Steel decarbonization

The scale of the challenge

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September 12, 2023
The state of the industry
Steel was an early mover in decarbonization, but others have now made major commitments.

Source: BloombergNEF. Note: Plastics include polyolefins and PET.
Steel is still expected to decarbonize faster than its peers

Direct CO2 emissions by sector relative to 2021

Source: BloombergNEF
Steelmaking will shift to direct reduction and electrification

Global steel production for net-zero, by process

Source: BloombergNEF. Note: Mt is million tons, MOE is molten oxide electrolysis, DR-EAF is direct reduction paired with an electric arc furnace, BF-BOF is a blast furnace paired with a basic oxygen furnace. Percentages may not sum to 100% due to rounding.
Changes need to happen right away

Transformation pathway for the steel sector

2020s
- Recycling rate rises, plants switch to clean energy

2030s
- Existing plants blend hydrogen, new-build mostly direct reduction

2040s
- All new capacity is hydrogen or MOE

Source: BloombergNEF
Recycling and hydrogen lead the way
Net-zero steel costs are high for now

Cost of net-zero steel, by technology, 2021

Levelized cost of steel ($/t crude steel)

<table>
<thead>
<tr>
<th>Technology</th>
<th>Germany</th>
<th>U.S.</th>
<th>China</th>
</tr>
</thead>
<tbody>
<tr>
<td>BAU production cost</td>
<td>475</td>
<td>551</td>
<td>572</td>
</tr>
<tr>
<td>Natural gas + offsets</td>
<td>889</td>
<td>990</td>
<td>1,035</td>
</tr>
<tr>
<td>Recycled steel</td>
<td>658</td>
<td>697</td>
<td></td>
</tr>
<tr>
<td>Hydrogen</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>CCS</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Electrolysis</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: BloombergNEF
But could be competitive by 2050

Cost of net-zero steel, by technology, 2050

Levelized cost of steel ($/t crude steel)

- Germany
- U.S.
- China

Source: BloombergNEF
Net-zero production options

Levelized cost of steel, 2021

Levelized cost of steel ($/t crude steel)

Source: BloombergNEF
Scrap prices dictate recycled steel costs

LCOS of net-zero recycling over scrap prices, U.S. 2021

Cost ($/t crude steel)

$/t scrap

Source: BloombergNEF
Steel scrap is following the super-cycle

Steel scrap and virgin price change since January 2020

Source: BloombergNEF, Kallanish, Scrap Monster, CU Steel
Net-zero production options

Levelized cost of steel, 2021

Levelized cost of steel ($/t crude steel)

Source: BloombergNEF
Hydrogen-made steel can compete

**LCOS with hydrogen prices, 2050**

Source: BloombergNEF. Note: H2 is hydrogen. Capex, opex and hydrogen price assumptions are based on Germany. For more on our assumptions for LCOS costs for CCUS, see Appendix B. The cost range of production from fossil fuels represents costs for new-build steel plants.
The amount of H2 needed to make steel is the greatest uncertainty

Hydrogen intensity’s impact on green steel costs

Source: BloombergNEF
Blue and green are competing today

Global range of green and blue LCOH₂ in 25 countries, 2022

$/kg (real 2021)

Source: BloombergNEF, NETL. Assumes our optimistic electrolyzer cost scenario. Renewable LCOH₂ range reflects a diversity of electrolyzer type, Chinese alkaline (low) to PEM (high). The electrolyzer’s electricity is sourced from the cheaper renewable resource. Capital and operational costs for blue hydrogen are sourced from the National Energy Technology Laboratory. Gas prices derived from BloombergNEF’s New Energy Outlook (web | terminal). Grid electricity prices assumed at $75 (real 2021) for all modeled markets.
Green overtakes blue by 2030

Global range of green and blue LCOH$_2$ in 25 countries, 2030

$/kg (real 2021)

Source: BloombergNEF, NETL. Assumes our optimistic electrolyzer cost scenario. Renewable LCOH$_2$ range reflects a diversity of electrolyzer type, Chinese alkaline (low) to PEM (high). The electrolyzer’s electricity is sourced from the cheaper renewable resource. Capital and operational costs for blue hydrogen are sourced from the National Energy Technology Laboratory. Gas prices derived from BloombergNEF’s New Energy Outlook (web | terminal). Grid electricity prices assumed at $75 (real 2021) for all modeled markets.
Global range of green and blue LCOH₂ in 25 countries, 2050

$/kg (real 2021)

Green is cheapest in the long run

Source: BloombergNEF, NETL. Assumes our optimistic electrolyzer cost scenario. Renewable LCOH₂ range reflects a diversity of electrolyzer type, Chinese alkaline (low) to PEM (high). The electrolyzer’s electricity is sourced from the cheaper renewable resource. Capital and operational costs for blue hydrogen are sourced from the National Energy Technology Laboratory. Gas prices derived from BloombergNEF’s New Energy Outlook (web | terminal). Grid electricity prices assumed at $75 (real 2021) for all modeled markets.
Corporate commitments
There is no consensus on a net-zero technology route

Net-zero corporate strategies, by technology

<table>
<thead>
<tr>
<th>Scope</th>
<th>Tech route</th>
<th>Option</th>
<th>maturity</th>
<th>Energy efficiency</th>
<th>Feedstock/raw material</th>
<th>H2 injection</th>
<th>Top-gas-recycling</th>
<th>H2 direct reduction</th>
<th>Carbon capture</th>
<th>Carbon utilization</th>
<th>Carbon transport and storage</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scope 1</td>
<td>Mature EAF-based</td>
<td>Increase EAF production</td>
<td>green</td>
<td>purple</td>
<td>blue</td>
<td>purple</td>
<td>purple</td>
<td>blue</td>
<td>purple</td>
<td>purple</td>
<td>purple</td>
<td>blue</td>
</tr>
<tr>
<td></td>
<td>Mature BF-based</td>
<td>Energy efficiency</td>
<td>purple</td>
<td>purple</td>
<td>purple</td>
<td>purple</td>
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<tr>
<td></td>
<td>BF-BOF based</td>
<td>Feedstock/raw material</td>
<td>purple</td>
<td>purple</td>
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<tr>
<td></td>
<td>DR-based</td>
<td>H2 injection</td>
<td>purple</td>
<td>purple</td>
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<tr>
<td></td>
<td>CCUS</td>
<td>Carbon capture</td>
<td>green</td>
<td>green</td>
<td>green</td>
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<tr>
<td></td>
<td>Others</td>
<td>Others</td>
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</tbody>
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Most steelmakers are aiming for net-zero in 2050, with two exceptions

Net-zero pathway for select steelmakers, for absolute scope 1 & 2 emissions reduction

Source: Company filings, BloombergNEF. Note: Emissions pathway begin with base year. The lines are illustrative only and do not necessarily indicate that corporates follow a linear emissions reduction pathway. For individual company assumption, see attached excel file.
ArcelorMittal leads in low-carbon project announcements

Low-carbon steel project count of steelmakers, by technology routes

Source: Company announcements, BloombergNEF. Note: EAF is building electric arc furnace. BF-BOF is emissions reduction based on blast furnace. CCU/S is carbon capture and utilization or storage. DR-EAF is hydrogen-based direct reduction. Others include electrolysis and FINEX. Projects include large demo and commercial projects.
Customers and policy are pushing steelmakers to net-zero

1. Countries go towards net-zero
2. Carbon pricing kicks in
3. Investors demand ESG effort
4. Market demands green products
5. Industry competes to upgrade tech and product

Policy landscape for steel industry decarbonization in selected countries, by push and pull factors

<table>
<thead>
<tr>
<th>Country/region</th>
<th>Operating companies</th>
<th>Official target for industry</th>
<th>Carbon market / tax</th>
<th>Subsidies or grants for low-carbon steel</th>
<th>Support for hydrogen</th>
<th>Support for CCUS</th>
<th>Green public procurement</th>
<th>Access to low-cost clean energy</th>
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</thead>
<tbody>
<tr>
<td>EU-27</td>
<td>SSAB</td>
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<tr>
<td>US</td>
<td>SSAB, Nippon Steel</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Recent, Recent, Recent</td>
</tr>
<tr>
<td>China</td>
<td>BAOWU, Nippon Steel</td>
<td></td>
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<td>Korea</td>
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</table>

Source: BloombergNEF. Note: Access to low-cost clean energy only considers the high-level policies and may not reflect the regional reality most relevant to the current and planned operation sites of the steelmakers. The policies marked “Recent” were rolled out during the writing of this report, the effect of which may yet be shown on the analyzed steelmakers. Green = strong policy and clear; yellow = somewhat effective policy/policy pending, red = does not exist/ineffective.
Customers are already signing contracts for green steel

Count of supply agreements for green steel

Source: BloombergNEF, company announcements
Early green steel projects rely heavily on public funding

ArcelorMittal’s steel projects with disclosed government support

Source: Company announcements, BloombergNEF. Note: The shaded projects are supported by local government, but the exact amount of government funding was not disclosed. BNEF estimates these to be around 50% of project cost.
A helping hand from policymakers
Incentives needed for net-zero

Carbon prices required to support net-zero steel making (at NOAK costs)

Source: BloombergNEF
Carbon-pricing programs by price and emissions covered

Source: Governments, exchanges, BloombergNEF. Note: Latest prices available at the time of writing. Where tax rates vary across fuels, sectors and greenhouse gases, figure uses median.
Carbon-pricing programs by price and emissions covered

Share of market emissions covered by carbon price

Source: Governments, exchanges, BloombergNEF. Note: Latest prices available at the time of writing. Where tax rates vary across fuels, sectors and greenhouse gases, figure uses median.

2020 CO2 PRICE REQUIRED FOR PARIS GOAL

Bubble size: jurisdiction’s volume of emissions

= 200 million metric tons

Market - Annex I
Market - Non-Annex I
Tax - Annex I
Tax - Non-Annex I

0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%

Share of market emissions covered by carbon price

Market - Annex I
Market - Non-Annex I
Tax - Annex I
Tax - Non-Annex I

0 10 20 30 40 50 60 70 80

Carbon price, $ per metric ton of CO2-equivalent

Sweden $142
U.K. $95
Norway
EU ETS

2020 CO2 PRICE REQUIRED FOR PARIS GOAL

Net-zero steel

Source: Governments, exchanges, BloombergNEF. Note: Latest prices available at the time of writing. Where tax rates vary across fuels, sectors and greenhouse gases, figure uses median.
EU carbon prices are set to rise, but industry gets a pass

Historical and forecast EU emissions allowance price

Source: BloombergNEF
With free allowances in place, steel needs a price of thousands of dollars per ton

Source: BloombergNEF. Note: From 2026 to 2030, the upper range assumes a linear phase-out of free allocation from 2026 to 2032, while the lower range assumes a linear phase-out of free allocation from 2026 to 2036.
China’s emissions may already have peaked

BNEF estimate of China’s steel sector historical and projected emissions

Actual emissions may have peaked in 2020 if output curb is kept in place

Emissions target: Peak by 2030

Output curb is needed to achieve 30% reduction by 2035

Output curb is needed to achieve 30% reduction by 2035

Capacity swapping makes EAFs more attractive

Source: BloombergNEF, Provincial government websites. Note: Data include only announcements made in 2021. The total amount includes plans without completion dates.
Green materials get a bit cheaper with the US’s IRA subsidies

Reduction in green chemical and steel costs with 45Q and hydrogen subsidies

Levelized cost ($/t material)

Source: BloombergNEF. Note: ATR is autothermal reforming, DR-EAF is a direct reduction furnace paired with an electric arc furnace. H2 is hydrogen. Blast furnace cost is for an existing, coal-fired plant. Ethane cracker costs are for a new-build plant.
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