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An Open-Source Framework for Evaluating the Cost and Greenhouse Gas Emission Impacts of Design Decisions in Hydrogen Direct Reduced Iron Production

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Decarbonizing primary steel production is essential for steel producers to achieve their climate goals. The cost-effectiveness of different decarbonization pathways varies with regional energy and input prices, operational choices, technology designs, and incentives to decarbonize. The Decarbonizing Steelmaking TechnoEconomic EvaLuation (decarbSTEEL) tool was developed to support industry and policymakers in navigating these trade-offs. decarbSTEEL is an open-source, transparent and highly customizable framework for assessing the cost and carbon dioxide (CO_2) emissions impacts of various steel decarbonization strategies. The model evaluates seven major steel production pathways — blast furnace-basic oxygen furnace (BF-BOF), BF-BOF with carbon capture and sequestration (BF(CCS)-BOF), scrap-based electric arc furnace (Scrap-EAF), natural gas–based direct reduced iron with EAF steelmaking (NG-DRI-EAF), NG-DRI-EAF with CCS (NG-DRI(CCS)-EAF), hydrogen-based DRI-EAF (H_2-DRI-EAF), and a reductant-flexible DRI-EAF (Flex-DRI-EAF) — and calculates the variable cost, production cost of steel and CO_2 emissions intensity for each pathway. Users can explore how design decisions, such as hydrogen preheating methods, hydrogen and electricity sourcing, and DRI plant configurations, impact costs and emissions under different scenarios. As an interactive, adaptable and transparent tool, decarbSTEEL supports detailed analyses of different decarbonization pathways, helping stakeholders select cost-effective technology configurations to reduce CO_2 emissions.

Introduction

Steel is the most widely used metal in the world and a foundational material for modern economies, yet iron and steel production is a major contributor to global greenhouse gas (GHG) emissions, accounting for approximately 7% of global energy-related CO_2 emissions.[1] Even with efforts to improve material efficiency and enhance circularity, global steel demand is projected to rise through 2050 due to economic development and population growth.[1] Because of its unique material properties and low cost, steel is difficult to substitute away from, including in much of the new construction required for the clean energy transition.[2,3] As a result, decarbonizing iron and steel production is central to meeting the Paris Agreement's goal of limiting global temperature rise to well below 2°C.[4]

Deep decarbonization, however, will require a transformative shift in production technologies. In response to increasing pressure from governments, environmental organizations and downstream industries, major steel companies have committed to net-zero targets and are formulating decarbonization strategies.[5–7] Lowering CO_2 emissions at least cost is essential to achieve these climate goals, but the cost-effectiveness of various pathways will vary based on regional energy prices and resource availability, operational choices, and technology decisions. A transparent understanding of the sensitivities and key drivers of costs and CO_2 emissions affecting different steel