Paper Proposal: The Costs and Distributional Impacts of Decarbonizing the Iron and Steel Industry in the United States

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Abstract: Decarbonizing iron and steel production will require mitigating greenhouse gas (GHG) emissions associated with sourcing and preparation of input materials, production of energy inputs such as electricity, heat, and hydrogen, and transport across multiple process steps, including non-combustion and fugitive sources. While industrial GHG emissions are often treated as point sources with annual reporting at the plant or firm level, aggregated statistics mask the diversity, interdependencies, and often distributed geography of production processes, which will affect the set of available decarbonization strategies for any particular industrial system and its supply chain. First, this analysis will describe the technology composition, geography, and costs of iron and steelmaking in the United States today (core processes include ironmaking and steelmaking in the blast furnace-basic oxygen furnace route, BF-BOF, and use of scrap for steelmaking in electric arc furnace or EAF) and briefly compare it to other major world regions. Second, we will present several technology pathways for deeply decarbonizing iron and steelmaking and evaluate their effectiveness, costs, and interactions with existing technologies and location-specific inputs. Third, we will characterize variation across plant locations in the composition of the workforce, education level, racial composition, and political affiliation as a starting point for analyzing how the impacts of decarbonization investments will be distributed, focusing on jobs and local environmental pollution outcomes. The results of this study will provide a basis for improved design of policy incentives to support technological change while addressing workforce and community impacts. Its findings will also serve as a benchmark for comparisons for iron and steel decarbonization investments planned or in progress in other world regions.

Background: Iron and steel production is a major source of greenhouse gas emissions, accounting for around 8% of the total worldwide and in the United States. Globally, 85% of steel production occurs in ten countries (Global Energy Monitor, 2022).

Steel production today primarily involves one of two routes: integrated steelmaking from iron ore using the blast furnace-basic oxygen furnace route (BF-BOF), or electric arc furnace (EAF) steelmaking, which uses electricity to melt recycled scrap alone or in combination with direct reduced iron (DRI, also called sponge iron) and pig iron. The BF-BOF route accounts for 71% of current global production, the EAF route with scrap for 24%, DRI for 5%, and other routes for

less than 1%. In the United States, this ratio is reversed, with the EAF route accounting for roughly 70%, and BF-BOF steelmaking for around 30%. Due to the energy required to melt the iron ore at temperatures of 1600 C or more, BF-BOF steelmaking results in emissions of 1.5-3 tons CO_2 per ton crude steel, while EAF steelmaking, which today uses primarily scrap steel and pig iron as inputs, is much lower but depends on the electricity source and the extent of carbon combustion on the furnace.

Several routes exist to decarbonize steel production: for the BF-BOF process, biomass reductants could replace natural gas, if biomass is locally available. Injecting hydrogen produced from low carbon processes into the blast furnace as an alternative to pulverized coal injection, an approach to raise efficiency, offers CO_2 emissions reductions of up to 20%, however, the need for coking coal is not eliminated. The blast furnace could be retrofitted with carbon capture and sequestration (CCS). A second route involves shifting production to EAFs. This change requires a sufficient supply of scrap, DRI, or pig iron. CO_2 emissions from DRI production will need to be addressed. Today, coal and natural gas are the main fuels used, but in the future, hydrogen could replace fossil fuels in this process. If hydrogen can be produced with zero-carbon sources of energy, steelmaking by the EAF route could be almost emissions free. Molten oxide electrolysis, in which electricity is used to melt iron ore directly, offers the possibility to greatly simplify the process and reduce energy consumption and CO_2 emissions. However, anode corrosion at the high required process temperatures remains a major challenge (Allanore et al., 2021).

Our analysis will focus primarily on options for decarbonizing of BF-BOF production in the United States, which including coking accounts for the majority of iron and steelmaking GHG emissions. The need to address GHG emissions from multiple, often interconnected, process steps means that incremental and deep decarbonization pathways may have different implications for technology choices. Our analysis will characterize least-cost pathways for existing BF-BOF production to achieve a 20% reduction in GHG emissions relative to today's production by 2030 and compare them to least-cost pathways assuming a 40% reduction by 2030 and a 90% reduction by 2050.

Retrofitting, retiring, or replacing BF-BOF production has the potential to reduce not only GHG emissions, but also emissions of local air pollutants. However, these closures may simultaneously imply a loss of jobs for workers and economic hardship for communities connected to a plant. Our analysis will characterize the sociodemographic characteristics and local air quality in counties surrounding BF-BOF plants operated in the United States at any time since 2000, including plants that closed during this period. Characteristics of interest include the composition of employment by sector in neighboring counties, education level and other workforce characteristics, racial composition, and political affiliation. The goal of this analysis is to begin to bound the implications of future BF-BOF plant closures for jobs and air pollution and characterize how regional factors, such as energy prices and ore transport costs, will affect the economics of co-locating future decarbonized production with existing facilities.

Data and Methods: Data for iron and steelmaking plants in the United States will be developed using lists and inventories provided by environmental agencies such as the U.S. Environmental Protection Agencies Facility Level Information on Greenhouse Gases Tool (FLIGHT), U.S. Securities and Exchange Commission filings, annual reports, and data from the AIST Roundup. FLIGHT includes data on all stationary sources that emit more than 25,000 tons of CO_2 annually (U.S. EPA, 2022). For the global comparison, we will rely on a newly-released dataset from the Iron and Steel Plant Tracker from the Global Energy Monitor (Global Energy Monitor, 2022).

For data on community demographics where BF-BOF production is or was located since 2000, we will use the Neighborhood Change Database (NCDB), which we have acquired from GeoLytics. The NCDB provides US Census harmonized data from 1970, 1980, 1990, 2000, and 2010 at the census tract level.

For air quality data we will use readings from available monitoring networks used to assess compliance with the National Ambient Air Quality Standards (NAAQS). To complement data from the EPA pollution monitors, we will use data from Di et al. (2016), who produce daily PM2.5 concentrations at a 0.01 degree by 0.01 degree resolution (1km by 1km at the equator) for the contiguous U.S. from 2000-2015. These data were recently used by Currie et al. (2022) to study NAAQS-driven environmental justice issues. We will spatially intersect this gridded, raster data with Census tract boundary files from the 2000 and 2010 Census.

If sufficient data are available for this study, we will use BF-BOF plant closures or periodic downtime for furnace relining in multiple locations as natural experiments to assess the air quality benefits using an event study, difference-in-differences approach, matching closed plants to similar plants that continued to operate. We have taken steps to obtain these data and are optimistic that we will be able to gain access in time to include relevant analysis in the paper.

Relationship to NBER call on the Economics of Industrial Decarbonization: The author team has recently been awarded a Partnerships for International Research and Education (PIRE) grant from the National Science Foundation (NSF) focused on developing detailed plant-level analysis of industrial decarbonization technologies and its community impacts, with a focus on the iron and steelmaking industry. This paper will draw on a combination of newly available data sets collated from a variety of sources and serve as a starting point for developing cross-national comparisons of the distributional impacts of pathways to deep decarbonization in the iron and steel industry. Given that the minimum required data sets for this work are readily available and the team is starting work under the grant in January 2023, we expect to have a full version of the paper ready well in advance of the September 2023 meeting.

References

Allanore, A., Yin, L. & Sadoway, D.R. (2013). A new anode material for oxygen evolution in molten oxide electrolysis. *Nature*, 497, 353-356.

AIST Roundup (2022). Association for Iron and Steel Technology. (https://digital.library.aist.org/categories/roundups.html)

Currie, Janet, John Voorheis, and Reed Walker. (2022). What Caused Racial Disparities in Particulate Exposure to Fall? New Evidence from the Clean Air Act and Satellite-Based Measures of Air Quality, *American Economic Review*, forthcoming.

Di, Qian, Itai Kloog, Petros Koutrakis, Alexei Lyapustin, Yujie Wang, and Joel Schwartz. (2016). "Assessing PM2.5 exposures with high spatiotemporal resolution across the continental United States." *Environmental Science & Technology*, 50(9): 4712-4721.

Global Energy Monitor (2022). Global Steel Plant Tracker. https://globalenergymonitor.org/projects/global-steel-plant-tracker/

U.S. EPA [United States Environmental Protection Agency] (2022). Facility Level Information on Greenhouse gases Tool (FLIGHT).