HYDROGEN FOR PRIMARY STEEL

Prospects

GOOD

This fact sheet is part of an Energy Innovation paper assessing clean hydrogen's value for cutting climate pollution from 12 end uses. The full report includes context, analysis, policy recommendations, and citations—see QR code or link at bottom.

Hydrogen is the clearest path to clean up steel, though new technologies are on the way.

CONTEXT: Most primary steel (i.e., high-quality steel originating from iron ore) is made today from the combination of a blast furnace (BF), responsible for 93 percent of global ironmaking, and a basic oxygen furnace (BOF), responsible for 71 percent of global steelmaking. The two processes are often integrated in a single system (BF-BOF) and rely heavily on coal. A lower-emitting method involves using natural gas to purify iron ore via the direct reduced iron (DRI) process, then using electricity to make steel in an electric arc furnace (EAF). Hydrogen can replace natural gas in the DRI process, providing a near-term path to fully clean primary steel.

INFRASTRUCTURE NEEDS: There are two key hydrogen-based steelmaking routes: hydrogen-based direct reduction to electric arc furnace (H2-DRI-EAF) and hydrogen-based direct reduction to smelter (H2-DRI-SMELT-BOF). Each has its own infrastructure considerations.

Modern natural gas-based DRI systems can already accept up to 30 percent hydrogen, and minor retrofits can enable the use of 100 percent hydrogen. Thus, it's possible to gradually clean up steelmaking by building natural gas DRI facilities (which cut climate pollution 70 percent compared to coal-based BF-BOF) and adding hydrogen as it becomes available.

DRI-EAF plants can be integrated (like BF-BOF) or separated. This means iron production can be sited where iron ore and renewable energy are abundant, with iron shipped elsewhere to produce, finish, and shape steel (making up the vast majority of jobs). This also "considerably decreases" hydrogen infrastructure needs, since iron can be moved rather than hydrogen.

Both hydrogen routes require relatively high-quality iron ore. However, H2-DRI-EAF is limited to the highest-quality pellets, while H2-DRI-SMELT-BOF can use a much wider range of ore. Both processes also require a small amount of solid carbon to strengthen the steel, remove impurities, and increase process efficiency, but this requirement is higher for H2-DRI-SMELT-BOF. Adding carbon drives some CO_2 emissions, so it must come from a net-zero source like charcoal. H2-DRI-SMELT-BOF facilities also can reuse BOFs in coal-based BF-BOF plants—an option that may allow for a smoother transition for these facilities.

SOCIAL IMPACTS: Hydrogen can eliminate the public health risks of the highly polluting coal-based BF-BOF process, such as factory workers' and fenceline communities' higher rates of asthma and cancer (from emissions of fine dusts and carcinogens like cadmium and arsenic). Hydrogen can also reinvigorate steel communities by providing a viable path to keep plants open and competitive. For example, an analysis of the Ohio River Valley shows iron and steel jobs would fall under business as usual but increase significantly under a transition to H2-DRI-EAF, due in part to coal mine closures and rising clean steel demand, respectively.

COMPETING TECHS: There are four categories of low-carbon steel: primary with hydrogen, primary with electricity, primary with fossil fuels and carbon capture and storage (CCS), and secondary with electricity and scrap. Hydrogen is best positioned to make clean primary steel in at least the near to medium term given its commercial readiness and deep emissions reductions. H2-DRI-EAF and H2-DRI-SMELT-BOF have similar cost ranges but different roles.

Two technologies under development that would directly electrify steelmaking are **molten oxide electrolysis** and **alkaline electrolysis**. Both processes can use relatively low-grade iron ore, allow for smaller, modular steelmaking plants, and avoid the need for hydrogen infrastructure (though molten oxide electrolysis requires a large and constant electricity supply to maintain very high temperatures). Their energy requirements are also at least comparable with hydrogen processes and hold potential to become much more efficient. However, they won't be commercially available until 2035-45, and they have high cost uncertainty—meaning it's too risky to wait for them to begin cleaning up steelmaking.

Fossil fuel-based steelmaking with **carbon capture and storage** will not be able to compete with hydrogen. This pathway involves high residual emissions (upstream from coal mining or methane leaks as well as onsite from imperfect carbon capture rates), costly CO_2 pipeline and storage investments, and risks of not qualifying as "clean" in global markets.

Lastly, 20 percent of the global steel market (and 70 percent of U.S. steel production) is **secondary steel**, made with scrap and an EAF. This process uses no iron ore and uses five to seven times less energy than primary steelmaking; thus, it should be expanded wherever possible. However, there are limits to scrap availability (which can be increased with higher-quality recycling and processes to remove impurities), and secondary steel is lower quality (restricting its application to uses like construction). Thus, it cannot replace all primary steel.

TAKEAWAY: Nearly half of U.S. primary steel facilities will have to make major investments to continue operations. Policymakers must act quickly to ensure they transition to cleaner processes (like DRI plants that can move to 100 percent clean hydrogen) to avoid locking in coal-based BF-BOF steelmaking for decades to come. As steel is a highly competitive global market, producers need policy support to ensure they'll remain profitable through such a transition. Newer electric-only technologies may someday play a big role, but hydrogen-based processes are poised for immediate growth and are necessary to clean up steel on a meaningful timeline.

FURTHER READING:

- Agora Industry, Wuppertal Institute, and Lund University, "Low-carbon technologies for the global steel transformation. A guide to the most effective ways to cut emissions in steelmaking," April 11, 2024, https://www.agora-industry.org/publications/low-carbon-technologies-for-the-global-steel-transformation
- Jeffrey Rissman, *Zero-Carbon Industry: Transformative Technologies and Policies to Achieve Sustainable Prosperity*, Columbia University Press, 2024, https://zerocarbonindustry.com/#chapter-1, p.11-36
- Jacqueline Ebner, Kathy Hipple, Nick Messenger, and Irina Spector, "Green Steel in the Ohio River Valley: The Timing is Right for the Rebirth of a Clean, Green Steel Industry," Ohio River Valley Institute, April 2023, https://ohiorivervalleyinstitute.org/wp-content/uploads/2023/04/Green-Steel-in-the-Ohio-River-Valley-FINAL-6.pdf
- **Featured story:** Maria Gallucci, "The trillion-dollar quest to make green steel," Canary Media, October 25, 2023, https://www.canarymedia.com/articles/clean-industry/the-trillion-dollar-quest-to-make-green-steel
- **Full report:** https://energyinnovation.org/publication/hydrogen-policys-narrow-path-delusions-and-solutions