environmental regulations gradually tightening

12.6.2 International Cooperation

Partnership Focus:

- Technology transfer from Japan, South Korea, and China
- Joint ventures with international steel companies
- Participation in ASEAN steel industry cooperation
- Export market development in Southeast Asia and beyond

12.7 Future Outlook

Short-term (2025-2030):

- Continued capacity expansion to meet domestic demand
- Technology modernization of existing facilities
- Gradual improvement in environmental performance
- Expansion into higher value-added steel products

Long-term (2030-2050):

- Potential adoption of breakthrough technologies as economy develops
- Integration with regional decarbonization efforts
- Increased focus on export markets with higher quality requirements
- Gradual transition to less carbon-intensive processes

13 Italy Steel Research and Industrial Policy

13.1 Strategic Context

Italy ranks 12th globally in steel production with approximately 20 million tonnes annually, positioning itself as a significant producer within the European Union. The country's steel industry is characterized by specialization in high-quality products, strong export orientation, and adaptation to EU environmental regulations.

13.2 Industry Structure and Production

Parameter	Current Status (2025)
Crude Steel Production	20.0 MT annually
EU Share	16% of EU production
Major Companies	Acciaierie d'Italia, Arvedi, Feralpi
BF-BOF Share	40%
EAF Share	60%

Table 17: Italy Steel Industry Overview

13.3 Research and Development Framework

13.3.1 Steel Research Institutions

Key Organizations:

- Italian Steel Federation (Federacciai)
- Research Institute for Innovation and Transference (RIT)
- Polytechnic University of Milan Materials Department
- University of Bologna Metallurgical Engineering Department

13.3.2 Research Priorities

Focus Areas:

- Development of high-quality specialty steel grades
- Energy efficiency improvements in EAF operations
- Digitalization and automation of production processes
- Environmental management and emissions reduction
- Circular economy and resource efficiency

13.4 Decarbonization Strategy

13.4.1 Current Emissions Profile

Key Statistics:

- Steel industry accounts for 12% of Italy's industrial CO2 emissions
- Carbon intensity: 1.9 tCO2 per tonne of steel (below global average)
- Already high EAF share provides emissions advantage

13.4.2 Adaptation Strategies

Pragmatic Approaches:

- Focus on EAF efficiency improvements (already 60% of production)
- Increased scrap utilization and quality improvement
- Energy efficiency measures in existing facilities
- Limited exploration of hydrogen-based steelmaking
- Integration with renewable energy development

13.5 Major Steel Companies' Innovation Strategies

13.5.1 Acciaierie d'Italia (formerly Ilva)

Technology Focus:

- Largest steel producer in Italy (6 MT capacity)
- Investment of €1.5 billion in environmental upgrade (2020-2025)
- Development of high-quality flat steel products
- Energy efficiency improvements targeting 10
- Expansion of product mix toward higher value-added steel

13.5.2 Arvedi Group

Innovation Initiatives:

- Focus on thin slab casting and rolling technology
- Development of high-quality flat steel products
- Investment in renewable energy for plant operations
- Partnership with domestic research institutions
- Target: 15

13.5.3 Feralpi Group

Resource Efficiency Focus:

- Specialization in long steel products
- Investment in modern EAF technology
- Development of high-strength reinforcement steel
- Expansion of export markets in Europe and Mediterranean
- Exploration of scrap-based steelmaking expansion

13.6 Policy Support and Government Initiatives

13.6.1 State Support Mechanisms

Government Programs:

- National Recovery and Resilience Plan (PNRR) funding for steel industry

- Investment incentives for modern steel facilities
- Export promotion policies targeting EU and Mediterranean markets
- Infrastructure development supporting steel industry growth
- Environmental regulations aligned with EU Green Deal

13.6.2 European Integration

EU Policy Alignment:

- Active participation in EU RFCS and Horizon Europe
- Support for Carbon Border Adjustment Mechanism (CBAM)
- Alignment with EU Green Deal objectives
- Advocacy for level playing field in global markets

13.7 Challenges and Opportunities

Key Challenges:

- High energy costs compared to international competitors
- Need for investment in decarbonization
- Competition from lower-cost imports
- Workforce transition requirements

Strategic Opportunities:

- Specialization in high-quality steel products
- Strong domestic manufacturing industries
- Advanced research infrastructure
- Political commitment to industrial transformation

14 Comparative Analysis Across Jurisdictions

14.1 Funding Mechanisms

Country	Primary Mechanism	Annual Budget	Industry Co-funding
China	State industrial policy	Not disclosed	Variable by project
India	Steel Development Fund	$150M+	25-50% typical
Japan	Green Innovation Fund	¥45B/year (avg)	50% typical
United States	DOE + IRA tax credits	$136M+ DOE R&D	Tax credit leverage
Russia	State research centers	Limited by sanctions	Primarily state-funded
South Korea	K-Steel Act framework	TBD by master plan	Variable incentives
Germany	EU RFCS + national funds	€50M+ national	30-50% typical
Türkiye	State incentives	Limited dedicated	High private share
Brazil	Mixed public-private	Limited dedicated	High private share
Iran	State support	Limited by sanctions	Primarily state-funded
Viet Nam	State incentives	Limited dedicated	High private share
Italy	EU RFCS + national funds	€30M+ national	30-50% typical

Table 18: Steel Research Funding Mechanisms Comparison (Top 12 Producers)

14.2 Decarbonization Technology Pathways

Country	Primary Pathway	Secondary/Alternative
China	EAF expansion (15%+ target)	Ultra-low emissions BF-BOF, long-term H2
India	H2-DRI pilot projects	Increased scrap utilization, CCUS
Japan	BF hydrogen injection + CCUS	Large-scale hybrid EAF, overseas H2-DRI
United States	Natural gas DRI + EAF	BF-BOF CCUS, future green H2
Russia	Natural gas optimization	Limited hydrogen exploration, efficiency focus
South Korea	HyREX (H2 reduction)	EAF expansion, CCUS
Germany	H2-DRI + EAF	CCUS on BF-BOF, electrification
Türkiye	EAF expansion	Modernization of existing facilities
Brazil	Biomass/charcoal in BF	Green H2-DRI, MOE technology
Iran	Natural gas DRI	Energy efficiency, limited hydrogen exploration
Viet Nam	EAF expansion	Scrap utilization, energy efficiency
Italy	H2-DRI + EAF	CCUS on BF-BOF, electrification

Table 19: Regional Decarbonization Technology Priorities (Top 12 Producers)

14.3 Policy Emphasis and Strategic Priorities

Country	Key Strategic Emphases
China	Capacity discipline, quality over quantity, digital transformation, emissions trading
India	Rapid capacity expansion, import substitution, technology transfer, green hydrogen development
Japan	Quality leadership maintenance, international BAT transfer, incremental BF improvement
United States	Reciprocal tariffs, domestic capacity utilization, IRA tax credit leverage, political volatility
Russia	Technological sovereignty, sanctions adaptation, resource efficiency, market realignment
South Korea	National security framing, comprehensive government support, regulatory modernization needs
Germany	Carbon border adjustment, industrial competitiveness, strategic autonomy, defense applications
Türkiye	Regional leadership, export orientation, customs union advantages, modernization
Brazil	Renewable energy advantage, green hydrogen export potential, COP30 leadership opportunity
Iran	Self-sufficiency, sanctions adaptation, regional market focus, domestic technology development
Viet Nam	Rapid growth, export expansion, technology modernization, gradual environmental improvement
Italy	Industrial competitiveness, energy transition, EU policy alignment, specialty steel development

Table 20: National Policy Strategic Emphasis (Top 12 Producers)

14.4 Industry Structure and Governance

Country	Industry Model	Governance Approach
China	State-influenced giants	Top-down policy, capacity controls, emission standards
India	Mixed with state presence	State-owned enterprises, private sector growth, policy guidance
Japan	Three major integrated	Industry-government coordination, METI leadership
United States	Diverse (integrated + EAF)	Limited federal coordination, company-driven
Russia	Vertically integrated giants	State influence, sanctions-driven adaptation, resource control
South Korea	Two major integrated	Presidential oversight, 5-year master plans
Germany	Mixed (integrated + EAF)	Industry-led research, EU coordination, national partnerships
Türkiye	Private sector dominated	State incentives, export orientation, customs union integration
Brazil	Mixed ownership	Market-driven with government facilitation
Iran	State-controlled	State ownership, sanctions adaptation, regional focus
Viet Nam	Mixed with private growth	State incentives, foreign investment, export orientation
Italy	Mixed (integrated + EAF)	Industry-led research, EU coordination, national partnerships

Table 21: Industry Structure and Governance Models (Top 12 Producers)

14.5 Timeline to Carbon Neutrality

Country	Interim Target	Net-Zero Target
China	Peak before 2030	2060
India	No specific interim target	2070 (national target)
Japan	60% by 2035, 73% by 2040	2050
United States	Variable by administration	2050 (Paris Agreement)
Russia	No specific interim target	No formal commitment
South Korea	Pathway development	2050
Germany	55% reduction by 2030	2050
Türkiye	No specific interim target	2053 (national target)
Brazil	42% reduction (SDS scenario)	2050 (implied)
Iran	No specific interim target	No formal commitment
Viet Nam	No specific interim target	2050 (national target)
Italy	55% reduction by 2030	2050

Table 22: Carbon Neutrality Timeline Commitments (Top 12 Producers)

15 Cross-Cutting Themes and Global Trends

15.1 Hydrogen Economy Development

All regions recognize hydrogen as critical for steel decarbonization, but approaches differ significantly:

Green Hydrogen Leaders (Renewable Energy-based):

- Germany: Large-scale electrolyzer deployment, hydrogen infrastructure strategy
- Brazil: Renewable energy advantage, export potential
- India: Green hydrogen mission with $2.5 billion allocation

Mixed/Transitional Approaches:

- United States: Natural gas-based blue hydrogen with CCUS, incremental green scaling
- China: Coal-to-hydrogen with carbon capture, gradual renewable integration
- Russia: Natural gas-based hydrogen with limited green scaling

Technology Innovation Focus:

- Japan: GREINS project, Super COURSE50, hydrogen blast furnace injection
- South Korea: HyREX proprietary technology development
- Germany: tkH2Steel and SALCOS hydrogen-based steelmaking

15.2 Scrap-based Steelmaking (EAF) Expansion

Country	Current EAF Share	Target/Trend
China	10%	15% by 2025 target
India	35%	45% by 2030 target
Japan	25%	Major new capacity announced
United States	70%	Already EAF-dominant
Russia	35%	Limited growth potential
South Korea	30%	Expansion underway
Germany	30%	Increasing gradually
Türkiye	65%	Already EAF-dominant
Brazil	24%	Growth with green H2-DRI
Iran	45%	Limited growth potential
Viet Nam	70%	Already EAF-dominant
Italy	60%	Already EAF-dominant

Table 23: Electric Arc Furnace Capacity Trends (Top 12 Producers)

Key Enabling Factors:

- Scrap availability and quality improvement
- DRI production to supplement scrap for high-quality steel
- Renewable electricity access for low-carbon EAF operation
- Technological advances in EAF efficiency and control

Constraints:

- Scrap supply limitations in rapidly industrializing regions (China, India)
- Quality requirements for automotive and construction grades
- Tramp element management in recycled content
- Infrastructure for scrap collection and processing

15.3 Carbon Capture, Utilization, and Storage (CCUS)

Leaders in CCUS Deployment:

- United States: 45Q tax credits ($85/tonne), commercial deployment advancing
- Germany: Innovation Fund support, CCS infrastructure development
- Japan: Super COURSE50 integrated approach

Technology Readiness:

- Capture: Demonstration to early commercial (TRL 7-8)
- Transport: Proven for existing pipelines, scaling needed
- Storage: Regional geology-dependent, permitting challenges
- Utilization: Limited market size compared to emissions volume

Economic Challenges:

- High capital expenditure for retrofits
- Energy penalty reduces plant efficiency
- Requires carbon pricing or subsidies for viability
- Long-term storage liability concerns

15.4 Digital Transformation and Industry 4.0

All regions emphasize digitalization, but implementation varies:

Advanced Applications:

- AI/ML for process optimization (quality prediction, energy efficiency)
- Digital twins for plant simulation and training
- Predictive maintenance and asset management
- Supply chain optimization and demand forecasting
- Real-time emissions monitoring and reporting

Regional Priorities:

- China: 80% key process numerical control, 30+ smart factories by 2025
- Germany: Industry 4.0 integration in national steel strategy
- Japan: Manufacturing DX (Digital Transformation) initiatives
- United States: DOE support for advanced manufacturing technologies

15.5 Circular Economy and Material Efficiency

Scrap Management:

- Collection infrastructure expansion (South Korea, China)
- Quality improvement and sorting technologies
- International trade considerations (export restrictions trend)
- Urban mining from end-of-life products

Byproduct Utilization:

- Slag use in cement and construction
- Recovered zinc and other metallics
- Waste heat recovery for district heating or power
- CO2 utilization in chemicals or building materials

Design for Recyclability:

- Automotive industry collaboration on steel grades
- Coating and joining methods facilitating separation
- Product passports and material tracking
- Extended producer responsibility frameworks

15.6 Trade and Competitiveness Concerns

Common Challenges:

- Chinese overcapacity and below-cost exports
- Carbon leakage risks with asymmetric climate policies
- Critical raw materials supply security
- Balance between environmental ambition and competitiveness

Policy Responses:

- Trade protection measures (tariffs, safeguards)
- Carbon border adjustments (EU CBAM, Canadian consultations)
- Domestic content requirements in government procurement
- Strategic partnerships and supply chain diversification

Emerging Issues:

- Definition and certification of "green steel"
- Harmonization of carbon accounting methodologies
- Market development for premium low-carbon products
- International cooperation versus protectionism tension

16 Policy Recommendations and Best Practices

16.1 Funding and Support Mechanisms

Lesson 1: Sustained, Predictable Funding

- EU's RFCS-to-Horizon Europe transition model provides continuity
- Japan's doubled Green Innovation Fund shows government commitment
- Boom-bust funding cycles undermine long-term technology development

Lesson 2: Risk Sharing and Co-funding

- EU's enhanced co-funding rates (70% for industry) reduce barriers
- Tax credit approaches (US IRA) leverage private investment
- Mixed mechanisms address different TRL stages appropriately

Lesson 3: Industry Leadership

- Projects must remain industry-led to ensure relevance
- Academic partners provide critical knowledge but not direction
- Pre-competitive research enables industry collaboration

16.2 Technology Strategy

Lesson 4: Multiple Pathways Needed

- No single technology solution fits all contexts
- Regional resources and industrial structures dictate optimal pathways
- Portfolio approach manages technological and market uncertainties

Lesson 5: Near-term and Long-term Balance

- Energy efficiency and incremental improvements deliver near-term reductions
- Breakthrough technologies require sustained investment despite uncertainty
- Phased deployment aligns with capital replacement cycles

Lesson 6: Infrastructure Co-development

- Hydrogen infrastructure must develop alongside production capacity
- CCUS requires coordinated pipeline and storage development
- Grid upgrades essential for electrification pathways
- Government role critical in infrastructure coordination

16.3 Policy Coordination

Lesson 7: Horizontal Policy Integration

- Steel research policy must align with:
  - Energy policy (renewable deployment, hydrogen strategy)
  - Trade policy (competitiveness, border adjustments)

  - Industrial policy (capacity management, competitiveness support)
  - Climate policy (emissions targets, carbon pricing)
- Siloed policies create contradictions and inefficiencies

Lesson 8: Regulatory Modernization

- South Korea's experience: "Positive regulation" hinders innovation
- Permitting processes must accommodate new technologies
- Standards and certification for new products (green steel)
- Regulatory sandboxes for pilot/demonstration projects

Lesson 9: International Cooperation

- Technology development benefits from global knowledge sharing
- Standards harmonization reduces trade friction
- Avoid zero-sum competition in subsidy races
- Industrial Deep Decarbonization Initiative model (Brazil participation)

16.4 Market Development

Lesson 10: Demand-Side Policies

- Government procurement preferences for low-carbon steel
- Building codes and product standards incorporating embodied carbon
- Consumer awareness and willingness-to-pay development
- Value chain collaboration (automotive, construction sectors)

Lesson 11: Price on Carbon

- Carbon pricing provides ongoing incentive for emissions reduction
- Protection mechanisms needed during transition (border adjustments)
- Revenue recycling for decarbonization investments
- Predictable price trajectory enables investment planning

Lesson 12: Certification and Traceability

- Credible methodology for carbon accounting (lifecycle basis)
- Third-party verification and certification systems
- Digital product passports for transparency
- International mutual recognition agreements

16.5 Regional Strengths to Leverage

EU Strengths:

- Sophisticated funding mechanisms and partnerships
- Leadership in circular economy and standards
- CBAM as policy innovation for competitiveness protection

- Strong university-industry collaboration culture

Asian Strengths (China, Japan, South Korea, India):

- Government-industry coordination capability
- Large-scale deployment experience
- Manufacturing excellence and process optimization
- Domestic market size for technology commercialization

Americas Strengths (US, Brazil):

- Natural resource advantages (ore, energy, biomass)
- Entrepreneurial innovation culture
- Large geographic areas for CCUS storage
- Diverse technology pathways exploration

17 Conclusions and Outlook

17.1 Key Takeaways

Production Landscape:

The global steel production landscape is dominated by Asia, with China accounting for over 50% of world production. India has solidified its position as the second-largest producer with continued growth, while traditional producers like Japan, the United States, and Germany maintain significant output despite gradual declines. Emerging producers like Vietnam and Iran continue to expand their capacity, reshaping the global production map.

Technology Pathways:

No single pathway dominates globally. Instead, regional characteristics drive technology preferences:

- **Resource-rich regions** (Brazil, Canada): Green hydrogen-DRI leveraging renewable energy
- **Scrap-constrained regions** (China, India): Balanced BF-BOF improvement with EAF expansion
- **Quality-focused regions** (Japan, Germany): Incremental BF retrofitting with long-term H2 vision
- **EAF-dominant regions** (United States, Turkey, Vietnam): DRI quality improvement and continued EAF efficiency

Policy Approaches:

Successful policies share common elements despite implementation differences:

- Sustained, predictable funding over multiple decades
- Risk-sharing between government and industry
- Industry-led project selection and execution
- Integration across policy domains (energy, trade, climate, industrial)
- Balance between near-term incremental and long-term breakthrough

17.2 Critical Success Factors for Steel Decarbonization

17.2.1 Technology Deployment

Scalability:

- Pilot and demonstration projects must provide credible pathway to commercial scale
- Manufacturing capacity for key equipment (electrolyzers, CCUS components)
- Supply chain development for critical materials and components
- Workforce capabilities for construction and operation

Cost Reduction:

- Learning-by-doing through repeated deployments
- Technology improvements through R&D

- Scale economies in equipment manufacturing
- Input cost reductions (green hydrogen, renewable electricity)

Integration:

- New technologies must integrate with existing infrastructure where possible
- Brownfield retrofit pathways reduce capital requirements
- Synergies between steel and other industrial sectors (hydrogen valleys, industrial clusters)

17.2.2 Market Development

Demand Creation:

- Government procurement playing market-making role
- Automotive and construction sectors specifying low-carbon steel
- Consumer awareness and preferences development
- Corporate sustainability commitments creating pull

Value Recognition:

- Price premiums for certified green steel products
- Differentiation by carbon intensity levels
- Long-term offtake agreements reducing investment risk
- Financial instruments (green bonds) supporting projects

Level Playing Field:

- Border adjustment mechanisms preventing carbon leakage
- Harmonized carbon accounting methodologies
- Fair competition with imports from non-carbon-constrained regions
- Anti-dumping and countervailing duties for distorted markets

17.2.3 Policy Stability

Long-term Certainty:

- Political transitions should not upend fundamental policy direction
- Multi-party consensus where possible (South Korea K-Steel Act example)
- Legislated frameworks rather than executive discretion
- Automatic adjustment mechanisms (carbon price trajectories)

Adaptive Management:

- Regular review and update cycles (5-year plans common)
- Evidence-based policy adjustment
- Stakeholder engagement in policy evolution
- Learning from international experiences

17.3 Risks and Uncertainties

Technological Risks:

- Technical performance of first-of-a-kind facilities may disappoint
- Unforeseen integration challenges in complex industrial systems
- Alternative technologies may emerge disrupting current pathways
- Long development timelines create risk of technology obsolescence

Economic Risks:

- Cost reduction may not materialize as projected
- Input prices (hydrogen, electricity, carbon) highly uncertain
- Market acceptance and willingness to pay may be limited
- Stranded asset risks for existing facilities

Policy Risks:

- Political shifts undermining long-term commitments (US experience)
- Trade tensions escalating into technology decoupling
- Insufficient carbon pricing or border adjustments
- Subsidy competition creating inefficient outcomes

Geopolitical Risks:

- Critical materials supply disruptions (rare earths, PGMs)
- Technology access restrictions for strategic competition
- Energy security concerns affecting hydrogen strategies
- Regional conflicts disrupting global supply chains

17.4 Outlook to 2030 and Beyond

Near-term (2025-2030):

- Acceleration of pilot and demonstration projects across all pathways
- China EAF share reaching 15%+ with continued capacity discipline
- India continued capacity expansion toward 300 MT target
- Germany and Japan hydrogen-based steelmaking validation
- South Korea HyREX pilot to commercial transition
- United States IRA-supported projects reaching operation
- Brazil green hydrogen projects launching commercial phases
- First green steel premium products reaching market at scale

Medium-term (2030-2040):

- Commercial-scale hydrogen-based steelmaking deployments
- Substantial BF-BOF capacity retirement and replacement in Europe

- China steel production peak and structural transformation
- CCUS widespread on remaining integrated mills
- Green steel becoming cost-competitive in some markets
- Circular economy achieving high scrap utilization rates
- Digital technologies fully integrated into global steel operations

Long-term (2040-2050):

- Majority of new steel capacity hydrogen-based or EAF
- Residual BF-BOF operations with full CCUS
- Mature green steel markets with differentiated products
- Global standards and certification systems established
- Net-zero steel production achieved in leading regions
- Technology transfer enabling global decarbonization

17.5 Final Reflections

The steel industry's decarbonization represents one of the most significant industrial transformations of the 21st century. Success requires sustained collaboration among governments, industry, academia, and civil society. The policy frameworks examined in this document demonstrate both convergence on the challenge and diversity in approaches.

Key to success will be:

1. **Maintaining ambition** while managing transition costs and competitiveness
2. **Supporting multiple pathways** rather than premature technology lock-in
3. **Ensuring just transitions** for workers and communities
4. **Fostering international cooperation** despite geopolitical tensions
5. **Learning and adapting** as experience accumulates

The research policies outlined here provide the foundation for technological breakthrough. Implementation, however, requires broader policy alignment, sustained political will, and societal support. The steel industry has repeatedly demonstrated capacity for innovation and adaptation over its long history. The current transformation, while unprecedented in scope, can succeed with the comprehensive approach now emerging globally.

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This document was compiled based on the World Steel Association production data for 2023-2024 and complementary policy research across major steel-producing regions. Information current as of October 2025.