# Industrial Decarbonisation

Electrification, Hydrogen, CCS, and Hard-to-Abate Sector Transition Pathways

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H Heuristics Research

# Executive Summary

Industrial decarbonisation represents one of the most challenging and critical components of global climate action. Heavy industry—including steel, cement, chemicals, and refining—accounts for approximately 30% of global $CO_2$ emissions, yet faces unique technical and economic barriers to decarbonisation. Unlike power generation or transportation, many industrial processes require extreme temperatures, specific chemical reactions, or produce emissions as inherent byproducts of production.

Three primary decarbonisation pathways are emerging for hard-to-abate sectors: electrification of industrial heat and processes using renewable electricity, hydrogen as a clean fuel and chemical feedstock, and carbon capture and storage (CCS) to address unavoidable process emissions. The optimal pathway varies by industry, geography, and timeframe, with most sectors requiring a portfolio approach combining multiple technologies.

Investment in industrial decarbonisation is accelerating dramatically, reaching $127 billion globally in 2025, up from $45 billion in 2020. Government policies including carbon pricing, clean hydrogen subsidies, and CCS tax credits are creating economic incentives for early movers. However, significant challenges remain including technology readiness, infrastructure requirements, cost competitiveness, and the need for coordinated action across value chains.

This report examines the state of industrial decarbonisation technologies, sector-specific transition pathways, policy and investment landscapes, and strategic recommendations for industrial companies, technology providers, policymakers, and investors navigating this transformation. The window for action is narrowing—achieving net-zero industrial emissions by 2050 requires deployment at scale beginning immediately.

## Key Findings

**Emissions Challenge**

Heavy industry accounts for 30% of global $CO_2$ emissions

**30%**
Global Emissions

**Investment Surge**

Industrial decarbonisation investment reached $127B in 2025

**$127B**
2025 Investment

**Technology Readiness**

Electrification and hydrogen technologies approaching commercial scale

**2025-2030**

Deployment Window

**Cost Gap**

Green premium for low-carbon industrial products ranges 20-80%

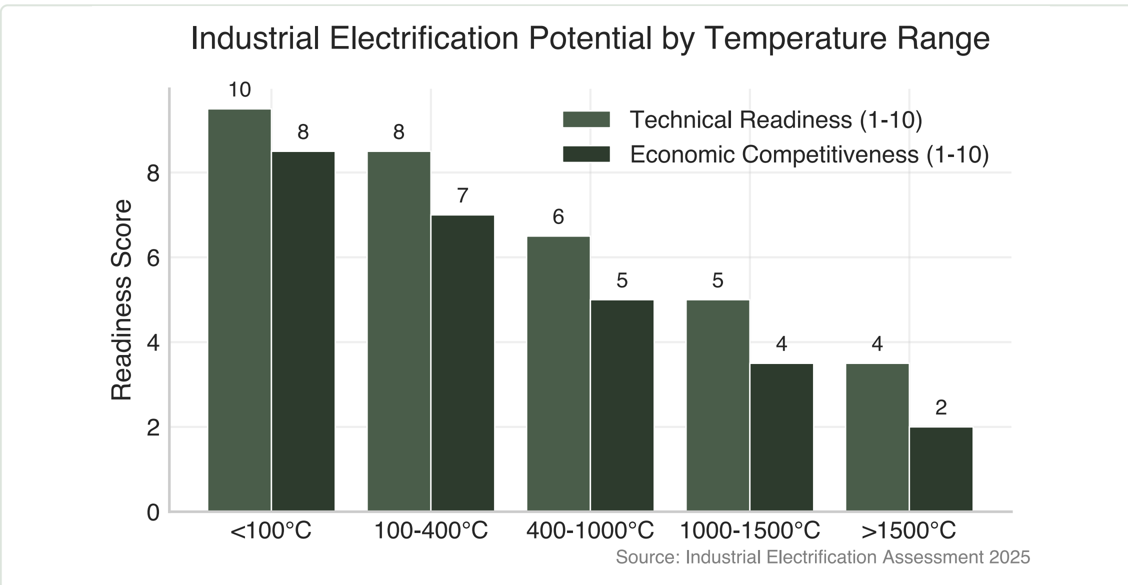
**20-80%**

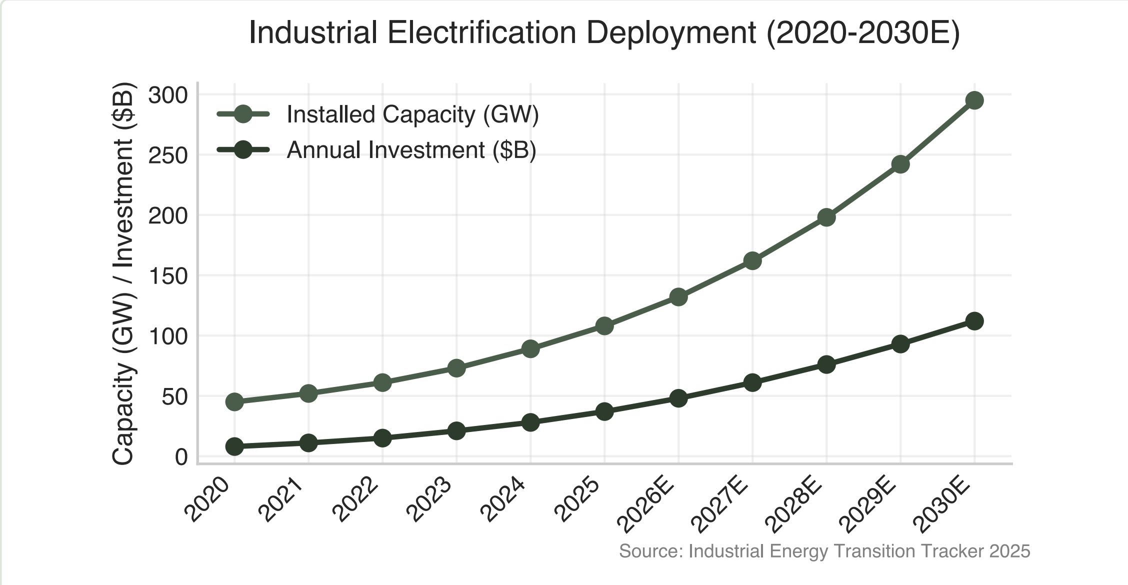
Cost Premium

# Electrification: Transforming Industrial Heat and Processes

Industrial electrification represents the most straightforward decarbonisation pathway for processes that can be powered by electricity rather than fossil fuels. As renewable electricity costs continue to decline and grid carbon intensity decreases, electric industrial processes become increasingly attractive both economically and environmentally.

Low and medium temperature industrial heat (below 400°C) is highly amenable to electrification. Heat pumps, electric boilers, and resistance heating can efficiently replace natural gas and coal for applications including food processing, textiles, chemicals, and paper manufacturing. Industrial heat pumps achieving coefficients of performance above 3.0 deliver heating at costs competitive with fossil fuels in many regions, particularly where carbon pricing applies.






### Electrification Technologies by Industrial Application

| Industry Sector | Primary Application | Technology | Readiness | Cost vs. Fossil |
|---|---|---|---|---|
| Food & Beverage | Process heat <150°C | Heat pumps, electric boilers | Commercial | Competitive |
| Chemicals | Steam generation | Electric boilers, heat pumps | Commercial | +10-20% |
| Paper & Pulp | Drying processes | Electric dryers, heat pumps | Commercial | +15-25% |
| Steel (Recycling) | Melting scrap | Electric arc furnace | Mature | Competitive |
| Glass | Melting >1400°C | Electric melting | Pilot/Demo | +30-50% |
| Cement | Kiln heating >1450°C | Plasma/resistance | R&D/Pilot | +50-80% |

*Source: Industrial Electrification Technology Assessment 2025*

High-temperature electrification (above 1000°C) presents greater technical challenges but is advancing rapidly. Electric arc furnaces for steel recycling are well-established, and emerging technologies including plasma heating, induction furnaces, and microwave heating are enabling electrification of cement kilns, glass furnaces, and chemical reactors. Pilot projects demonstrate technical feasibility, though cost competitiveness requires continued renewable electricity cost declines.

The primary barrier to industrial electrification is not technology but infrastructure and economics. Many industrial facilities require substantial electrical capacity upgrades, grid reinforcement, and on-site renewable generation or storage. The capital investment required for electrification retrofits can be substantial, creating financing challenges particularly for energy-intensive, low-margin industries.

Policy support is accelerating electrification adoption. Production tax credits for clean electricity, accelerated depreciation for electrification equipment, and carbon pricing mechanisms improve the economics of electric industrial processes. Industrial clusters with shared infrastructure and coordinated grid upgrades are emerging as an efficient deployment model.

**Low-Temp Success**

Heat pumps achieving 3.0+ COP make low-temperature electrification cost-competitive

**3.0+**
COP

**Capacity Growth**

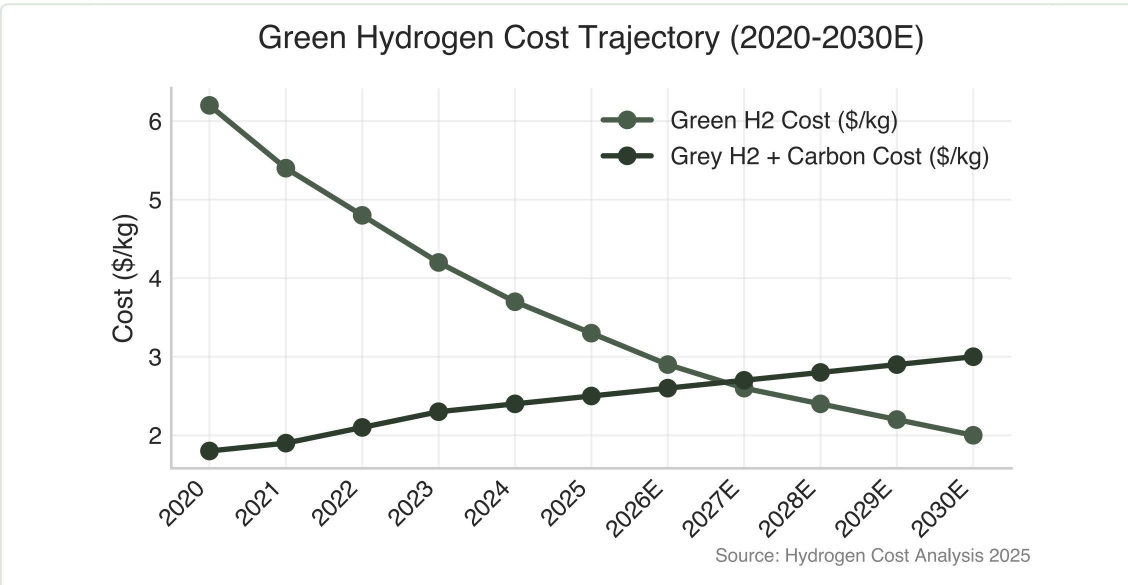
Industrial electrification capacity projected to reach 295 GW by 2030

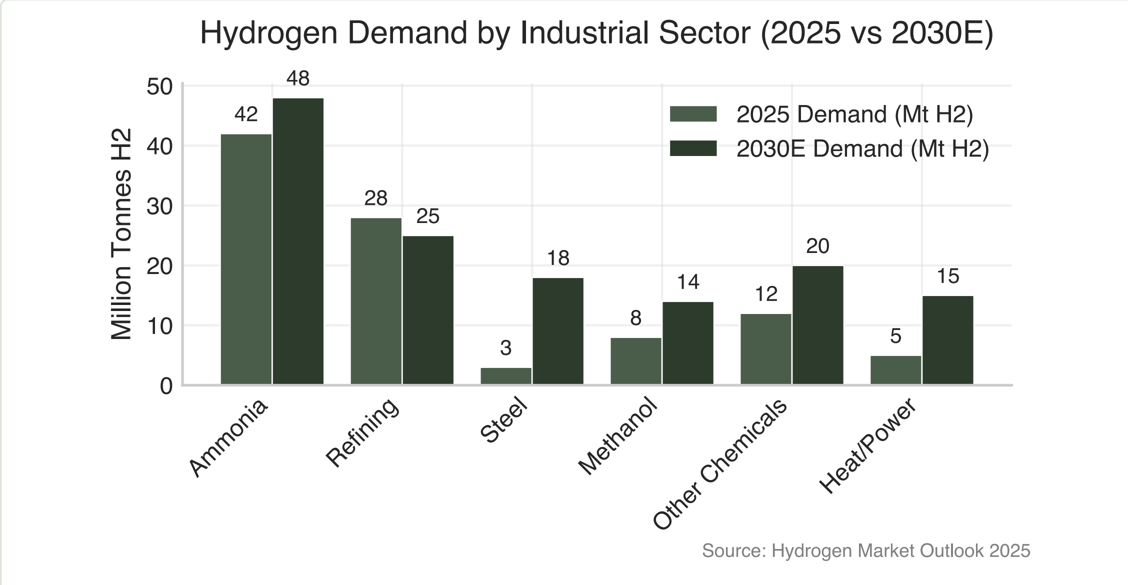
**295 GW**
2030 Capacity

# Hydrogen: Clean Fuel and Feedstock for Heavy Industry

Hydrogen is emerging as a critical enabler of industrial decarbonisation, serving both as a clean fuel for high-temperature heat and as a chemical feedstock replacing fossil-based hydrogen in ammonia, methanol, and refining. The hydrogen economy is transitioning from grey (fossil-based) to blue (with CCS) and green (electrolysis from renewable electricity) production pathways.

Green hydrogen production costs have declined dramatically, from over \$6/kg in 2020 to approximately \$3-4/kg in favorable locations in 2025, driven by electrolyzer cost reductions and cheap renewable electricity. Projections suggest \$2/kg green hydrogen is achievable by 2030 in optimal locations, approaching cost parity with grey hydrogen plus carbon pricing. However, significant regional variation exists based on renewable resource quality and electricity costs.






### Hydrogen Production Pathways Comparison

| Pathway | Current Cost | 2030E Cost | Carbon Intensity | Maturity | Key Challenges |
|---|---|---|---|---|---|
| Grey H2 (SMR) | $1.5/kg | $1.8/kg | 10 kg CO2/kg H2 | Mature | High emissions |
| Blue H2 (SMR+CCS) | $2.2/kg | $2.0/kg | 1-2 kg CO2/kg H2 | Commercial | CCS infrastructure |
| Green H2 (Electrolysis) | $3.3/kg | $2.0/kg | 0 kg CO2/kg H2 | Emerging | Cost, renewable power |
| Turquoise H2 (Pyrolysis) | $2.8/kg | $2.2/kg | 0 kg CO2/kg H2 | Pilot | Technology scale-up |

*Source: Hydrogen Production Technology Assessment 2025*

Steel production represents hydrogen's most promising near-term industrial application. Direct reduced iron (DRI) using hydrogen instead of coal can eliminate 95% of steelmaking emissions. Multiple pilot and demonstration projects are operating, with commercial-scale green steel facilities planned for 2025-2027 startup. However, green steel production costs are 30-50% higher than conventional routes, requiring carbon pricing or green premiums to be economically viable.

Ammonia and methanol production currently consume approximately 70 million tonnes of grey hydrogen annually, representing a captive market for green hydrogen. Replacing fossil hydrogen in existing applications avoids the infrastructure challenges of new hydrogen end-uses while delivering immediate emissions reductions. Several large-scale green ammonia projects are under development, targeting both fertilizer markets and hydrogen carriers for export.

Hydrogen infrastructure remains a critical bottleneck. Industrial clusters are developing shared hydrogen production and distribution infrastructure to achieve economies of scale. Hydrogen pipelines, storage facilities, and import terminals require substantial investment. The chicken-and-egg challenge of supply and demand coordination is being addressed through government support, offtake agreements, and industrial partnerships.

**Cost Convergence**

Green hydrogen approaching $2/kg by 2030, competitive with grey + carbon pricing

**$2/kg**

2030 Target

**Steel Opportunity**

Hydrogen-based DRI steel demand projected to reach 18 Mt $H_2$ by 2030

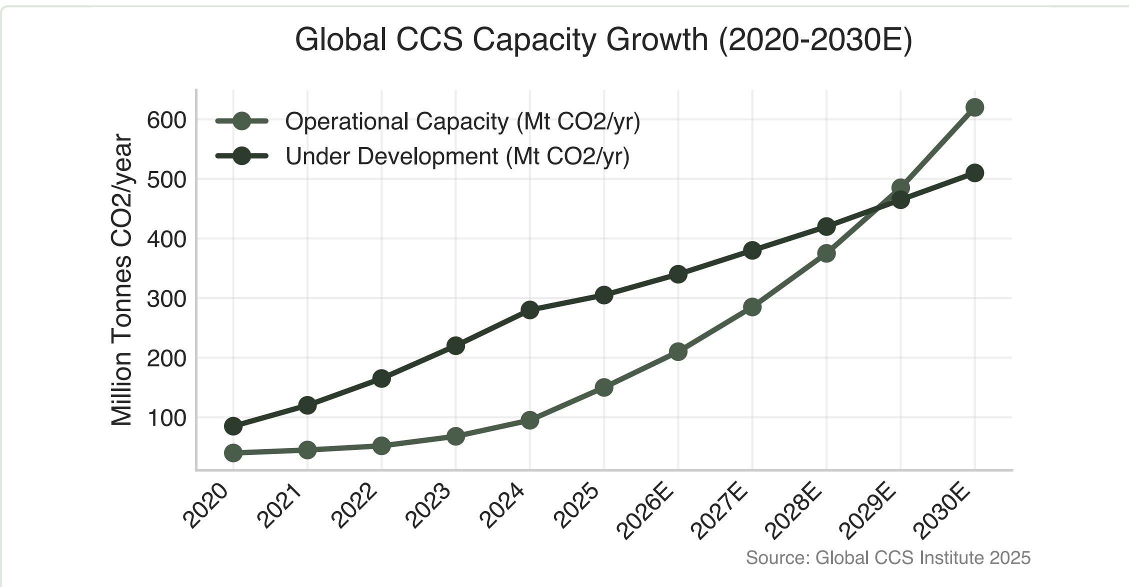
**18 Mt**

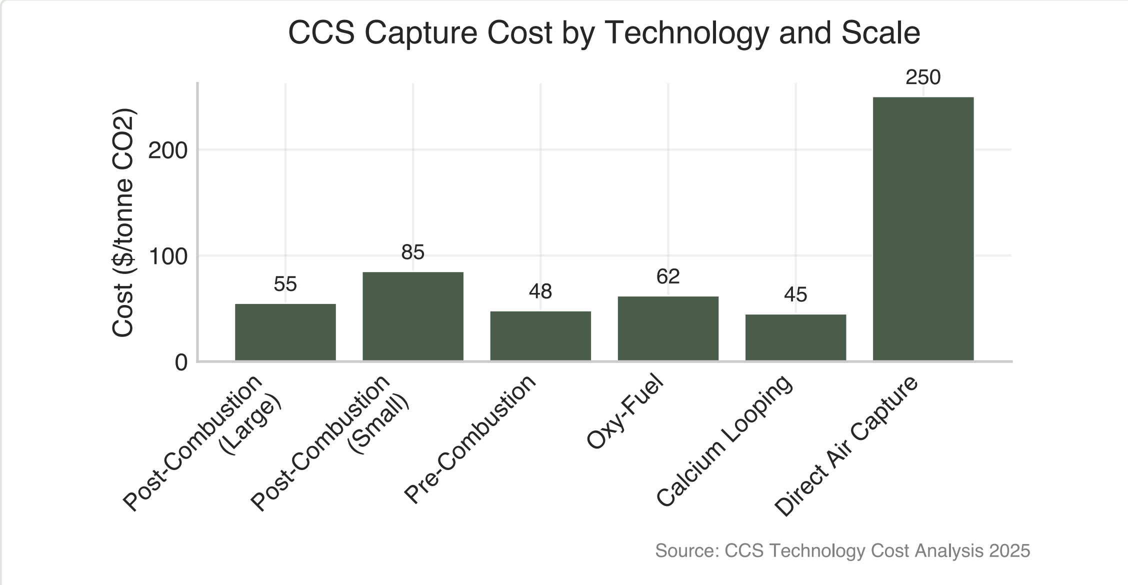
$H_2$ Demand

# Carbon Capture and Storage: Addressing Unavoidable Emissions

Carbon capture and storage (CCS) is essential for decarbonising industrial processes with inherent CO2 emissions, particularly cement and chemicals where emissions result from chemical reactions rather than fuel combustion. CCS also enables continued use of existing industrial assets during the transition to zero-carbon alternatives.

CCS technology has advanced significantly, with capture costs declining from $80-100/tonne CO2 in 2020 to $50-70/tonne for large-scale industrial applications in 2025. Post-combustion capture using amine solvents is commercially proven, while emerging technologies including calcium looping, membrane separation, and direct air capture offer potential for further cost reductions and efficiency improvements.

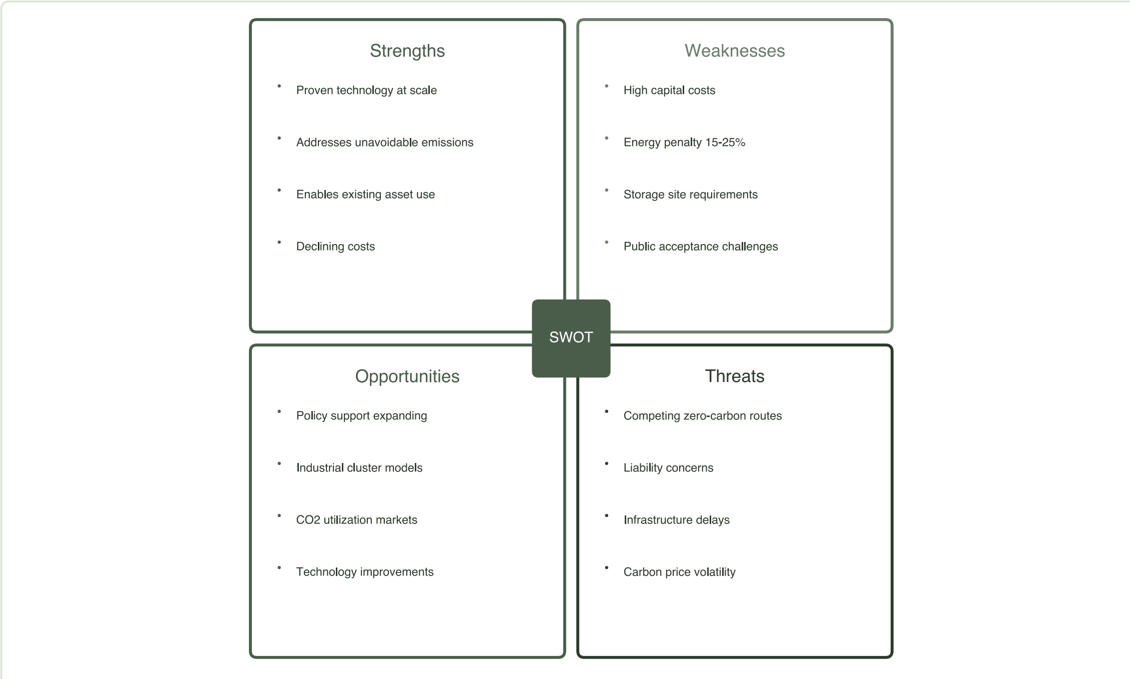





## CCS Applications by Industrial Sector

| Industry | Emissions Source | Capture Technology | Cost ($/t CO2) | Deployment Status |
|---|---|---|---|---|
| Cement | Process + fuel | Calcium looping, amine | $50-70 | Demo/Commercial |
| Steel (BF-BOF) | Blast furnace gas | Pre-combustion | $45-60 | Pilot/Demo |
| Chemicals | Process emissions | Post-combustion | $55-75 | Commercial |
| Refining | Hydrogen production | Pre-combustion | $40-55 | Commercial |
| Ethanol | Fermentation | High-purity capture | $25-35 | Commercial |
| Power Generation | Flue gas | Post-combustion | $60-80 | Demo/Commercial |

*Source: Industrial CCS Application Assessment 2025*




Global CCS capacity has grown from 40 million tonnes $CO_2$ per year in 2020 to approximately 150 million tonnes in 2025, with over 300 million tonnes under development. Industrial CCS projects are concentrated in regions with favorable geology for $CO_2$ storage and supportive policy frameworks, particularly the United States (45Q tax credit), Europe (Innovation Fund), and the Middle East.

Cement production represents CCS's most critical application, as process emissions from limestone calcination account for 60% of cement's carbon footprint and cannot be eliminated through fuel switching alone. Multiple cement CCS projects are operational or under construction, demonstrating technical feasibility. However, the cost premium for low-carbon cement remains substantial, requiring policy support or green procurement commitments.

CCS infrastructure development is accelerating through industrial cluster approaches. Shared $CO_2$ transport and storage infrastructure serves multiple industrial emitters, achieving economies of scale and reducing per-tonne costs. Major CCS hubs are developing in the US Gulf Coast, North Sea, and Middle East, with government support for infrastructure investment.

### Capacity Expansion

CCS capacity projected to reach 620 Mt $CO_2$/year by 2030

**620 Mt**

2030 Capacity

### Cost Reduction

Large-scale industrial CCS costs declined to $50-70/tonne $CO_2$

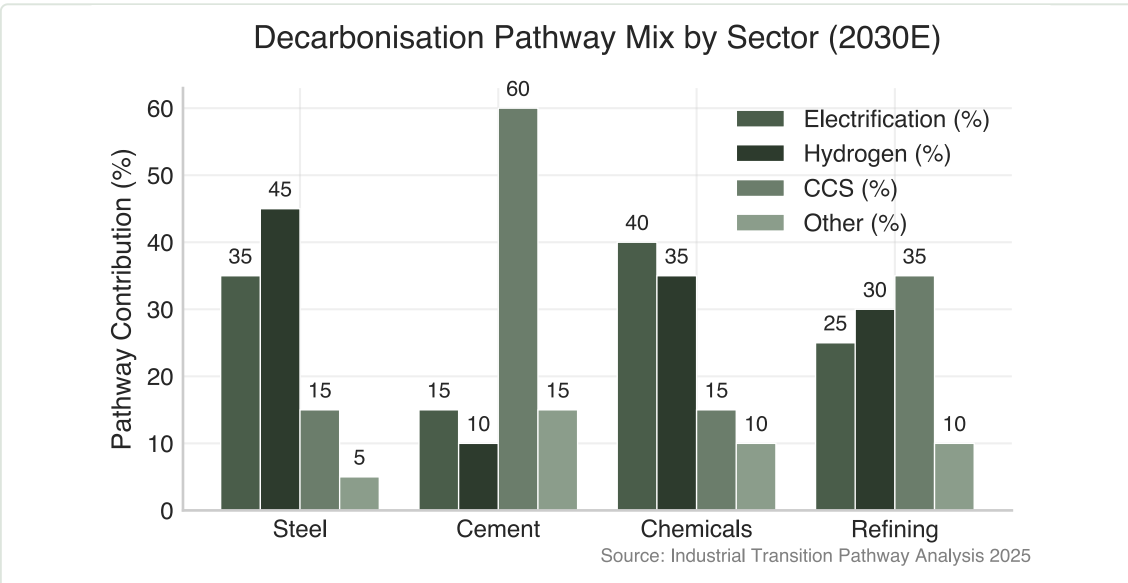
**$50-70**

Capture Cost

# Hard-to-Abate Sector Transition Pathways

Different industrial sectors face unique decarbonisation challenges and opportunities, requiring tailored transition strategies. Steel, cement, chemicals, and refining—collectively responsible for over 20% of global emissions—are pursuing distinct pathways based on technical constraints, economics, and market dynamics.

Steel production is pursuing multiple parallel pathways. Electric arc furnace (EAF) steel from scrap is already low-carbon and cost-competitive, but scrap availability limits growth. Hydrogen-based direct reduced iron (H-DRI) offers near-zero emissions for primary steel but faces cost challenges. Blast furnace CCS provides a bridge solution for existing assets. The optimal pathway varies by region based on scrap availability, electricity costs, and hydrogen access.



### Sector-Specific Transition Strategies

| Sector | Primary Pathway | Secondary Pathway | Timeline | Key Barriers | Policy Needs |
|---|---|---|---|---|---|
| Steel | H2-DRI | EAF + CCS | 2025-2035 | H2 cost, infrastructure | H2 subsidies, green procurement |
| Cement | CCS | Alt materials, fuels | 2025-2040 | CCS cost, storage | CCS credits, carbon pricing |
| Chemicals | Electrification | Green H2, bio-based | 2025-2040 | Process complexity | Clean electricity, R&D |
| Refining | H2 + CCS | Biofuels, SAF | 2025-2045 | Demand decline | CCS credits, SAF mandates |
| Aluminum | Electrification | Inert anode | 2025-2035 | Electricity cost | Clean power access |
| Glass | Electrification | H2, oxy-fuel | 2025-2035 | High temp electrification | Technology support |

*Source: Sector Transition Strategy Assessment 2025*

Cement decarbonisation requires a portfolio approach combining fuel switching, alternative materials, CCS, and demand reduction. Electrification of cement kilns is technically challenging but advancing. Alternative fuels including biomass and waste reduce fossil fuel use. Novel cement chemistries and supplementary cementitious materials lower clinker content. However, CCS remains essential for addressing process emissions from limestone calcination.

Chemical industry decarbonisation focuses on electrification of steam crackers, green hydrogen for ammonia and methanol, and bio-based feedstocks. The sector's diversity creates complexity—different chemical products require different solutions. Circular economy approaches including chemical recycling reduce virgin feedstock demand. Carbon capture from concentrated streams offers near-term emissions reductions.

Refining faces a declining long-term outlook as transportation electrifies, but near-term decarbonisation remains important. Hydrogen production with CCS, renewable hydrogen for hydroprocessing, and electrification of process heat reduce refinery emissions. Some facilities are pivoting toward biofuels, sustainable aviation fuel, and chemical production to maintain relevance in a decarbonising economy.

**Steel Transformation**

Hydrogen-DRI pathway targeting 45% of steel decarbonisation by 2030

**45%**
Pathway Share

**Cement CCS Critical**

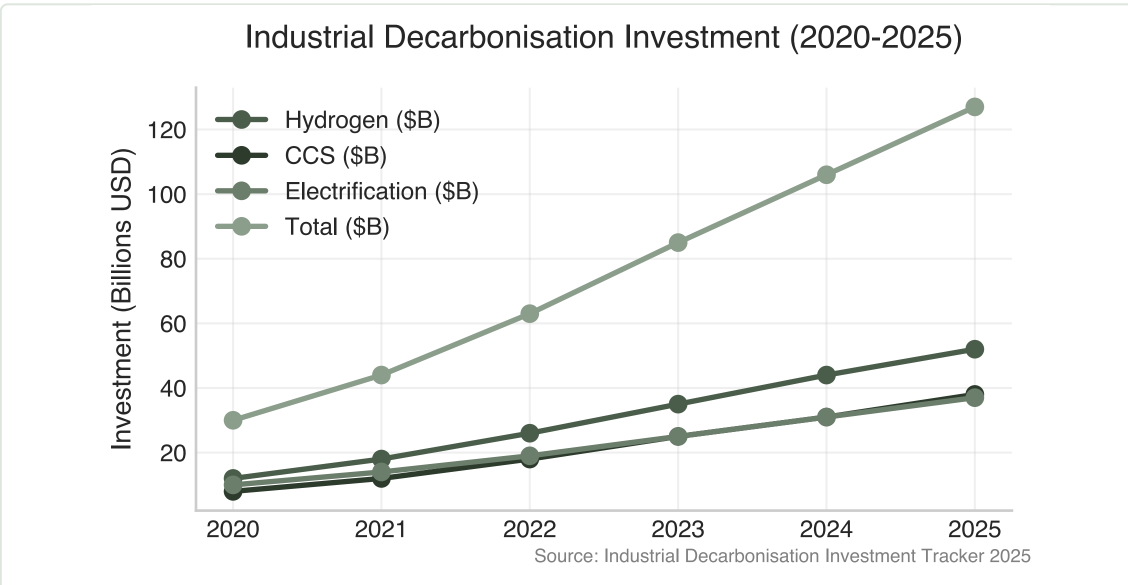
CCS essential for 60% of cement decarbonisation due to process emissions

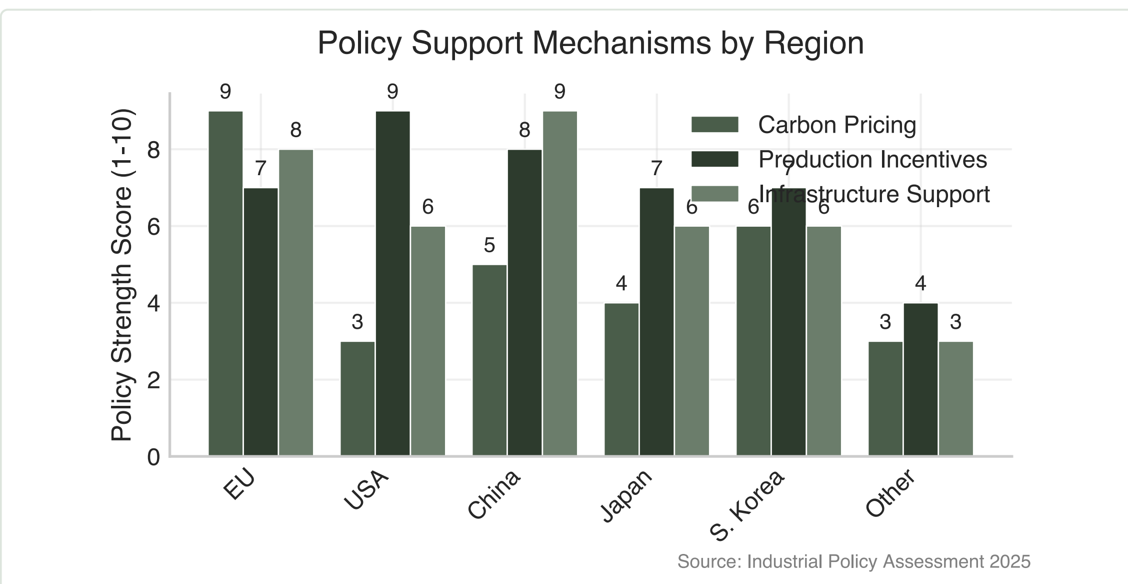
**60%**
CCS Share

# Policy Frameworks and Investment Dynamics

Policy support is accelerating industrial decarbonisation through carbon pricing, production incentives, infrastructure investment, and green procurement mandates. The policy landscape varies significantly by region, creating competitive dynamics and investment location decisions.

The European Union leads on carbon pricing through the Emissions Trading System (ETS), with allowance prices exceeding €80/tonne CO2 and the Carbon Border Adjustment Mechanism (CBAM) addressing competitiveness concerns. The EU Innovation Fund provides billions in support for breakthrough industrial decarbonisation projects. However, high energy costs and regulatory complexity create challenges for European industry.



### Key Policy Mechanisms and Impact

| Policy Type | Example | Impact | Geographic Coverage | Effectiveness |
|---|---|---|---|---|
| Carbon Pricing | EU ETS, CBAM | €80/t CO2 | EU, 30+ countries | High |
| H2 Production Credit | US 45V | Up to $3/kg | USA | Very High |
| CCS Tax Credit | US 45Q | Up to $85/t CO2 | USA | High |
| Green Procurement | LeadIT, SteelZero | Demand signal | Global | Medium |
| Infrastructure Fund | EU Innovation Fund | €40B available | EU | Medium-High |
| Mandates | China H2 targets | Volume requirements | China | High |

*Source: Industrial Decarbonisation Policy Analysis 2025*

The United States Inflation Reduction Act transformed industrial decarbonisation economics through production tax credits for clean hydrogen (up to $3/kg), CCS (up to $85/tonne), and clean electricity. These technology-neutral incentives are driving substantial private investment in industrial decarbonisation projects. However, permitting challenges and infrastructure bottlenecks constrain deployment speed.

China's industrial policy emphasizes technology development and domestic deployment through mandates, subsidies, and state-directed investment. Pilot programs for hydrogen steel, carbon trading expansion, and renewable energy integration are advancing. China's scale advantages in manufacturing and deployment could create competitive advantages in low-carbon industrial products.

Investment in industrial decarbonisation reached $127 billion in 2025, with hydrogen projects attracting $52 billion, CCS $38 billion, and electrification $37 billion. However, the investment required to achieve net-zero industrial emissions by 2050 is estimated at $10-15 trillion cumulatively, indicating a massive financing gap. Innovative financing mechanisms including green bonds, carbon contracts for difference, and blended finance are emerging to mobilize capital.

**Investment Acceleration**

Industrial decarbonisation investment grew from $30B to $127B (2020-2025)

**$127B**

2025 Investment

**Financing Gap**

$10-15 trillion cumulative investment needed by 2050

**$10-15T**

Total Need

# Strategic Recommendations

1 **Develop Integrated Decarbonisation Roadmap**

Create sector-specific transition roadmaps combining electrification, hydrogen, and CCS based on technical feasibility, economics, and infrastructure availability. Prioritize no-regret moves including energy efficiency and low-temperature electrification while preparing for longer-term hydrogen and CCS deployment.

*Immediate - 6 months*

2 **Secure Low-Carbon Energy Supply**

Establish long-term contracts for renewable electricity and green hydrogen through power purchase agreements, hydrogen offtake agreements, and strategic partnerships. Consider on-site renewable generation and industrial cluster participation to achieve competitive energy costs.

*6-12 months*

3 **Pilot and Demonstrate Technologies at Scale**

Deploy pilot projects for critical technologies including hydrogen-based processes, high-temperature electrification, and CCS to validate technical performance, costs, and integration challenges. Leverage government funding for demonstration projects and share learnings across industry.

*12-24 months*

4 **Engage in Industrial Cluster Development**

Participate in regional industrial clusters developing shared hydrogen, CCS, and electrical infrastructure. Cluster approaches achieve economies of scale, reduce infrastructure costs, and enable coordinated transition planning. Engage with government agencies and other industrial players.

*12-18 months*

5 **Advocate for Supportive Policy Frameworks**

Engage policymakers on carbon pricing, production incentives, infrastructure investment, and green procurement policies. Participate in industry associations and policy working groups. Support policies that level the playing field globally through border adjustments or international coordination.

*Ongoing*

6 **Develop Green Product Strategies**

Create premium green product lines targeting customers willing to pay for low-carbon materials. Establish transparent carbon accounting and certification. Build brand value around sustainability leadership. Explore carbon contracts for difference to bridge cost gaps during transition.

*12-24 months*

7

### Build Internal Capabilities and Partnerships

Develop internal expertise in decarbonisation technologies, carbon accounting, and transition planning. Establish partnerships with technology providers, engineering firms, and research institutions. Invest in workforce training for new technologies and processes.

*6-18 months*

8

### Prepare for Stranded Asset Risks

Assess existing asset base for stranded asset risks under various carbon price and policy scenarios. Develop contingency plans for early retirement or retrofit of high-emission assets. Consider strategic shifts toward low-carbon products or circular business models.

*12-24 months*

# Conclusion

Industrial decarbonisation represents one of the defining challenges and opportunities of the energy transition. The technologies required—electrification, hydrogen, and CCS—are advancing rapidly and approaching commercial viability. Policy support is strengthening globally, creating economic incentives for early movers. However, the scale of transformation required is immense, demanding coordinated action across industry, government, and finance. Companies that move decisively to decarbonise operations will gain competitive advantages through lower carbon costs, access to green premiums, and positioning for a net-zero economy. The window for action is narrowing—achieving net-zero industrial emissions by 2050 requires deployment at scale beginning immediately.