Policy Evaluation for Decarbonization of the U.S. Iron/Steel and Cement Industries


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A Group Project submitted in partial satisfaction of the requirements for the degree of Master of Environmental Science and Management for the Bren School of Environmental Science & Management.

Bren School of Environmental Science & Management
UNIVERSITY OF CALIFORNIA, SANTA BARBARA

Evergreen Action

Signature Page

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The Group Project is required of all students in the Master of Environmental Science and Management (MESM) Program. The project is a year-long activity in which small groups of students conduct focused, interdisciplinary research on the scientific, management, and policy dimensions of a specific environmental issue. This Group Project Final Report is authored by MESM students and has been reviewed and approved by:

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Glossary

Term	Definition
ACEEE	American Council for an Energy Efficient Economy
AIST	Association for Iron & Steel Technology
BAU	Business-As-Usual (refers to scenario with no policy intervention)
BF	Blast Furnace
BIL	Refers to the Infrastructure Investment and Jobs Act (2021), also known as the Bipartisan Infrastructure Law
BOF	Basic Oxygen Furnace
CARB	California Air Resources Board
CAA	Clean Air Act, 42 U.S.C. §§ 7401-7671q
CBAM	Carbon Border Adjustment Mechanism
CCS	Carbon Capture & Storage
CEJST	CEQ's Climate & Economic Justice Screening Tool
CEMS	Continuous Emission Monitoring System, a device that continually collects information on the quantity of a gas being emitted
CEQ	Council on Environmental Quality
CO_2e	CO_2 equivalent
Disadvantaged Community	Census tracts which, according to CEJST, are (1) at or above the threshold for one or more environmental, climate, or other burdens AND are at or above the threshold for an associated socioeconomic burden; OR are (2) completely surrounded by disadvantaged communities AND are at or above the 50% percentile for low income (U.S. DOT, n.d.).
DOE	U.S. Department of Energy
EAF	Electric Arc Furnace
EJ	Environmental Justice
EIA	U.S. Energy Information Administration
End-use	Process or purpose for which fuel is consumed in an industrial facility. There are 13 end-use categories defined in the MECS data (IEA, n.d.)
Energy Community	Census tracts which the federal government has identified as hard-hit by coal mine and coal power plant closures and has prioritized for focused federal investment through the §48C tax credit (U.S. Congress, 2022).

EPA	U.S. Environmental Protection Agency
FLIGHT	Facility Level Information on GreenHouse gasses Tool
Four Pillars	Four technological pillars identified by DOE to significantly reduce emissions for heavy industry: (1) energy efficiency, (2) electrification, (2) low-carbon fuel, feedstocks, and energy sources (e.g. hydrogen), and (4) CCS (IEA, 2020).
GEM	Global Energy Monitor
GHG	Greenhouse Gas
GHGRP	U.S. EPA's Greenhouse Gas Reporting Program
GIS	Geographic Information System
H2	Hydrogen fuel
H2-DRI / HBI	Hydrogen Direct Reduced Iron / Hot Briquetted Iron
Heavy Industry	Collective term for industry sectors that involve large-scale equipment, high capital costs, high levels of energy use, and high barriers to entry.
IEA	International Energy Agency
IRA	Inflation Reduction Act of 2022
ISP / ISM	Integrated Steel Plant / Integrated Steel Mills. These terms refer to steel facilities that use a BF-BOF production pathway.
MECS	U.S. Energy Information Administration's Manufacturing Energy Consumption Survey
mt	Metric tons
NAAQS	U.S. Environmental Protection Agency's National Ambient Air Quality Standards
NAICS	North American Industry Classification System. This system is used by federal agencies in classifying business establishments for the purpose of collecting, analyzing, and publishing statistical data related to the U.S. business economy.
NO_x	Nitrogen oxides
OCED	U.S. DOE's Office of Clean Energy Demonstrations
PM2.5	Particulate matter with diameters up to 2.5 micrometers
Process Emissions	Refers to the GHG emissions that result from chemical reactions within the industrial process.
RMI	Rocky Mountain Institute
§48C	Refers to the Qualifying Advanced Energy Project Credit program, which provides tax credits for projects that expand clean energy manufacturing in Energy Communities.
Scope 1, 2, and 3	Refers to classifications of GHG emissions, with Scope 1 being direct emissions

	from owned and controlled sources, Scope 2 being indirect emissions from the generation of purchased energy, and Scope 3 being all indirect emissions not included in Scope 2 that occur in the value chain of the reporting company, including both upstream and downstream emissions (Greenhouse Gas Protocol, n.d.).
SO_x	Sulfur oxides
Stationary Combustion	Facilities' on-site combustion of fossil fuels, in most cases to achieve high heat for industrial processes.
TBtu	Trillion British thermal units (Btu)

1. Project Overview

Heavy industry is the cornerstone of modern civilization: These industries provide raw materials for everyday services and large-scale projects that are essential for economic growth and a functioning society. However, heavy industry produces a significant amount of U.S. greenhouse gas (GHG) emissions and, particularly Iron/Steel and Cement facilities, are often located in low-income or historically marginalized communities, exposing these communities to the health impacts of industrial pollution. Acknowledging the importance of heavy industry, it becomes imperative to ensure the continued production of these essential materials without further exacerbating the climate crisis and polluting disadvantaged communities.

While many organizations are currently working toward decarbonizing heavy industry, prevailing interventions tend to adopt a broad industry-wide scope and lack a granular examination of individual facilities. This poses a challenge in understanding the distributional impacts of pollution across different communities and hinders the identification of targeted technologies and interventions to reduce emissions in these industries. Our project aims to advance current research and produce new insights by modeling an industry-level breakdown of emissions by process and end-use at the scale of individual facilities. This granular understanding of facility-level emissions reveals geographical hotspots of emissions in addition to helping us understand which facilities have a considerable opportunity to reduce emissions given current technologies. In tandem with these emissions breakdowns, we label facilities by federally-designated community type in order to understand the distributional impacts of pollution across communities and identify opportunities for funding through current and future legislation.

This methodology enabled our team to evaluate the effectiveness of major policy proposals for the decarbonization of heavy industry at the facility level, both in terms of potential reduction to GHG emissions and positive impact on disadvantaged communities. These policy evaluations were delivered to our client to be used as the basis for further policy research and advocacy. Other project deliverables include a final report with visualizations and a database with a detailed breakdown of facility-level emissions by process and end-use, intended for use by policy makers, researchers, and advocacy groups in promoting decarbonization goals.

2. Background

Industrial emissions constitute approximately 30% of US energy-related GHG emissions and are projected to grow in the absence of intervention (DOE, 2022). Meeting the carbon neutrality targets set by the Paris Agreement by 2050 necessitates a swift and substantial decarbonization of the industrial sector (United Nations, n.d.). Unlike sectors such as transportation or energy, which can more readily transition to electrification powered by renewable energy sources, many industrial processes face significant challenges to decarbonization. Our project focuses on two major emitters in heavy industry — Iron/Steel and Cement — and identifies their major challenges and opportunity areas in pursuing decarbonization.

Some of these challenges have to do with the business model of “heavy industry.” Heavy industry sectors, including Iron/Steel and Cement, involve large-scale equipment, high capital costs, high levels of energy use, and high barriers to entry. They are considered “difficult-to-decarbonize” due to three technical factors: (1) industrial processes require temperatures that are currently difficult to achieve without fossil-fuel combustion, (2) chemical reactions in key industrial processes may produce GHGs as a by-product, and (3) industrial process equipment is capital intensive and often has long lifespans, leading to long replacement cycles and slow stock turnover (IEA, 2020). In addition to high capital costs, low profit margins in the Iron/Steel and Cement industries contribute to decarbonization challenges by making large-scale investments challenging. Production is highly dependent on raw material costs and projected economic growth, creating uncertainty that may disincentivize industry investment in advanced low-carbon technologies. Additionally, because Iron/Steel and Cement are purchased by the industries’ customers in bulk, they can be very price sensitive — buyers primarily focus on cost due to the perception that products are the same across suppliers. This further turns market forces away from sustainable alternatives (Gangotra et al., 2023).

Due to these challenges, there has been limited market-led progress toward the decarbonization of the Iron/Steel and Cement industries; therefore, government intervention via policy mechanisms presents a promising opportunity to reduce emissions in these heavy-polluting sectors. In this project, our team has especially focused on federal policy, which promises timely and broad-reaching intervention to decarbonize Iron/Steel and Cement facilities not only nationwide but also in environmental justice (EJ) communities across the U.S.

Our interest in EJ communities aligns with the current administration’s priority to advance environmental justice through implementing and enforcing national environmental and civil rights laws, as exemplified in initiatives such as Justice40 (White House, 2023a). Due to a legacy of racial discrimination and segregation, disadvantaged populations disproportionately bear the burdens of heavy industry activities. Iron/Steel and Cement facilities are often located near disadvantaged communities, exposing marginalized people to high levels of pollution and particulate matter which increase the risk of illnesses like respiratory disease and cancer. Without any decarbonization policies, research indicates that disadvantaged communities could be exposed to up to 34% more air pollution compared to the national average between 2020–2050 (Goforth et al., 2022). Technologies that cut carbon emissions often also reduce local air pollution (ACEEE, 2023). Current legislation, most notably the Inflation Reduction Act of 2022 (IRA) and the Bipartisan Infrastructure Law of 2023 (BIL), offers funding and tax incentives for decarbonization projects in federally designated communities, particularly Energy Communities and Disadvantaged Communities (EPA, 2023). Utilizing these federal community designations will facilitate an understanding of the distribution of marginalized populations in relation to industrial facilities — and will further illuminate opportunities for federal funding to reduce emissions in these marginalized communities.

This project builds on a large and growing body of research on decarbonization policy in the U.S. In particular, we draw from literature from the U.S. Department of Energy (DOE), which has identified four technological pillars to significantly reduce emissions for heavy industry. The Four Pillars are: (1) energy efficiency, (2) electrification, (2) low-carbon fuel, feedstocks, and energy sources (e.g. hydrogen), and (4) carbon capture and storage (CCS) (DOE, 2022).

The Four Pillars form the basis of many policy proposals for heavy industry decarbonization today. These policies are often evaluated on how they help to decarbonize the U.S. economy as a whole, over the next decade and beyond. Such high-level analysis obscures the impact of these technologies on individual facilities. This is a critical information gap, important not only to industry but also local communities. We seek to build on existing research by estimating the potential benefits of DOE's technological recommendations at the facility level. By creating a facility-level emissions breakdown by process and end-use, we can understand which specific process technologies account for emissions and therefore how impactful each of the DOE's Four Pillars would be in driving down emissions at each individual Iron/Steel and Cement plant in the U.S. By mapping these facilities, we can also understand which communities would be most impacted by decarbonization efforts and where federal funding is available. Together, these insights helped us to create a list of policy recommendations that result in the most impactful decarbonization options for the U.S. Iron/Steel and Cement sectors overall and within Energy & Disadvantaged Communities.

3. Methodology Overview

As explained above, our team seeks to build on existing research by **modeling potential benefits of current policy proposals to heavy industry decarbonization, especially in Energy and Disadvantaged Communities**. We have chosen to focus on Cement and Iron/Steel facilities for three reasons: (a) *Significance*: Iron/Steel and Cement are two of the top three emitters among heavy industry sectors in the U.S.; (b) *Data availability*: Both industries have been widely studied for decarbonization potential, ensuring a robust foundation of data for use in our project; and (c) *Simplicity*: Existing production pathways are few and well-studied, unlike more complex sectors like Chemical (EPA, n.d.f).

We first take a close look at today's Cement and Iron/Steel facilities, using public data on their operations to produce a facility-level breakdown of annual fuel combustion emissions by end-use and process (Section 3.1). We then look at major policy proposals for heavy industry decarbonization, collecting data from government sources, scholarly papers, and expert interviews to understand how those policies work in addition to their potential for reducing emissions from industrial fuel combustion or processes (Section 3.2). Next, we use these reduction estimates to model policy impacts on individual facilities, calculating how their total emissions would change if the reductions were applied to applicable end-uses or processes; following this step, we aggregate the data across facilities nationwide and within Energy or Disadvantaged Communities in order to understand the distributional impacts of each intervention (Section 3.3.1). We supplement this quantitative analysis with further qualitative evidence about potential policy impacts, including social and economic impacts in Energy or Disadvantaged Communities (Section 3.3.2). Finally, we compile this information into a single, public data source that can be used by our client and other advocacy organizations to advance heavy industry decarbonization efforts (Section 3.3.3).

A visualization of our methodology can be found in Figure 1 below, and a high-level step-wise summary of the methodology can also be found in Appendix H. Further information on our data sources, including justifications for their selection, can be found in Appendix A.

Further detail on our methodology, including the software we used, assumptions and limitations, and calculation steps, is provided below in Sections 3.1–3.3.

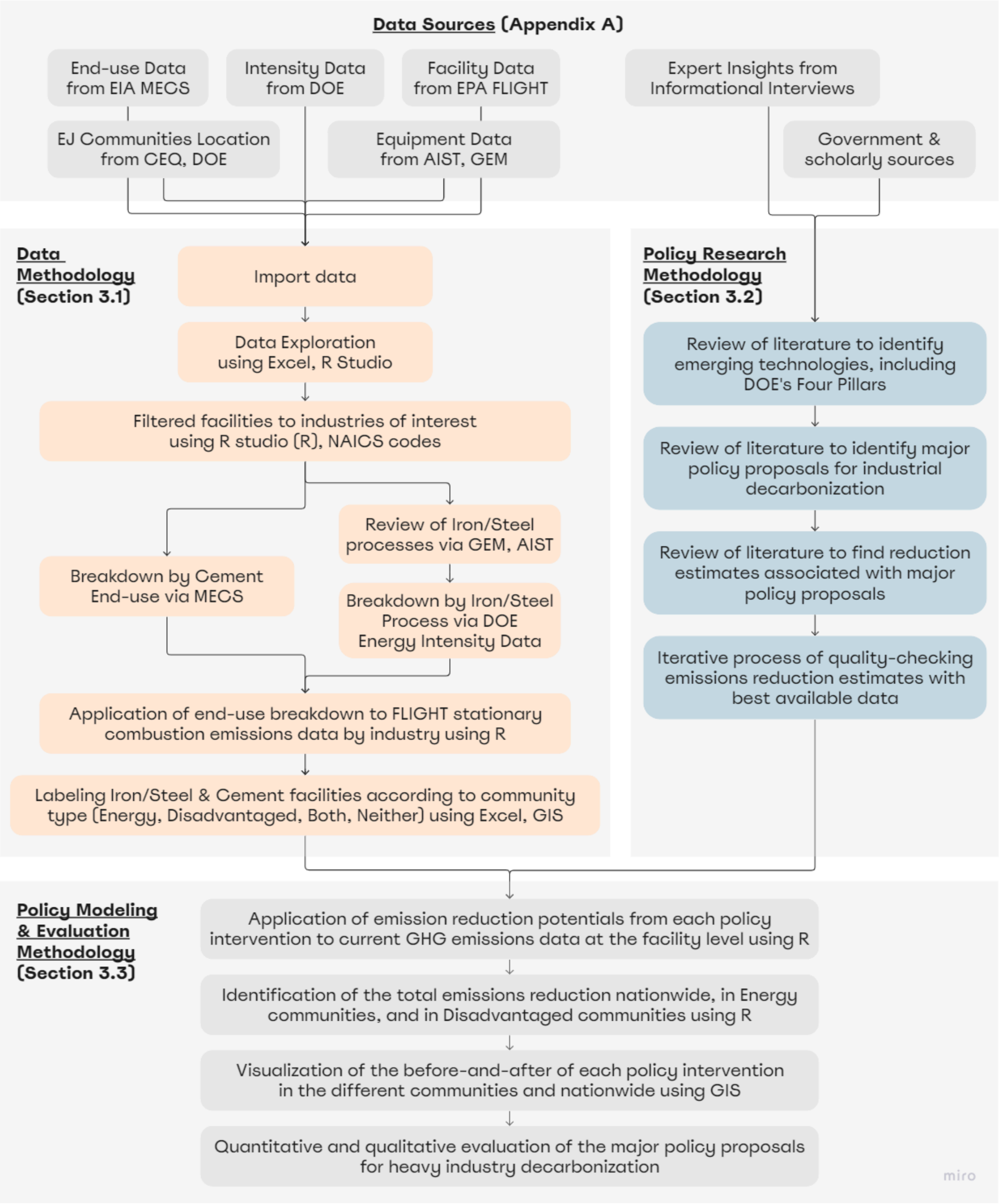

Figure 1. Methodology Overview. This figure provides a high-level overview of our project methodology. Various data sources (shown at the top of the figure) were used in our data (**orange**) and policy research (**blue**). These research pathways were the foundation of our policy modeling and evaluation, which produced a comprehensive look at how current policy proposals can advance heavy industry decarbonization today at the facility level.

3.1 Data Methodology

This section details the steps we took to produce a facility-level breakdown of annual fuel combustion emissions from Cement and Iron/Steel facilities according to end-use and process.

Note that this analysis is limited to Scope 1 (direct) carbon emissions only, with Scope 2 and 3 excluded. We have made no estimation or conducted modeling of non-carbon pollutants like SOx, NOx, and particulate matter — although these emissions are still considered in the Policy Evaluation part of our project (see Section 3.3.2). A reason for this is that Scope 1 emissions are reliably measured and reported in FLIGHT and other databases and do not require estimation through grid emission factors or other (especially in the case of Scope 3 emissions) still-developing methodologies.

3.1.1 Background on EPA GHGRP and FLIGHT database

The Facility Level Information on GreenHouse gasses Tool (FLIGHT), maintained by the Environmental Protection Agency (EPA), is a public database of large emitters, fuel and industrial gas suppliers, and CO_2 injection sites in the U.S (EPA, n.d.e; EPA, n.d.g). It includes all large industrial facilities, i.e. those emitting over 25,000 metric tons of CO_2e per year, which are required to report annually to the EPA through its Greenhouse Gas Reporting Program (GHGRP). GHGRP data is self-reported, yet verified by the EPA and is considered a reliable data source (EPA, n.d.e).

Over 40 different industry types report to the GHGRP (EPA, n.d.e). Of the 99 cement facilities in the U.S. and Puerto Rico, 90 of these are captured in FLIGHT (EPA, n.d.g; USGS Mineral Yearbook, 2024). Of the 120 Iron/Steel facilities in the dataset, all 9 Integrated Steel Mills (ISMs) using blast furnaces and basic oxygen furnace production pathway (BF-BOF) in the U.S. are included. Each facility reports its annual amounts of stationary combustion and process emissions, which sum to total emissions, in metric tons of CO_2e:

- Stationary combustion (Subpart C): Stationary emissions refer to any emissions produced from the combustion of fuel on site for a various number of end uses. The fuel sources can vary between industries. See Appendix D for a more detailed description of emissions that are covered under Subpart C.

- Process emissions (Subparts D-QQ): Process emissions result from chemical reactions taking place in the manufacturing process. The composition of these emissions is different for each industry. Every industry reporting to GHGRP is assigned a Subpart letter. For this project, we have used process emissions data for Cement (Subpart H) and Iron & Steel & Ferroalloy (Subpart Q).

In addition to emissions, the FLIGHT data has information on the name, address, city, state, and the geographical coordinates of each facility and the North American Industry Classification System (NAICS) code they classify themselves under (EPA, n.d.f; EPA, n.d.g).

3.1.2 Downloading FLIGHT data; data cleaning, filtering, and scoping

This analysis used the GHGRP's "Direct Emitters" facility-level Scope 1 data. GHGRP data is updated annually and available for download every October, and can be accessed via the EPA website. The specific data downloaded was the "2022 Data Summary Spreadsheets," a zipped file that contains files for all GHGRP data from the years 2010 to the present. This project used the 2022 file, the most recent dataset available (EPA, n.d.c).

In R Studio, we removed variables for the original dataset that were not relevant to our specific industries of interest, Iron/Steel and Cement. We removed variables for subparts D–QQ except for those relevant to iron/steel (subpart Q) or cement (subpart H). We then filtered the dataset using two different classifications: the Census Bureau's North American Industry Classification System (NAICS) code, and the EPA's GHGRP Industry Subpart letter. The discrepancies were minimal between the facilities captured in each classification. NAICS codes were also present in the MECS dataset, so we moved forward using NAICS code to filter the GHGRP dataset of all reporting industrial facilities into the ones relevant for our analysis.

3.1.3 Background on Energy Information Agency's Manufacturing Energy Consumption Survey (MECS) data

The end-uses that contribute to Subpart C stationary combustion emissions can be approximated by using industry average energy consumption data for major industrial end-use applications, tabulated in the Energy Information Agency's Manufacturing Energy Consumption Survey (MECS). MECS identifies 13 end-use categories, including Process Heating, Process Cooling, HVAC, and more (see Table 1 below). In addition to end use, the MECS data is also broken down by NAICS code and by fuel type in trillions of British thermal units (TBtu).

Table 1. List of end-uses defined in 2018 MECS data for Cement (DOE, 2018).

MECS End-Use Category	Description
Conventional Boiler Use	A boiler vessel that consumes fuels or electricity as the primary energy source to produce heat that generates steam or hot water.
CHP and/or Cogeneration Process	The production of electrical energy along with another form of useful energy (such as heat or steam) through the sequential use of energy.
Process Heating	The direct process end use in which energy is used to raise or maintain the temperature of substances involved in the manufacturing process

Process Cooling and Refrigeration	The direct process end use in which energy is used to lower the temperature of substances involved in the manufacturing process.
Machine Drive	The direct process end use in which thermal or electric energy is converted into mechanical energy and is used to power motor-driven systems, such as compressors, fans, pumps, and materials handling and processing equipment.
Electro-Chemical Processes	The direct process end use in which electricity is used to cause a chemical transformation (e.g., reduction of alumina to aluminum and oxygen)
Other Process Use	The direct process end use that includes energy used for other direct process uses not falling under a specified process end use category
Facility HVAC	The direct nonprocess end use that includes energy used to provide heating, ventilation, and air conditioning for building envelopes within the industrial plant boundary.
Facility Lighting	The direct nonprocess end use that includes energy used in equipment that illuminates buildings and other areas within the industrial plant boundary.
Other Facility Support	The direct nonprocess end use that includes energy used in diverse applications that are normally associated with office or building operations such as cooking, operation of office equipment, and the operation of elevators.
Onsite Transportation	The direct nonprocess end use that includes energy used in vehicles and transportation equipment that primarily consume energy within the boundaries of the establishment.
Conventional Electricity Generation	Consists of onsite electricity obtained from generators running on combustible energy sources including natural gas, fuel oils, and coal.
Other Nonprocess Use	The direct nonprocess end use that includes energy used for nonprocess uses other than the defined nonprocess energy categories.
End Use Not Reported	End-use is unknown.

MECS data is collected about every 5 years. Our project used data from the most recent survey year, 2018; due to the long replacement cycles of heavy industry equipment, we expect that each facility's energy consumption profile has not significantly changed since then.

3.1.4 Facility emissions breakdown by end-use

Using the FLIGHT data on stationary combustion emissions for each facility and the MECS data on average energy consumption by end-use for the Cement industry, we were able to estimate the CO_2e emissions produced from each end-use at each Cement facility. This allows us a better, albeit rough, understanding of the CO_2e emissions in this facility, the sources, and potential processes that could be targeted for reductions. This analysis was done in R Studio, and our code repository will be open-source and available online in the future

We used NAICS codes to match facilities in the FLIGHT database with the corresponding industry average end-use data from MECS. We then used fuel-specific emission factors from the DOE to convert the MECS energy consumption data in TBtu to carbon emissions in kg of CO_2e (DOE, 2018). We divided the emissions for each end-use by the total emissions for all end-uses, producing the percent of total emissions for each end-use (see Figures 1 and 2 below). These percentages were then applied to facility-level stationary combustion emissions (Subpart C). This step provided estimated end-use-level granularity on the sources of stationary combustion emissions at each facility.

The resulting dataset has each facility's total, stationary combustion, and process emissions (from the FLIGHT dataset) and the breakdown of the stationary combustion emissions by end-use categories. Each category in this breakdown correlates to specific end-uses or equipment in a facility. This breakdown is open source and available to the public in our online database.

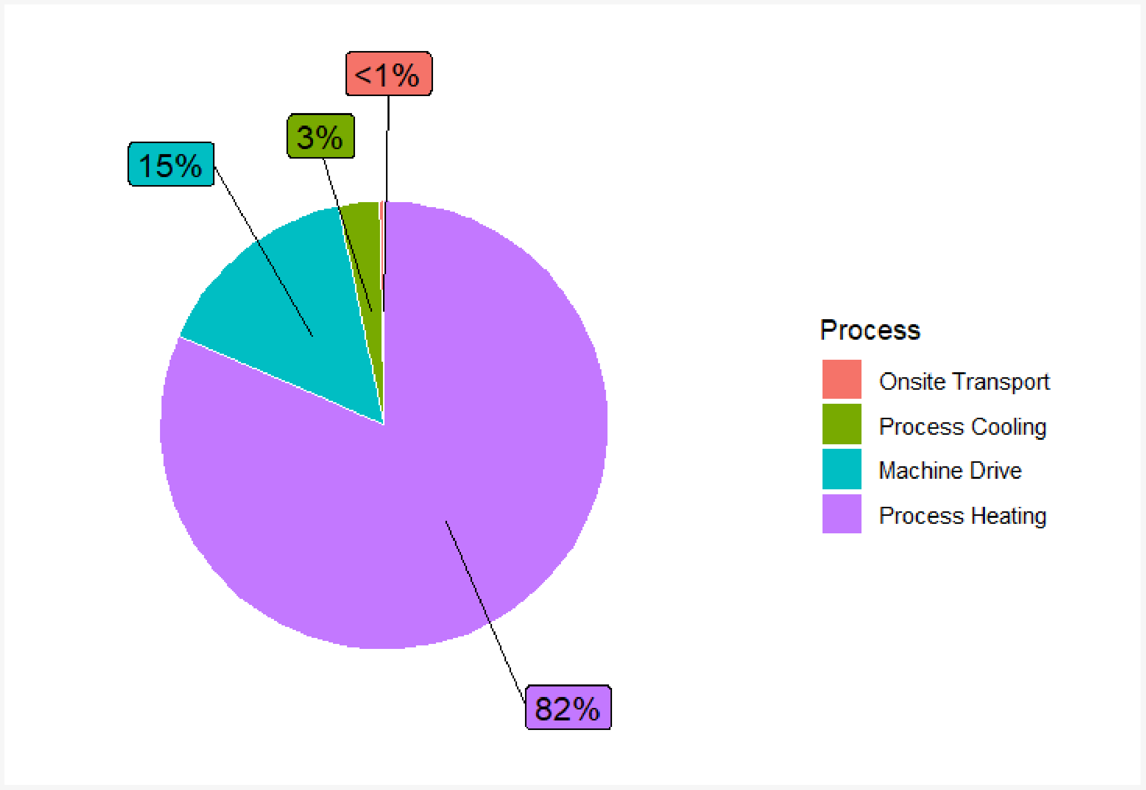

Figure 2. Pie chart showing breakdown of Cement emissions by MECS end-use. This includes stationary combustion emissions only.

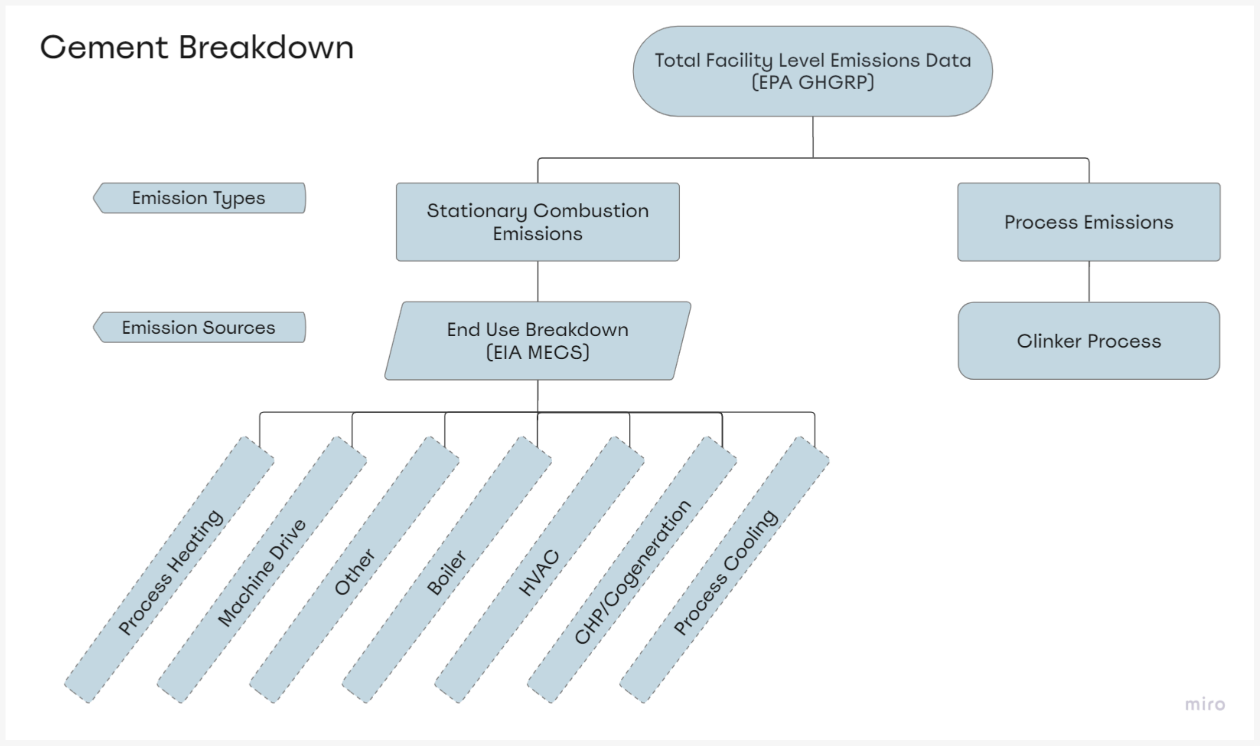

Figure 3. Diagram showing breakdown of Cement emissions by end-use (left side of diagram).

It is important to note that since we are relying on industry averages, this emissions breakdown by end-use may not be entirely accurate at the individual facility level. However, it gives us a way to reasonably analyze trends at the broader industry level.

This level of breakdown is suitable for industries with facilities that are fairly uniform and do not deviate much from the average energy consumption profile. In the case of the Cement industry, production is fairly standardized and there is not much variability in core production processes between facilities because nearly all combustible fuels are used for process heating, and the main process heating technology is the cement kiln. There are four variations of kilns used in the cement industry: long wet kilns, long dry kilns, kilns with a preheater, and kilns with a precalciner (EPA, 2010). While the variations in kiln type results in different kiln efficiencies and fuel mixes, there is hardly any variation in how plant energy consumption is spread among different process steps at the average U.S. cement facility. Knowing this level of detail would provide insight into potential efficiency improvements and biofuel blending, but would not change the percent of process emissions attributable to the kiln. For this reason, we do not vary our MECS breakdown of Cement facility emissions according to kiln type.

For industries with more complex and variable facilities — such as Iron/Steel — a different type of breakdown can be performed, which yields more clarity on the energy consumption of specific technologies, detailed in Section 3.1.5 below.

3.1.5 Energy intensity emissions breakdown by process

We were able to obtain a more detailed breakdown of Iron/Steel emissions through the use of facility-specific equipment data and energy intensity data. The use of facility-specific information, rather than an industry average, provided a more accurate breakdown of energy consumption by each process step in the overall steelmaking process (i.e. whether basic oxygen furnace [BOF], blast furnace [BF], electric arc furnace [EAF], vacuum degasser [VD], ladle metallurgy furnace [LMF], casting, rolling, etc. were present in a given facility).

We first obtained typical energy intensity values for steelmaking process steps (in 10^6 Btu per ton of steel) from a 2000 DOE report, shown in Table 2 below (DOE, 2000). The data energy intensity in TBtu was normalized to a ton of steel, allowing us to calculate the typical percent of the total energy that is consumed by each process present, assuming that every ton of steel passed through all processes present. This is an oversimplification of the steelmaking process, where in reality production lines are not always linear so steel may pass through only several unit processes. Actual energy consumption data by unit process from Iron/Steel facilities would be ideal, but this data either is not publicly available or does not exist because a facility doesn't report energy consumption to this level. Instead, the data from a DOE commissioned report was deemed sufficient for the purposes of this project. The energy consumption data from the study dates back to 2000, and given likely improvements in energy efficiency in the past twenty years, these are conservative estimates. However because most Iron/Steel process technologies have been mature for decades, these efficiency gains are expected to be relatively small. Still, an updated study would improve the accuracy of these energy consumption values and thus the emission reduction estimates made in this report.

Table 2. Iron/Steel production processes and their associated energy intensities per ton of steel produced. These figures are pulled from a 2000 DOE report on energy consumption by Iron/Steel facilities and show the typical energy intensity of Iron/Steel-making processes. Our team manually double-checked each facility to determine if it uses the Integrated Steelmaking or EAF-Based Steelmaking model, based on information from GEM (2023) and AIST (2023).

Process	Integrated Steelmaking (10^6 BTU/ton steel)	EAF-Based Steelmaking (10^6 BTU/ton steel)
Sintering	0.24	0
Cokemaking	3	0
Pulverized Coal Injection	0	0
Ironmaking	10.54	0
BOF Steelmaking	0.67	0
EAF Steelmaking	0	0.67

Vacuum Degassing and Ladle Metallurgy	0.3	0.1
Continuous Casting	0	0
Ingot Casting	1.21	0
Slab Mill	1.75	0
Hot Rolling (With Reheating)	1.5	0.65
Pickling (Hot Rolling)	0.4	0.36
Hot Dip Galvanneal	2	1
Tempering and Finishing (Hot Rolling)	0.1	0
Cold Rolling (With Cleaning/Annealing)	0.7	0
Tempering and Finishing (Cold Rolling)	0.2	0

Next, we used various data sources to determine which processes are present at each iron and steel facility in the FLIGHT dataset. Using Global Energy Monitor, Association of Iron and Steel Technology records (available for purchase), and website information, each Iron/Steel facility was marked with the equipment present at the facility (AIST, 2023; GEM, 2023). This process was done manually; due to discrepancies between the different data sources, our team had to double-check all information against historical records and company websites. We have sought to be as comprehensive as possible in identifying the equipment present at each facility; at the very least, we have successfully identified the major production pathways at each facility — whether they used a BF-BOF or EAF pathway.

As a simplifying assumption, and due to a lack of facility-level operations data, we assumed that each tonne of steel produced at a given Iron/Steel facility would pass through each equipment type present in that facility. This enabled us to estimate a fuel consumption breakdown for each part of the process according to the DOE energy intensity values in Table 2 above, normalized for one tonne of steel. Note that the DOE's original table included a range of energy intensity values; we have used the average value for each range in our analysis. This normalization enabled us to derive percentages of emissions that come from each part of the process at each facility. These percentages were applied to total CO_2e emissions reported for each facility in FLIGHT, similar to the MECS application to combustion emissions detailed in Section 3.1.4 above.

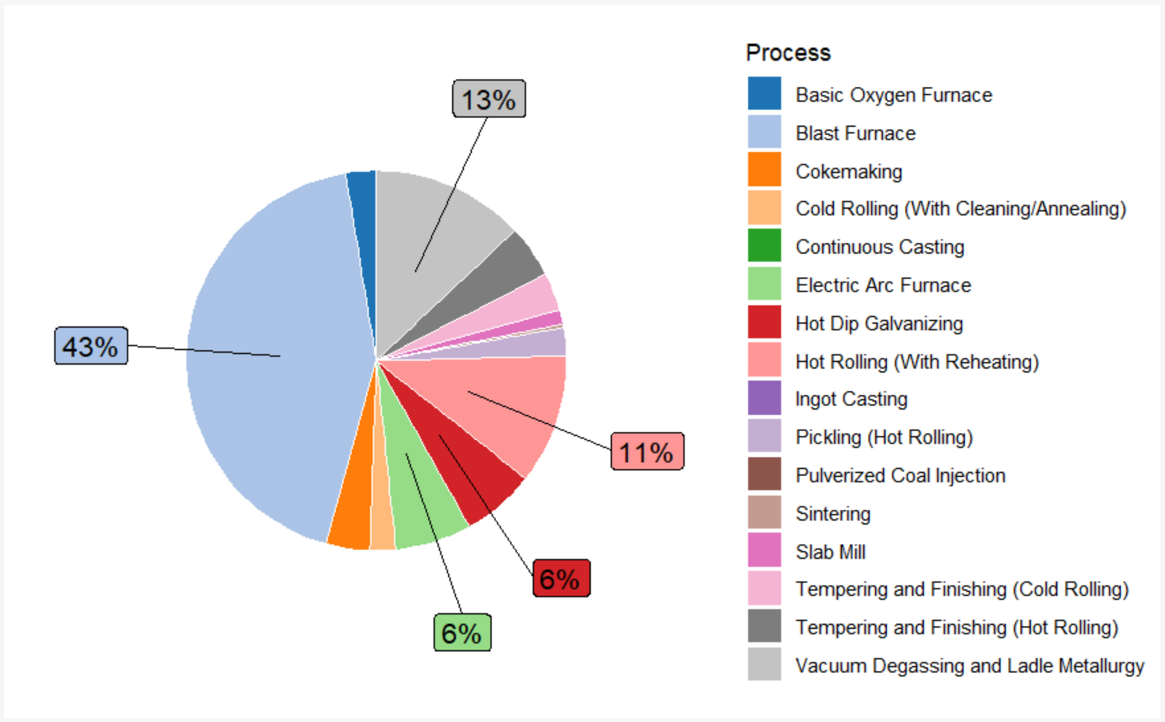

Figure 4. Pie chart showing breakdown of Iron/Steel emissions by process. This includes stationary combustion emissions only. Only process percentages above 5% are labeled.

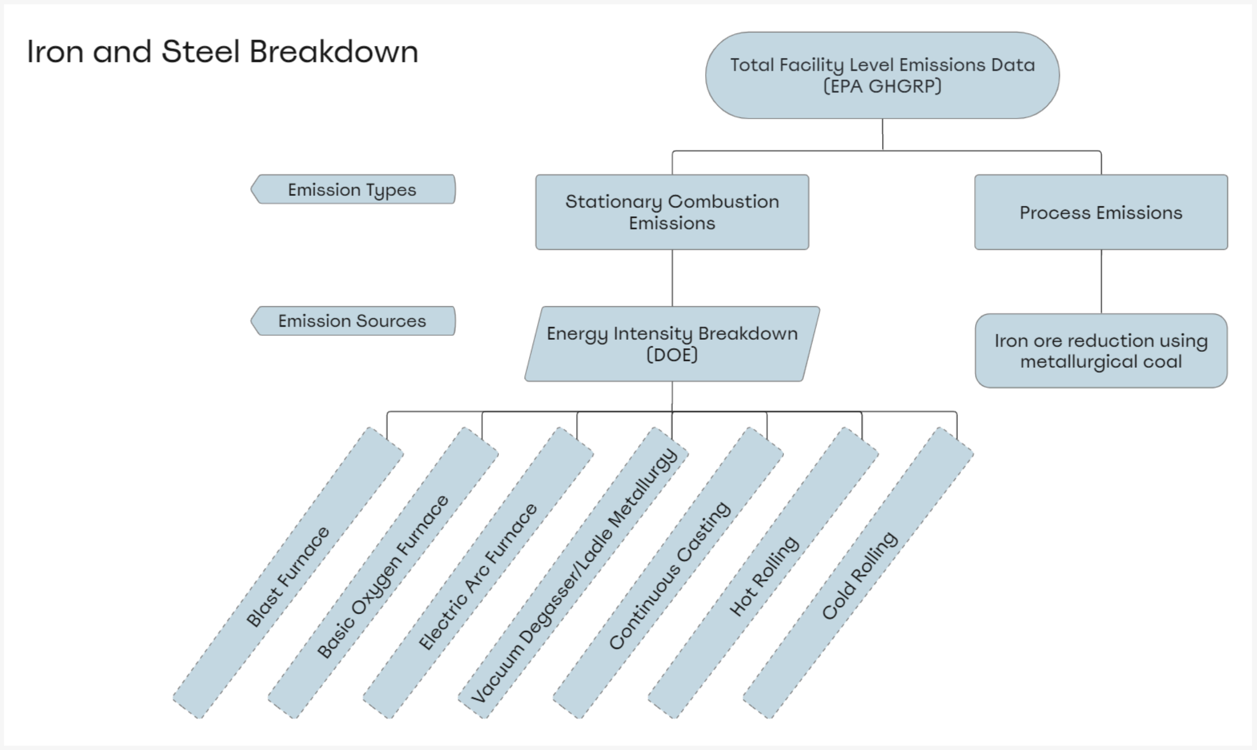

Figure 5. Diagram showing breakdown of Iron/Steel emissions by process (left side of diagram).

By applying the percentages to the FLIGHT data in this way, we estimated a detailed, facility-level emissions breakdown of total GHG emissions according to various Iron/Steel in-plant processes. This provided further insight into which processes are most responsible for emissions from this industry. For example, despite being present at only 10 out of 116 facilities, the blast furnace was responsible for over a third of the total emissions.

3.1.6 Identification of facilities within Energy or Disadvantaged Communities

For the following, we will be addressing EJ communities, specifically federally-designated Disadvantaged Communities and Energy Communities. As explained in our Background section, current federal legislation offers funding and tax incentives for decarbonization projects in these community types. Using these community designations will help us understand the distribution of marginalized populations in relation to industrial facilities and illuminate opportunities for federal funding to reduce emissions.

We used QGIS, a Geographic Information System (GIS) software, to map our Iron/Steel and Cement facilities based on the latitude and longitude coordinates included in the FLIGHT dataset. We then created two additional layers: (1) a map of census tracts designated as Energy Communities under IRA §48C and other federal legislation and (2) a map of census tracts designated as Disadvantaged Communities by the Council for Environmental Quality (CEQ). Layer 1 is maintained by the DOE and downloaded from the National Energy Technology Laboratory website (EDX, n.d). Layer 2 is maintained by the CEQ and downloaded from the Climate and Environmental Justice Screening Tool (CEJST) (CEQ, n.d.). Note that CEJST partly utilizes data from EPA's EJScreen tool, which uses assumed, instead of measured, values for some census tracts. This is a data limitation of our project. However, given that this data set is being used across federal agencies seeking to implement Justice40 goals, we consider our approach at least aligned with leading efforts in this space.

We displayed all three layers on QGIS and used the "Extract by location" tool to isolate Iron/Steel and Cement facilities located *only* within Energy Communities or Disadvantaged Communities. Our team then manually edited our spreadsheet of facilities to label each facility as within an Energy Community, a Disadvantaged Community, or both.

We then used the edited spreadsheet to create maps of the FLIGHT facilities in R Studio (see Figures 6–7 below). These maps show the geographical location of Cement and Iron/Steel facilities in FLIGHT with their associated emissions, color-coded according to whether they are located in an Energy Community, Disadvantaged Community, both, or neither.

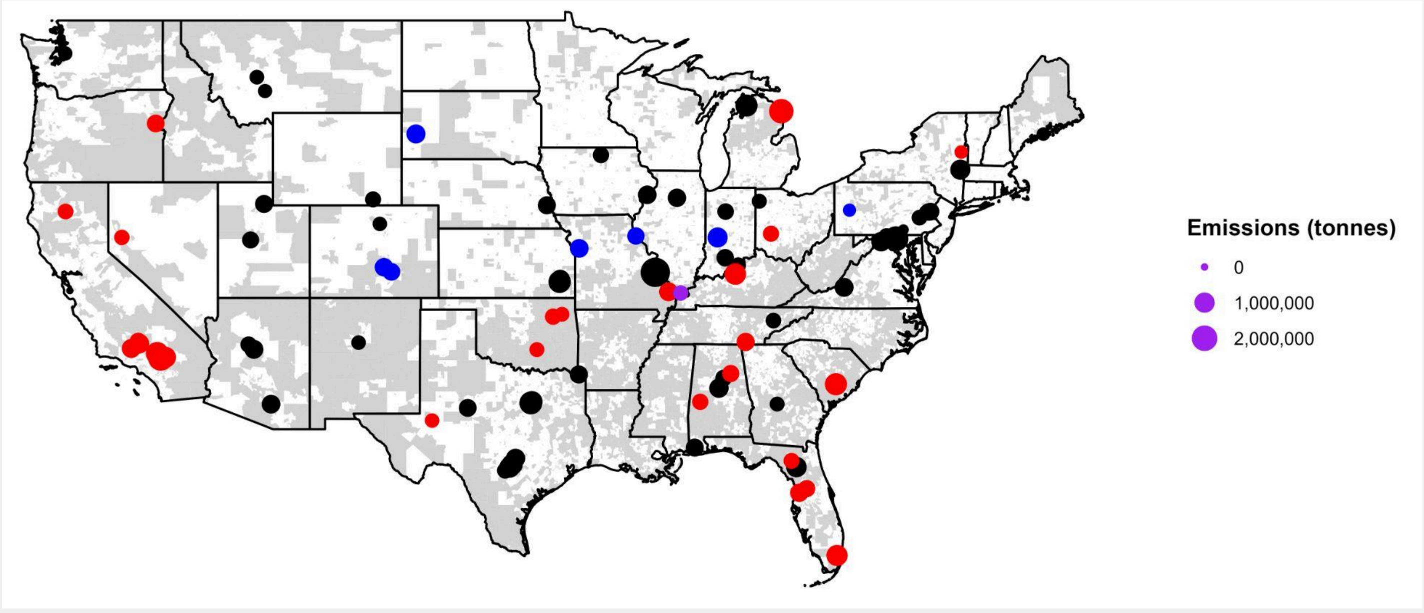

Figure 6. Map of Cement facilities and associated annual emissions in the absence of policy intervention. The location of each dot corresponds to the facility's geographic location, while the size of the dot indicates the size of its emissions ("orig_total" refers to emissions prior to policy intervention, in units of kg CO_2e). The color of the dot indicates whether the facility is located in an Energy Community (**blue**), Disadvantaged Community (**red**), both (**purple**), or neither (**black**). Energy and Disadvantaged Communities are mapped in **light gray**. Note that there is only one facility located in both an Energy and Disadvantaged Community.

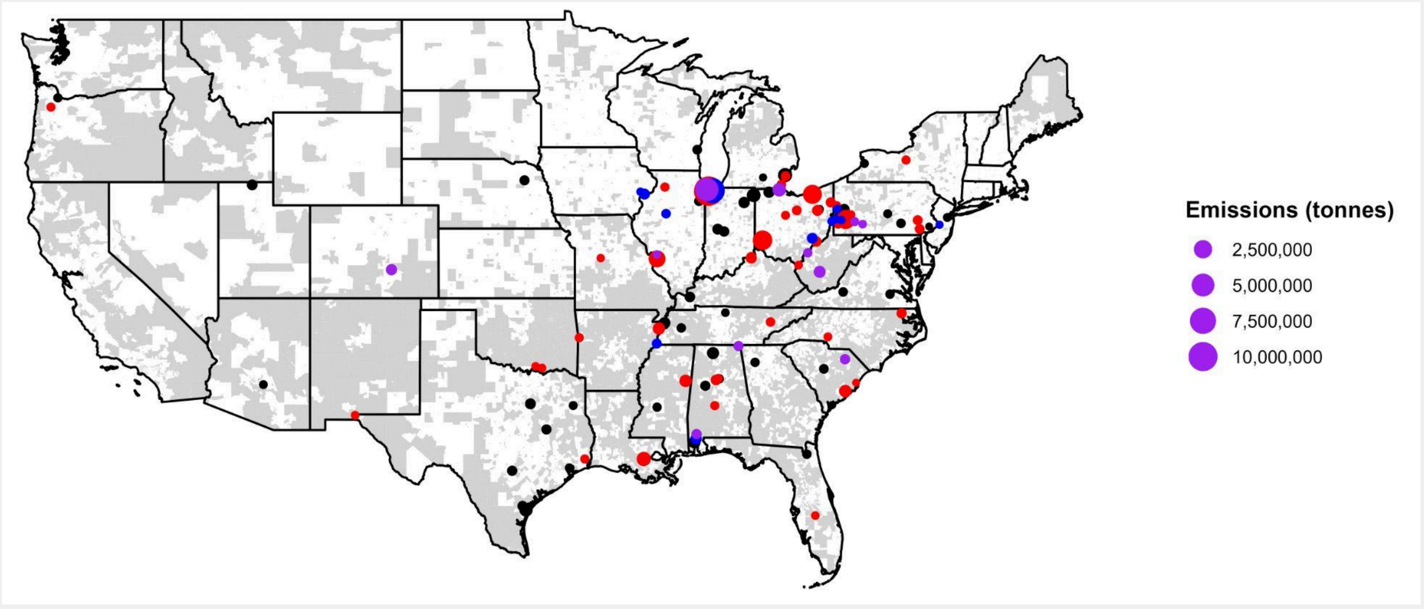

Figure 7. Map of Iron/Steel facilities and associated annual emissions in the absence of policy intervention, similar to Figure 6 for Cement facilities above. The color of the dot indicates whether the facility is located in an Energy Community (**blue**), Disadvantaged Community (**red**), both (**purple**), or neither (**black**). Energy and Disadvantaged Communities are mapped in **light gray**. Note how facilities are clustered in the midwest, a traditional corridor of heavy industry and especially Iron/Steel production.

3.2 Policy Research Methodology

To identify and categorize the current state of industrial decarbonization and related policies in the U.S., we conducted a literature review and a series of informational interviews. Interviews were conducted with industry professionals and experts in the fields of energy policy, heavy industry, and environmental nonprofit organizations. Interviewees included experts from the Lawrence Berkeley National Laboratory, the American Council for an Energy-Efficient Economy (ACEEE), Global Energy Monitor (GEM), Global Efficiency Intelligence, Energy Innovation LLC, and BlueGreen Alliance. Each correspondent was asked a series of questions relating to their expertise. Due to the varying professions that each interviewee holds, our team's questions were tailored to each interview to obtain different perspectives across the field of industrial decarbonization. A list of sample questions from these interviews is included in Appendix E.

The information gleaned from these interviews was used to determine our project scope (in terms of key industries and major policy proposals) and methodology (especially in determining availability of data inputs) and also served as starting points for our literature review. Interviewees have many times directed us towards pieces of literature that are widely recognized in their respective fields and provided critique or verification of the insights we have found out ourselves before meeting with each one. We began our literature review by identifying existing policies that are advancing decarbonization within the country. Our research is focused on federal policies and environmental regulations to tie together our goal of identifying emissions hotspots and addressing climate change impacts on EJ communities nationwide. Our focus remains on federal action as requested by our client as well as the limiting scope and timeline that is allowed for a 1-year project. The federal government has proposed and adopted several promising policies to address the decarbonization of heavy industry. Online literature often points towards industrial decarbonization funding opportunities found within the IRA and BIL.

The following list of policy recommendations has been compiled from the DOE and other scholarly references, such as ACEEE, International Energy Agency (IEA), Columbia University, and the Rocky Mountain Institute (RMI) to provide our research with a comprehensive understanding of policy implications and potential impacts. Note that not all possible policy proposals are included — although we have tried to be as inclusive as possible and to evaluate at least the most widely recommended policy proposals today. Using the suite of policy proposals listed below, our team created a data-driven approach to evaluating the industrial decarbonization policies summarized in Section 3.2.1, explained further in Section 3.3.

3.2.1 Existing Federal Policies

The policies in this category are already implemented — or partially implemented — at the federal level, with the possibility of further expansion. This suite of policies has been curated by reconciling the interests of our client with the industry insights gained from our informational interviews.

A. Research and development (R&D) of emerging technologies

The federal government distributes funding through grants, tax incentives, and subsidies to support the research and development of emerging technologies like CCS, hydrogen, and energy efficiency improvement.

The IRA and BIL have set up funding support through the DOE Office of Clean Energy Demonstrations (OCED)'s Industrial Demonstration Program (IDP) (DOE, 2023a). The IDP program has allocated approximately $6 billion in funding opportunities for projects focused on technological or operational efficiency. These projects must demonstrate feasibility and scalability while aligning with "industrial decarbonization and emission reduction goals" and mitigating impacts on surrounding communities.

a. Increased federal funding to deploy CCS

The IRA Section 45Q Tax Credit awards up to $85 per ton of CO_2 stored, subject to qualified projects commencing construction by the end of 2034. The §45Q tax credit permits the taxpayer to receive the credit for 12 years following the commencement of a project's operation. This provides funds towards the adoption and deployment of CCS. (DOE, 2023a)

b. Increased federal funding to deploy hydrogen technologies

The IRA Section 45V Tax Credit provides incentives of up to $3 per kilogram of hydrogen generated by eligible facilities (DOE, 2023a). This credit is applicable for 10 years following the commencement of a project's operation, provided that the facility maintains a well-to-gate GHG emissions intensity below 0.45 kilograms per kilogram of hydrogen (kg CO_2e/kg H_2). As an application, a study on the Iron/Steel industry shows that hydrogen can act as an auxiliary reducing agent for blast furnaces in place of the necessity of coal or coke (Fan, et al., 2021).

c. Increased federal funding to support R&D for material and energy efficiency

Material and energy efficiency refers to improving systems within each industry through the deployment of breakthrough technologies, which include innovative chemistry solutions. For the Cement industry in particular, clinker is a big contributor to GHG emissions. According to multiple bodies of research, clinker substitution could abate about a quarter of emissions if deployed aggressively by 2030 (DOE, 2023b). Replacing clinker with supplementary cementitious materials (SCMs) could significantly reduce energy intensity per tonne of cement produced (Shah, et al., 2022).

d. Increased federal funding to support advanced energy projects

The IRA Section 48C Tax Credit provides $10 billion for the development of advanced energy projects, of which at least $4 billion must be allocated to federally defined Energy Communities. Qualifying projects include those which re-equip, expand, or establish an industrial facility for the production or recycling of clean energy equipment; those which re-equip industrial facilities with equipment designed to reduce GHGs by at least 20%; and those that re-equip, expand, or establish an industrial facility for the processing, refining, or recycling of critical materials (The White House, 2023a). This tax credit is particularly important to accelerate the transition to EAFs for plants which still have BF-BOF equipment in operation.

B. Buy Clean (Low embodied carbon, clean chemicals, etc.)

The federal government promotes the prioritization of U.S.-made, lower-carbon construction materials in federal procurement and federally-funded projects. The Buy Clean initiative incentivizes the selection of materials with reduced carbon emissions, aiming to enhance sustainability and lessen the environmental impact of federal infrastructure endeavors. By establishing firm limits and requiring the government to purchase low-carbon building materials from compliant suppliers, the program seeks to stimulate the adoption of cleaner manufacturing practices within the construction industry. The Buy Clean Task Force (BCTF) incentivizes American producers to adhere to these standards through grants, tax incentives, and subsidies. Additionally, IRA Section 60503 allocates $2.15 billion to the U.S. General Services Administration (GSA) for the acquisition and installation of construction materials and products with significantly lower levels of embodied greenhouse gas emissions compared to industry averages, as determined by the Administrator of the EPA (DOE, 2023a).

3.2.2 Technological Policy Proposals

These policies have been proposed but not broadly implemented. These noticeably take inspiration from the DOE’s Four Pillars report as major technological avenues for heavy industry decarbonization (DOE, 2022). Similar to the previous category, this suite of policies has been curated by reconciling the interests of our client with the industry insights gained from our informational interviews.

C. *Federal standards on industrial emissions*

Under standards-based policies, the federal government would implement emissions caps for Iron/Steel and Cement facilities. This could be in the form of facility emissions limits, enforcement, and monitoring. California's cap-and-trade system is an example of such. California and Washington are states in the U.S. with a cap-and-trade system for industry, and has provided many environmental benefits (CCES, n.d.). While it leaves room for improvement concerning environmental justice, the state policy has made strides in reducing overall emissions and has been a vital step for California to meet its reduction goals (Holliman & Collins, 2023). When administered, facilities must self-report their emissions and be subject to yearly inspections by the EPA under the Clean Air Act (CAA) or the Office of Enforcement and Compliance Assurance (OECA). Exceeding emissions limits would subject a plant to purchase more emissions credits on the open market to compensate for the emissions in excess of their allowances.

D. *Incentives for low-carbon energy adoption*

Efforts to promote material recycling and circularity in industrial processes can be significantly enhanced through strategic infrastructure development and regulatory measures.

a. Circularity and recyclability of steel scrap

To enhance the circularity and recyclability of steel scrap, targeted measures can be implemented to incentivize procurement practices favoring recycled steel. By encouraging the use of recycled steel in procurement processes, industries can contribute to reducing the demand for virgin steel production and promote a more sustainable supply chain.

3.2.3 Social Policy Proposals

To address our concerns with the impacts that decarbonization policy may have on gaps in environmental justice, it is important to consider policy structures that could help attenuate inequities. This also aligns with the current administration's goal to improve on environmental justice, and cushion the adverse impacts on disadvantaged populations that are disproportionately affected by the operations of the heavy industry.

E. *Environmental Justice*

a. Funding for EJ communities

Targeted grants should be allocated specifically for decarbonization efforts within federally designated Energy and Disadvantaged communities. These grants would aim to address the disproportionate environmental burdens faced by EJ communities and support initiatives that mitigate emissions, improve air quality, and promote sustainable development in these areas. By directing funding towards decarbonization projects tailored to the needs of EJ communities, policymakers can ensure equitable access to clean energy solutions and advance environmental justice objectives.

b. Just Transition

Incorporating Just Transition principles into our top policy recommendations is essential for ensuring equitable outcomes in the transition to a low-carbon economy. This includes prioritizing grid decarbonization initiatives in EJ communities, where the impacts of environmental pollution and climate change are often most acutely felt. Additionally, measures must be implemented to assure proper job distribution and provide comprehensive training programs that equip residents of EJ communities with the skills and opportunities needed to participate in and benefit from the transition to cleaner energy sources. By centering justice and equity in our policy recommendations, we can foster inclusive economic development and empower communities disproportionately affected by environmental injustices.

3.3 Policy Modeling & Evaluation Methodology

The final part of our methodology was a quantitative and qualitative evaluation of the policies considered in our project, as listed in the previous section. This evaluation was based on the outputs of our methodology thus far, which were:

- A spreadsheet of Iron/Steel and Cement production facilities reporting in FLIGHT in 2022, including whether they were located in a designated Energy Community or Disadvantaged Community and a breakdown of their annual GHG emissions by end-use (based on the MECS data) and by process (for Iron/Steel facilities only, based on DOE emissions intensity estimates); and
- A list of potential federal policies addressing major gaps in current decarbonization efforts, including their GHG reduction potential, based on the literature review.

3.3.1 Quantitative Analysis

We combined our resources so far to perform a **quantitative** evaluation of each policy based on potential for GHG reductions in three regions: (1) Nationwide, (2) Energy Communities, and (3) Disadvantaged Communities. The methodology for each region was similar, as detailed below:

A. Gathering Reduction Estimates

For each policy, we performed a literature review to understand how — and by how much — the policy could reduce GHG emissions at Iron/Steel or Cement production facilities. Reduction estimates were compiled from the DOE and similarly reputable references like IEA, RMI, and Columbia University, as documented in Appendix B. Our group has done extensive research to gather as much information on emissions reduction estimates as possible. These reduction estimates could apply to the entire facility or only to a certain end-use or process within a facility. For example, the implementation of CCUS in integrated steel plants was associated with a 90% reduction in emissions from the BOF (DOE, 2023a). It is important to note that since reduction estimates come from a variety of sources, their estimation methodology may differ. For this reason, our team ensured that we were pulling information primarily from reputable sources, including government publications and peer-reviewed research. We consider these to be the best available data on emissions reductions resulting from policy implementation.

Reduction estimates were compiled into two Excel spreadsheets labeled "policy_list_steel.xlsx" and "policy_list_cement.xlsx" (Policy Lists). In each spreadsheet, each policy had its own row, and reduction estimates were organized into columns that mirrored our FLIGHT emissions breakdown, with a column for total emissions, for each end-use in Cement facilities, and for each process in Iron/Steel facilities. Reduction estimates were entered as the fraction of the emissions that would remain in that category if the policy were implemented. For instance, a 90% reduction in BOF emissions was entered into the "bof_steelmaking" column as 1 – 0.9 (or, 0.1). Where no emissions reduction was anticipated for an emissions category (or no estimate was available), we entered a 1, signifying a 0% reduction. See Appendix B for a list of all reduction estimates used in our methodology.

Each intervention was evaluated across its potential for reduction in the short term (~2030) and the long term (~2050). We assumed that some interventions would be more applicable in the short term, such as energy efficiency for currently available technology, while others were only significant in the long term, such as the adoption of emerging low-carbon technology. These cases are outlined clearly in Section 4 under the Implementation Timeline section of each policy and also summarized below in Table 3. For some cases outlined in Section 4, we adapted long term interventions into our short term model by choosing priority facilities to which to apply reduction estimates, modeling a partial adoption of this intervention. For these scenarios the priority facilities were chosen based on their CO_2e emissions and status of being located in an EJ community. Top 5 highest emitting facilities located in a Disadvantaged and/or Energy community were prioritized.

Table 3. Special case implementations. This table summarizes some "special case" policies for which we had to modify our methodology, which normally would have applied the policy's reduction estimates to all facilities. In these cases, the policies would only to select facilities in the short term, and then generally to all facilities in the long term. The selected facilities have high emissions and are located in Energy or Disadvantaged communities, and thus have been selected in order to maximize the modeled environmental, social, and economic benefit.

<u>Cement</u>	**Special Case Interventions**	● ccs_cement - Short term, CCS on process heat emissions of priority plants ● h2_cement - Short term, H2 used as a fuel mix for priority plants
	Priority Facilities	● Apple Valley, CA (Facility ID: 1002308) – #2 in CO_2e, YES in Disadvantaged ● Alpina, MI (Facility ID: 1005874) – #5 in CO_2e, YES in Disadvantaged ● Oro Grande, CA (Facility ID: 1007927) – #7 in CO_2e, YES in Disadvantaged ● Holly Hill, SC (Facility ID: 1006815) – #10 in CO_2e, YES in Disadvantaged ● Louisville, KY (Facility ID: 1007997) – #11 in CO_2e, YES in Disadvantaged
<u>Iron/Steel</u>	**Special Case Interventions**	● ccs_steel - Short term, CCS on BF-BOF emissions of priority plants ● h2blend_steel - Short term, H2 used as a fuel mix in BF of priority plants
	Priority Facilities	● Gary, IN (Facility ID: 1000418) – #1 CO_2e emissions, YES in disadvantaged (GEM: BF-BOF)[1] ● Burns Harbor, IN (Facility ID: 1003962) – #2 CO_2e, YES in energy (GEM: BF-BOF)[1] ● East Chicago, IN (Facility ID: 1000156) – #3 in CO_2e emissions, YES in both (GEM: BF-BOF)[1] ● Middletown, OH (Facility ID: 1000274) – #4 in CO_2e, YES in dis (GEM: BF-BOF)[1] ● Braddock, PA (Facility ID: 1000233) – #5 in CO_2e, YES in dis (GEM: BF-BOF)[1]

We prioritized facilities by CO_2e emissions and their label as an EJ community, because we recognize the need to address historical and present day environmental injustices in these communities due to their disproportionate exposure to pollutants from industry. This method of prioritization could be based on many other factors, and we recommend a more robust evaluation to improve future research. Exploration into local facility conditions that would support successful deployment could evaluate variables such as geological feasibility of carbon capture and storage, regional availability of

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[1] GEM, 2023.

infrastructure for emerging technologies, facilities' currently installed technologies, and facilities owned by corporations with net-zero carbon goals.

Some policies did not have any associated reduction estimates. This was the case, especially for technology- and industry-neutral programs supporting a Just Transition. These policies were excluded from the quantitative analysis and instead evaluated only through qualitative analysis, explained in Section 3.3.2 below.

B. Modeling Policy Implementation

Based on our reduction estimates, we created a model of each policy in R Studio. As explained above, for each policy, the Policy Lists contained one row with the policy name and reduction estimates according to the MECS and DOE breakdowns. These reduction estimates were applied to each facility in the FLIGHT spreadsheet, such that each reduction value (e.g., bof_steelmaking: 0.1) was multiplied by its corresponding emissions value (bof_steelmaking: 10,000) to obtain the emissions that would result if the policy were implemented (0.1 * 10,000 = 1,000) in tonnes CO_2e. This resulted in output emissions after policy intervention (E_{output}) for each <u>individual facility</u> as calculated below, across all n categories of end-use/process:

$$E_{output} = \sum_{i=1}^{n} \left(E_i \times r_i\right)$$

n : Number of end-use/process categories (differs for Iron/Steel vs. Cement)

E_i : Emissions value before policy intervention

r_i : Remaining emissions after policy intervention

This operation was performed for each of the 16 policies in the Policy Lists, producing 16 separate spreadsheets that each modeled a single policy for all facilities. These results were then combined into a master spreadsheet, containing the full output of our policy modeling. Our summary table can be viewed in Appendix C.

One key assumption in this part of our analysis is that reduction values r_i (as represented in the equation above) apply instantaneously and uniformly to emissions values E_i. For example, if CCUS were implemented, all facilities with BOF emissions would experience an instantaneous, uniform 90% reduction in BOF emissions (DOE, 2023a). For those facilities, there would be no variation in this *percentage* reduction or implementation timeline. However, there would be variation in the *mass* reduction across facilities: Since different plants will have different emissions quantities before the intervention, the total emissions reductions (in metric tons) attributable to that intervention will differ by plant, too. This assumption is not realistic, considering the variability in model, age, and capacity of steelmaking facility equipment (Gangotra et al., 2023a). It also produces an ambitious result, glossing over a potentially slow and incremental adoption timeline for CCUS technology. However, we think this methodology is still valuable in demonstrating a best-case scenario for CCUS implementation supported by federal policy. It previews the ambitious reductions that would be achievable through a broadly implemented CCUS program.

C. Defining Community Types & Aggregating Results

Using RStudio, we created two more versions of the master spreadsheet, one including only facilities located in Energy Communities (filtered with *Energy == "Y"*) and one including only facilities located in Disadvantaged Communities (filtered with *Disadvantaged == "Y"*). For each master spreadsheet (National, Energy, and Disadvantaged), we then aggregated total emissions across facilities within each policy model. Each master spreadsheet now displayed one row per policy, with a column for total resulting emissions in the relevant region. Our summary table can be viewed in Appendix C.

We separated the data into three master spreadsheets in order to better compare the performance of policies across regions. Iron/Steel and Cement facilities tend to cluster, creating distributional concerns that can be addressed by federal programs like the IRA's §48C tax credit (DOE, n.d.). By splitting the data this way, we hoped to highlight opportunities for regional interventions, as well as nationwide ones.

3.3.2 Qualitative Analysis

Our team additionally evaluated all policies through **qualitative** analysis, as explained below. We have sought to be as comprehensive as possible in collecting qualitative data so that the full impacts of the policy can be shown even in the absence of quantitative data. We believe that this approach provides substantial benefit to policymakers and advocacy organizations, who each have their own interests, priorities, and policy goals.

A. Identification of Qualitative Criteria

Early on in the project, our team worked with Evergreen Action to develop a list of criteria for policy evaluation. These formed the qualitative criteria — i.e., factors which are difficult to measure but important to consider in evaluating whether a policy would lead to positive change. The qualitative criteria formed the basis for our qualitative analysis, comprising the following factors in Table 4 below (listed in no particular order).

Table 4. List of qualitative criteria and a description of each category and how our team roughly measured each of the criteria.

Qualitative Criterion	Description & Approach
Ideal for federal action	Evaluates whether the policy can be accomplished through federal action, including through executive order or Acts of Congress. Examples include increasing federal funding for the development of carbon capture technologies or the creation of a multi-agency working group to study the impacts of hydrogen development on Energy Communities.[2] This was a critical criterion for our project and our primary filter for policies to include in our analysis. All policies evaluated in Section 4 (Results) are thus possible through federal government action.
Overcomes barriers to heavy industry decarbonization	Evaluates whether the policy directly addresses the three major barriers to heavy industry decarbonization, which are that (1) industrial processes require temperatures that are difficult to achieve without fossil-fuel combustion, (2) chemical reactions in key industrial processes may produce GHGs as a by-product, and (3) industrial process equipment is capital intensive and often has long lifespans, leading to long replacement cycles and slow stock turnover.[3]
Impact on other heavy industries	Evaluates whether the policy can also help to decarbonize other heavy industry sectors, including Chemicals and Aluminum. Our team was interested especially in potential impacts to the Chemicals sector, the 3rd highest-emitting heavy industry sector after Cement and Iron/Steel.[4] Policies ideally are sector-neutral, with application beyond Cement and Iron/Steel facilities. Our team has done our best to find evidence relevant to each policy's impact on other heavy industries. However, given time and resource constraints, we were not able to analyze this criterion in-depth for all policies. For this reason, not all policies in Section 4 (Results) have supporting data for this criterion.
Implementation timeline	Evaluates whether the policy can contribute to rapid decarbonization of the Cement and Iron/Steel sectors. Ideally, the policy would produce high GHG reductions in the short-term (by 2030).
Reduction to air/water pollution	Evaluates whether the policy reduces not only GHG emissions but also emissions of non-carbon pollutants, including SO_x, NO_x, and particulate matter. This can be direct (e.g., capture of non-carbon pollutants from the air) or indirect reduction (e.g., cutting down on fossil fuel combustion, which prevents the generation of the non-carbon pollutants in the first place). Our team was especially interested in policies that could reduce non-carbon pollutants in Energy and Disadvantaged Communities, considering the impact of such pollutants on marginalized communities in the U.S. today.[5]
Reduction to indirect GHG emissions	Evaluates whether the policy reduces not only Scope 1 (direct) emissions but also Scope 2 and 3 (indirect) emissions, either through a reduction in the purchase of fossil fuel energy or decarbonization of the upstream/downstream value chain. For instance, investment in green hydrogen technology (powered by renewable energy) could have significant Scope 2 and 3 impacts through the economy-wide reduction in reliance on fossil fuel energy sources.[6]
Labor, social & economic impacts	Evaluates whether the policy could have positive economic or social impacts in Energy and Disadvantaged Communities. Positive economic impacts include job creation,

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[2] CED, n.d.

[3] Gangotra, 2023a

[4] DOE, 2022

[5] ACEEE, 2023

[6] IEA, 2019

	support for local businesses, and creation of job training and education opportunities. Positive social impacts include improved health outcomes, reduction in health disparities between populations, and increased political engagement by local residents.
Political feasibility	Evaluates whether the policy has sufficient support among current federal policymakers to be adopted and implemented. Types of evidence our team looked for included: (1) whether the policy expands on an existing federal program, as opposed to introducing a new program; (2) whether the policy aligns with existing federal initiatives, including Justice40 or the EPA's Office of Just Transition[7]; and (3) whether the policy has received bipartisan support from policymakers, in the form of press releases, bill sponsorships, votes in favor, etc. Our team has done our best to find evidence relevant to each policy's political feasibility. However, given time and resource constraints — and the ever-shifting landscape of U.S. politics, heading into a presidential election year — we were not able to analyze this criterion in-depth for all policies. For this reason, not all policies in Section 4 (Results) have supporting data for this criterion.
Utilizes existing funding sources	Evaluates whether the policy is funded under federal law like the IRA, BIL, or other legislation in Energy and Disadvantaged Communities. For example, the BIL provides funding for emerging decarbonization technologies like carbon capture and hydrogen energy.[8] The existence of funding sources indicates that the policy could more easily be implemented in Energy and Disadvantaged Communities, magnifying its environmental, social, economic impacts in those areas.
Proven successful via domestic or international precedent	Evaluates whether the policy has been adopted at the state or municipal level in the U.S. or in other countries. The existence of a successful precedent demonstrates the policy's viability and provides helpful case studies for an equivalent federal program. In particular, our team looked at whether the policy had been implemented in California, historically a trend-setting region for U.S. environmental policy.[9]

B. *Qualitative Policy Research*

Our team conducted additional policy research based on these qualitative downselection criteria. For each policy, we researched its impacts on each of the qualitative downselection criteria and compiled this information into a spreadsheet. As with our initial policy research described above in Section 3.2, evidence was drawn from government records and resources (e.g., Congressional voting records, DOE publications, and White House press releases), scientific studies, and expert sources such as ACEEE, RMI, and our informational interviews. Although information was being drawn from different publications, our team has made sure to rely only on reputable sources.

This spreadsheet was combined with our quantitative results (see Section 3.3.1) to produce a final policy evaluation rubric.

3.3.3 Policy Evaluation

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[7] The White House, 2023a

[8] The White House, n.d.

[9] Baldassare, 2023

Both our quantitative research (see Section 3.3.1) and qualitative research (see Section 3.3.2) were combined into a new spreadsheet called the “Final Policy Evaluation Rubric.” This rubric listed all policies considered in our methodology, along with their potential impacts on Iron/Steel and Cement emissions, implementation timelines, and other criteria. This format enabled our team to compare and contrast each policy across all quantitative and qualitative categories. The results, presented in the next section, were sent to our client Evergreen Action for use in their policy research and advocacy efforts.

Our team has not attempted to rank policies according to the evidence compiled. While the purpose of this project is to identify top-performing policies for our client, we recognize that readers are likely to have different constituencies, policy interests, and goals. Thus we have presented a compilation, instead of a ranking, of policies below, so that our research can be utilized for a variety of policymaking contexts.

4. Results and Discussion

4.1 Estimated Emissions Savings

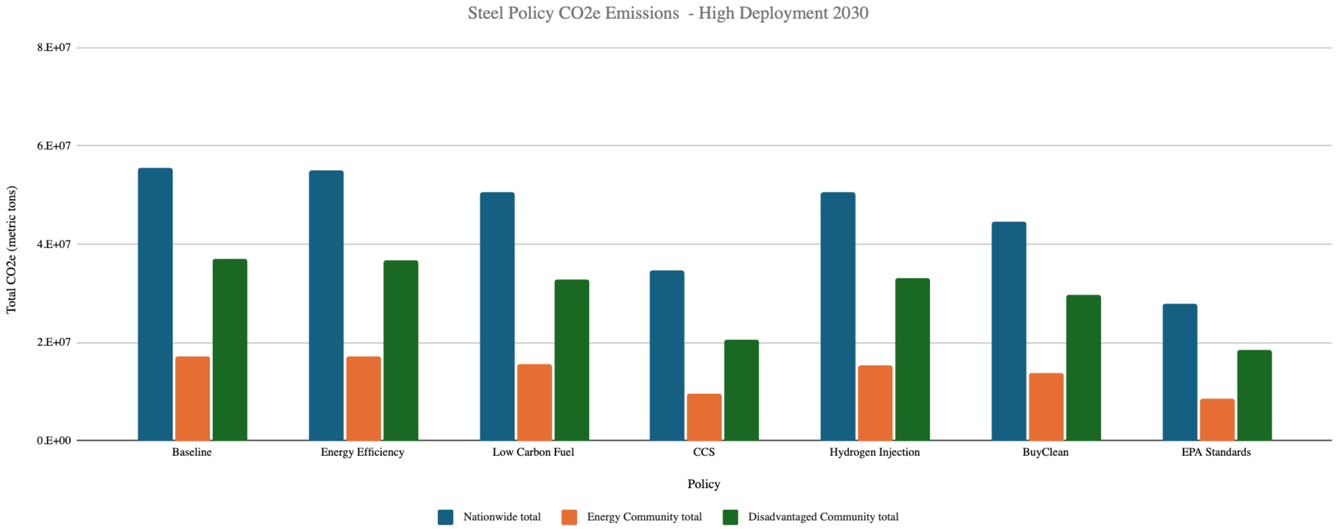

Figure 8 (above). Steel Policy CO_2 Emissions Savings — High Deployment Short Term (2030). In blue, the chart shows total CO_2e emissions nationwide that can be achieved if each policy is successfully deployed. In orange and green, resulting emission estimates are shown for Energy and Disadvantaged communities respectively. Each reduction is one specific intervention compared to the baseline of 2022 CO_2e emissions. EPA Standards achieve the highest reductions in the near term nationwide, in Energy communities, and in Disadvantaged communities.

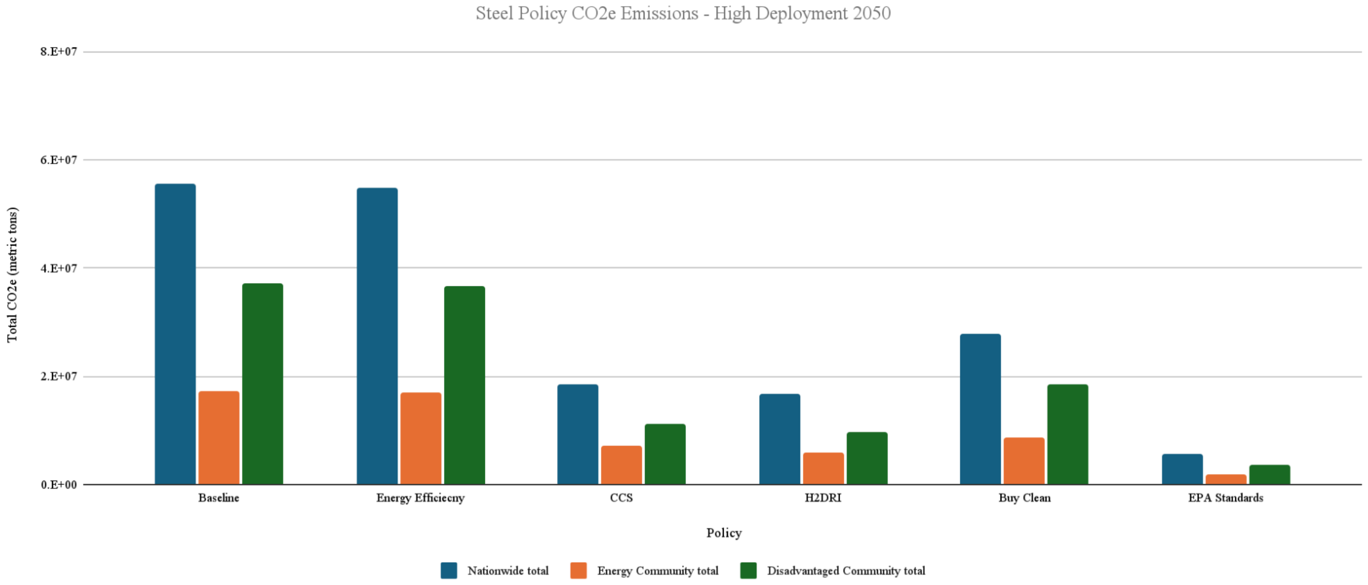

Figure 9 (above). Steel Policy CO_2 Emissions Savings — High Deployment Long Term (2050). In blue, the chart shows total CO_2e emissions nationwide that can be achieved if each policy is successfully deployed. In orange and green, the resulting emission estimates are shown for Energy and Disadvantaged communities, respectively. Each reduction is of one specific intervention compared to the baseline of 2022 CO_2e emissions. EPA Standards achieve the most reductions in the near term nationwide, in Energy communities, and in Disadvantaged communities.

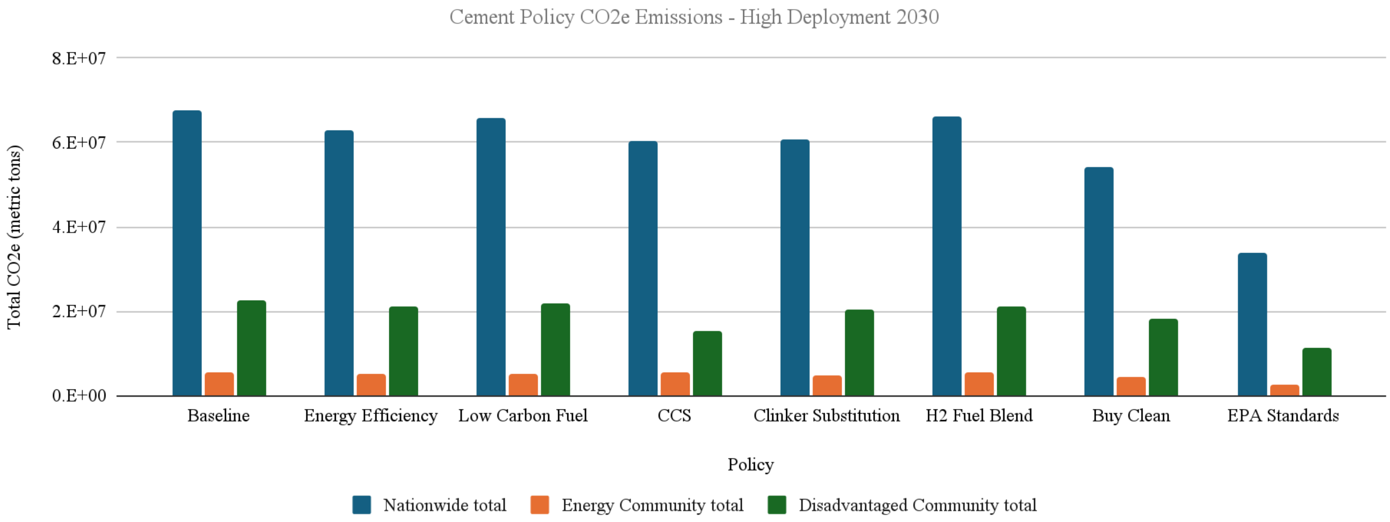

Figure 10 (above). Cement Policy CO_2 Emissions Savings — High Deployment Short Term (2030). In blue, the chart shows total CO_2e emissions nationwide that can be achieved if each policy is successfully deployed. In orange and green, the resulting emission estimates are shown for Energy and Disadvantaged communities, respectively. Each reduction is of one specific intervention compared to the baseline of 2022 CO_2e emissions. EPA Standards achieve the most reductions in the near term across the nation, in Energy communities, and in Disadvantaged communities.

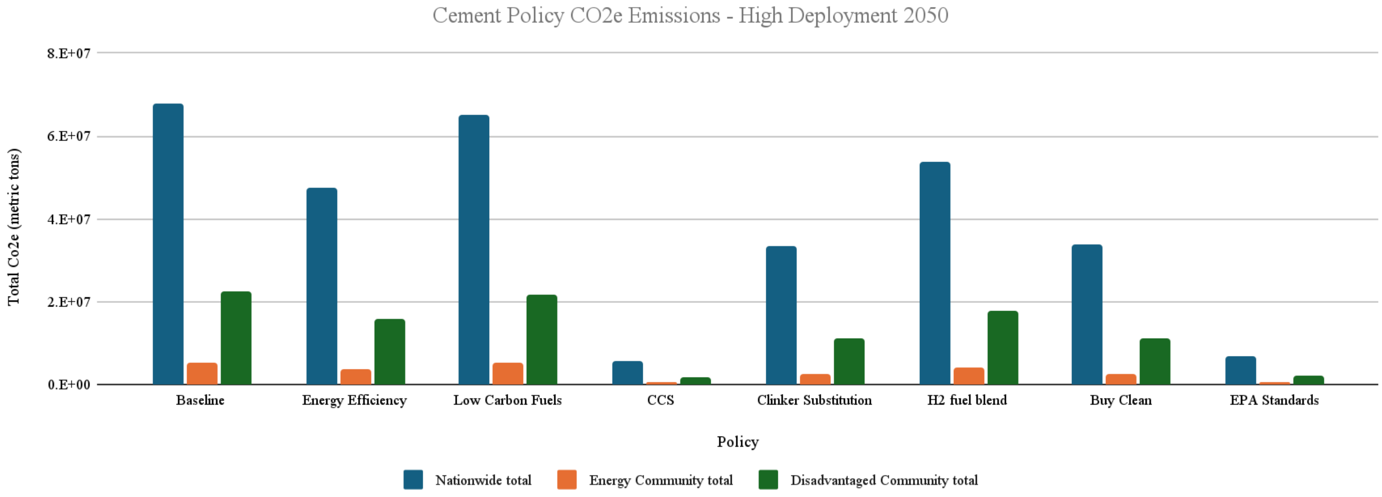

Figure 11 (above). Cement Policy CO_2 Emissions Savings — High Deployment Long Term (2050). In blue, the chart shows total CO_2e emissions nationwide that can be achieved if each policy is successfully deployed. In orange and green, the resulting emission estimates are shown for Energy and Disadvantaged communities, respectively. Each reduction is of one specific intervention compared to the baseline of 2022 CO_2e emissions. Carbon capture and storage achieves the most reductions nationwide, in Energy communities, and in Disadvantaged communities.

See the following section for a more detailed consideration of each policy that supports the interpretation of these results.

4.2 Technology and Policy Evaluation

In this section we analyze the critical low-carbon interventions for iron/steel and cement production listed above in Section 3. We recognize that no one solution exists, and therefore a broad portfolio of technological and policy solutions must be considered and deployed. In many cases, a combination of the following interventions will be necessary for full decarbonization. This said, our evaluation compares each intervention against a baseline of 2022 CO_2e emissions. In reality we anticipate that these interventions will happen in concert with one another and when deployed together can drive higher emission savings. Future research would use this methodology to estimate reductions at the facility level, nationwide, and in EJ communities, with a compilation of interventions. A facility-level evaluation of different factors that would enable successful deployment of interventions would also be useful to help facilities prioritize upgrades to invest in and policies to advocate for. As mentioned in Section 3.3.1.A, these factors could include the geological feasibility of CCS, the regional availability of infrastructure for emerging technologies, greater detail of facilities' equipment type, and facilities owned by corporations with net-zero carbon goals.

As described in Section 3, each intervention is evaluated across both quantitative and qualitative criteria wherever possible. Below, each intervention section contains a summary of the following qualitative discussion:

- The implementation timeline, considering technological and market readiness
- The impacts on non-carbon local pollution and air quality, through reducing PM 2.5, NO_x, SO_x
- What is the intervention's impact on local economies and the workforces surrounding these industries
- Is there funding already available through federal loans, grants, subsidies, and tax credits, and what is the need for more funding in order to successfully deploy this policy
- How effective are the working models, if any, in achieving the goals of the intervention? If technology-centric, how ready is this technology for deployment at scale

In addition, the following CO_2e emission impacts are quantified wherever possible, based on previous research providing reputable percent (%) CO_2e reduction potentials.

- Estimated GHG reductions nationwide, in Energy Communities, and in Disadvantaged Communities

The reduction impact of each intervention is evaluated across the short term, reflecting what could technically be feasible by ~2030, and the long term, reflecting the larger scale technological upgrades and advancements in facilities ~2050. In some cases the intervention is only applicable in the short term (e.g small retrofits). In other cases, the short-term scenario is a partial adoption of the technology by priority facilities across the US (e.g facilities that are high emitters in EJ communities). This is the case for interventions whose full successful deployment will take 10-20+ years to develop and scale. Each intervention scenario and assumption is detailed in the description section below.

4.2.1 Electrolytic Hydrogen in Steel Production

Description	Electrolytic hydrogen is used as a reducing agent, replacing the use of fossil fuels.
Implementation timeline	**Short term** - Retrofits are made to current BFs to use H2 as an auxiliary reducing agent to partly replace CO derived from pulverized coal, coke, and others. At optimal operating conditions, CO_2 emissions from the BF can be reduced by 21.4%..[10]
	Long term - Steel production replaces the current BF-BOF production with H2-DRI/HBI and EAF pathway. This pathway emits only 2.8% of CO_2, achieving a reduction of 97.2% from emissions across the BF-BOF pathway.[11]
Local Air Quality	Hydrogen produces only water vapor and no other gaseous byproducts when used as a reducing agent or fuel.[12] Using hydrogen instead of coal can mitigate the output of harmful air pollutants including NOx, SOx, and PM2.5, which are byproducts of fossil fuel combustion.[13] This technology has high potential to benefit local air quality, and by proxy, address public health issues in surrounding communities.
Workforce and Economy	Electrolytic hydrogen production will create a new market, new companies, and new jobs. This intervention depends on the development of a hydrogen market and infrastructure to produce, store, and transport H2 to steel facilities. Facilities that are co-located with other industrial large-scale use-cases could have lower barriers for adoption in the medium-term. Steel production is considered a “Second Wave” application.[14] As the market for green hydrogen develops, costs of production, storage, and transportation infrastructure are expected to come down. The development of the hydrogen market is a key barrier for successfully deploying this intervention. Any efforts and investments made to support development of hydrogen will indirectly but substantially enable deep decarbonization in many industries, including cement. At ISMs, iron and steel making processes are integrated and therefore we anticipate large shutdown costs for major upgrades to deploy H2-DRI/HBI.
Available	45V tax credits

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[10] Yilmaz et al., 2017
[11] Vogl et al., 2018
[12] Hasanbeigi et al., 2013
[13] ACEEE, 2023
[14] DOE, 2023a

Funding	EPA Greenhouse Gas Reduction Fund for Disadvantaged communities EPA Env and Climate Justice Grants H2 Hubs DOE will support H2 deployment in 7 regions[15] IRA 13204 - Clean Hydrogen Production Tax Credit IRA 50161 - Advanced Industrial Facilities Deployment Program
Working Models or Pilot Projects	Currently, less than 0.1% of global dedicated hydrogen production comes from water electrolysis. In its 2020 technology roadmap, the International Energy Agency (IEA) suggests that under its 'Sustainable Development Scenario' (SDS) scenario, green hydrogen is introduced as a primary reducing agent at a commercial scale in the mid-2030s. Use expands by 2050. However, this does not cover more than 14% of primary production in tonnes. Key H2-DRI projects include Hybrit[16] and ArcelorMittal's Hamburg pilot project.[17] H2 Green Steel modern manufacturing plant in Sweden produces electrolytic hydrogen and H2-DRI primary steel.[18]

Iron/Steel	**Short Term** CO_2e Reduction	**Long Term** CO_2e Reduction
Estimates from literature	21.4% to blast furnace emissions	97.2% to BF-BOF emissions
Nationwide	4,985,392 mt CO_2e	38,819,358 mt CO_2e
In Energy Communities	1,845,650 mt CO_2e	11,349,219 mt CO_2e
In Disadvantaged Communities	3,919,104 mt CO_2e	27,400,783 mt CO_2e

4.2.2 Electrolytic Hydrogen in Cement Production

Description	Hydrogen is used as a fuel to heat the kiln to temperatures for clinker production. This reduces emissions from stationary combustion for kiln heat and process emissions.
Implementation timelines	**Short term** - For existing infrastructure, H2can be 5-20% of fuel mix.[19] Our short term reduction assumes a 20% fuel mix at the top 5 highest emitting facilities located in EJ communities, achieving a 20% CO_2e reduction in these kiln emissions.
	Long term - Long term reduction assumes a 20% fuel mix at all facilities, achieving a 20% CO_2e reduction for all kiln emissions.
Local Air Quality	Hydrogen used as an energy source outputs water as a byproduct, in contrast with fossil fuels which output CO_2, along with harmful air pollutants including NOx, SOx, and PM 2.5; therefore, replacing fossil fuels with hydrogen will reduce industrial pollution in disadvantaged communities.[20]
Workforce and Economy	Use of electrolytic hydrogen as a fuel mix to heat the kiln is not seen as a viable short term solution industry-wide for several reasons, but may work for specific facilities where the cost and infrastructure needs are not prohibitive. The U.S. National Clean Hydrogen Strategy and Roadmap, sees cement production as a "Third Wave" application for hydrogen.[21] Accordingly, primary focus on hydrogen in cement production makes sense as a long term solution. As the market for green hydrogen develops, costs of production, storage, and transportation infrastructure are expected to come down. The development of the hydrogen market is a key barrier for successfully deploying this intervention. Any efforts and investments made to support development of hydrogen will indirectly but substantially enable deep decarbonization in many

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[15] OCED, n.d.
[16] Vattenfall, n.d.
[17] ArcelorMittal, n.d.
[18] H2GreenSteel, n.d.
[19] DOE, 2023b
[20] ACEEE, 2023
[21] DOE, 2023b

	industries, including cement.
Available Funding	45V tax credits
Working Models or Pilot Projects	In the EU, feasibility studies are being conducted to determine the viability of using hydrogen in a cement kiln system.[22]

Cement	**Short Term** CO_2e Reduction	**Long Term** CO2e Reduction
Estimate from literature	20% to kiln emissions at priority facilities	20% to kiln emissions at all facilities
CO_2e Reduction Nationwide	784,762 mt CO_2e	12,537,984 mt CO_2e
CO_2e Reduction in Energy Communities	0 mt CO_2e[23]	992,091 mt CO_2e
CO_2e Reduction in Disadvantaged Communities	784,762 mt CO_2e	4,173,272 mt CO_2e

4.2.3 Carbon Capture and Storage in Steel Production

Description	Carbon capture and storage is applied to smokestacks of facilities.
Implementation timeline	**Short term** - CCS reduces emissions from the BF and BOF of top emitting facilities in EJ communities by 90%
	Long term - CCS reduces emissions from all facility emissions by 90%
Local Air Quality	CCS implementation at BF-BOF facilities may help reduce pollution as a result of CCS technologies requiring scrubbing prior to capture being performed.[24]
Workforce and Economy	One of the primary concerns with CCS is that, opposed to other interventions,CCS is not a low-carbon energy solution. CCS's existence relies on the combustion of carbon-based fuels to capture and store emitted carbon.This ensures the continuation of the fossil fuel industry, an industry that is not consistent with a low carbon future and in which needs to be phased out. Also, while this technology reduces direct emissions from the unit processes it is applied to (Scope 1), it requires energy to manufacture and operate and may increase emissions in Scope 2 and 3.
Available Funding	45Q tax credits for project nationwide EPA Greenhouse Gas Reduction Fund for Disadvantaged communities EPA Env and Climate Justice Grants IRA 13204 -Clean Hydrogen Production Tax Credit IRA 50161 - Advanced Industrial Facilities Deployment Program
Working Models or Pilot Projects	Multiple CCS research efforts and pilot projects are underway across the Great Lakes.[25]

Iron/Steel	**Short Term** CO_2e Reduction	**Long Term** CO_2e Reduction
Estimates from literature	90% of BF and BOF emissions in priority facilities	90% of BF, BOF, EAF, and process emissions

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[22] Passaro, 2023.

[23] None of the cement facilities chosen as priorities for the short term scenario are located in Energy Communities. See implementation timeline above for more details

[24] Carey et al. 2023.

[25] Carey et al. 2023.

CO_2e Reduction Nationwide	20,957,733 mt CO_2e	37,171,247 mt CO_2e
CO_2e Reduction in Energy Communities	7,721,868 mt CO_2e	10,200,719 mt CO_2e
CO_2e Reduction in Disadvantaged Communities	16,572,756 mt CO_2e	25,869,553 mt CO_2e

4.2.4 Carbon Capture and Storage in Cement Production

Description	Carbon capture and storage is applied to smokestacks of facilities.
Implementation Timeline	**Short term** - CCS is applied to emissions from kilns (emissions from process heat in MECS breakdown) at top 5 highest emitting facilities in EJ communities.
	Long term - CCS is applied to all emissions at all facilities.
Local Air Quality	Pretreatment (scrubbing) for CCS can reduce local air pollutants and particulate matter[26]
Workforce and Economy	One of the primary concerns with CCS is that unlike other interventions, CCS is not a low-carbon energy solution. CCS's existence relies on the combustion of carbon-based fuels to capture and store emitted carbon.This ensures the continuation of the fossil fuel industry, an industry that is not consistent with a low carbon future and in which needs to be winded down. Also, while this technology reduces direct emissions from the unit processes it is applied to (Scope 1), it requires energy to manufacture and operate and may increase emissions in Scope 2 and 3.
Available Funding	45Q tax credits for project nationwide EPA Greenhouse Gas Reduction Fund for Disadvantaged communities EPA Env and Climate Justice Grants IRA 13204 -Clean Hydrogen Production Tax Credit IRA 50161 - Advanced Industrial Facilities Deployment Program
Working Models or Pilot Projects	CCS for the rotary kiln at the demonstration stage in the US[27]

Cement	**Short Term** CO_2e Reduction	**Long Term** CO_2e Reduction
Estimates from literature	90% of kiln emissions at priority facilities	90% of kiln emissions at all facilities
CO_2e Reduction Nationwide	784,762 mt CO_2e	56,420,930 mt CO_2e
CO_2e Reduction in Energy Communities	0 mt CO_2e[28]	4,464,413 mt CO_2e
CO_2e Reduction in Disadvantaged Communities	784,762 mt CO_2e	18,779,726 mt CO_2e

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[26] Stashwick, 2021

[27] DOE, 2023a

[28] None of the cement facilities chosen as priorities for the short term scenario are located in Energy Communities. See implementation timeline above for more details

4.2.5 Energy Efficiency in Steel Production

Description	Energy efficiency improvements include switching to the best available technology, modernizations, upgrades, machine learning, and utilizing artificial intelligence.[29] Efficiency improvements can often be a low-hanging fruit for facilities and is considered best practice. Based on a range of estimates from literature, we assume a fuel efficiency savings and CO2e reduction of 11%.[30]
Implementation Timeline	**Short term** - Most of the short term energy efficiency upgrades are applicable to the blast furnace and hot rolling mill.
	Long term - Steel facilities should not rely on incremental efficiency improvements as a long term solution for deep decarbonization. Instead, they should adopt new technology with significantly lower carbon impacts.
Local Air Quality	Reducing energy usage in industrial facilities will result in small improvements in industrial pollution. More efficient processes are not only lower GHG emitting, but often have less associated air pollutants overall.[31]
Workforce and Economy	This is an incremental, low-cost option for facilities that are not ready to invest into full equipment replacements. . Replacement of large and capital-intensive equipment for lower-carbon alternatives have to happen at or near the end of the current lifetime. Efficiency improvements would enable operations to proceed without any significant changes.
Available Funding	IRA 50161 - Advanced Industrial Facilities Deployment Program
Working Models or Pilot Projects	EU Energy Efficiency Directive: Making it binding for EU countries to collectively ensure an additional 11.7% reduction in energy consumption by 2030.[32] Under very demanding values of the directive and investment payback period, there is potential to improve CO_2 emissions by about 20-65%.[33]

Iron/Steel	**Short Term** CO_2e Reduction	**Long Term** CO_2e Reduction
Estimates from literature	11%	-
CO_2e Reduction Nationwide	634,622 mt CO_2e	-
CO_2e Reduction in Energy Communities	202,199 mt CO_2e	-
CO_2e Reduction in Disadvantaged Communities	340,349 mt CO_2e	-

4.2.6 Energy Efficiency in Cement Production

Description	Energy efficiency improvements include switching to the best available technology, modernizations, upgrades, machine learning, and artificial intelligence utilized.[34] Efficiency can often be a low-hanging fruit for facilities and is considered best practice. The cement industry has an opportunity for significant gains in energy efficiency with current technology such as modern roller presses and kilns with preheater/precalciner. Emerging technology could energy even further

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[29] DOE, 2023
[30] Worrel et al., 2022
[31] ACEEE, 2023
[32] European Commission, n.d.
[33] Moya et al., 2013
[34] DOE, 2023b

	efficiency gains.
Implementation Timeline	**Short term** - All facilities adopt current best available technologies to increase energy efficiency, achieving a 5-7% CO_2e reduction.[35]
	Long term - All facilities adopt emerging technology, achieving reductions of up to 30%.[36]
Local Air Quality	Reducing energy usage in industrial facilities will result in small improvements in industrial pollution. More efficient processes are not only lower GHG emitting, but often have less associated air pollutants overall.[37]
Workforce and Economy	This is an incremental, low-cost option for facilities that are not ready to invest into upgrades and retrofits. Replacement of incredibly large equipment for lower-carbon alternatives must happen at or near the end of the current lifetime. Efficiency improvements would enable operations to proceed without any significant changes.
Available Funding	$5.812 billion cumulative 2022-2031. Mechanism: Grant, rebate, direct loan, or cooperative agreement. Section 50161: Advanced Industrial Facilities Deployment Program.[38]
Working Models or Pilot Projects	India's Perform Achieve and Trade (PAT) scheme and Bureau of Energy Efficiency under its Ministry of Power: policy led to an energy intensity reduction of 2.7% for the cement industry.[39]

Cement	**Short Term** CO_2e Reduction	**Long Term** CO_2e Reduction
Estimates from literature	7% CO_2e reduction	30% CO_2e reduction
CO_2e Reduction Nationwide	4,738,057 mt CO_2e	20,305,959 mt CO_2e
CO_2e Reduction in Energy Communities	374,908 mt CO_2e	1,606,748 mt CO_2e
CO_2e Reduction in Disadvantaged Communities	1,577,064 mt CO_2e	6,758,846 mt CO_2e

4.2.7 Clinker Substitution in Cement Production

Description	Replacement of clinker with substitute cementitious materials (CMs) reduces emissions by lowering the demand for carbon-intensive clinker in cement. Clinker production is the most energy and carbon-intensive process in the production of cement. This is a form of material efficiency that is highly promising, particularly for applications where structural safety concerns are low. For example, a 20% reduction in limestone use per unit of clinker manufactured usually translates into slightly less than a 20% CO_2 emissions reduction per mass of cement.[40]
Implementation Timeline	**Short term** - All facilities adopt best available clinker substitution. Cement blends currently in widespread use, like Portland Limestone Cements (PLCs), substitute up to 10–15% of clinker with materials such as ground limestone, driving 5–10% emissions reductions.[41]
	Long term - All facilities adopt emerging clinker substitution like ternary blends or calcined clay cements (e.g., Limestone Calcined Clay Cement, "LC3"), allowing for 50% clinker substitution and leading to 50% reduction in emissions.[36]

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[35] DOE, 2023b

[36] Worrel et al., 2022

[37] ACEEE, 2023

[38] CRS, n.d.

[39] Oak, H., & Bansal, S., 2022

[40] Gartner, 2018

[41] DOE, 2023a

Local Air Quality	Air pollutants originating from cement facilities in the U.S. are regulated under programs such as the National Air Ambient Air Quality Standards (NAAQS). To comply with regulations, emissions of air pollutants can be controlled by various techniques: for example, NO_x can be controlled through clinker mineralization.[42]
Workforce and Economy	The wider industrial system will be impacted by clinker substitution, particularly industries that can provide substitute CMs, such as metal and agricultural by-products.[43]
Available Funding	$5.812 billion cumulative 2022-2031 Mechanism: Grant, rebate, direct loan, or cooperative agreement. Section 50161: Advanced Industrial Facilities Deployment Program. Provides funding to DOE for financial assistance for clean energy demonstrations by eligible facilities, with priority to projects to achieve GHG reductions, provide the greatest benefit for the greatest number of people in the area, and participate in a partnership with purchasers of the facility's output.[44]
Working Models or Pilot Projects	EU ETS[45]

Cement	**Short Term** CO_2e Reduction	**Long Term** CO_2e Reduction
Estimate from literature[36]	10% to kiln emissions	50% to kiln emissions
CO_2e Reduction Nationwide	6,268,992 mt CO_2e	31,344,961 mt CO_2e
CO_2e Reduction in Energy Communities	496,046 mt CO_2e	2,480,229 mt CO_2e
CO_2e Reduction in Disadvantaged Communities	2,086,636 mt CO_2e	10,433,181 mt CO_2e

4.2.8 Buy Clean

Description	Procurement standards for government infrastructure to have low embodied carbon materials procured during construction. This is a federal executive order.
Implementation Timeline	**Short term** - this program will incentivize companies to reduce emissions in order to fulfill federal government contracts.
	Long term - if this program remains in existence the standards can be tightened over time to incentivize companies to continue adopting new technology.
Local Air Quality	Work should be done to ensure the health and environmental impacts beyond GHG emissions are incorporated in a Buy Clean policies.[46]
Workforce and Economy	Buy Clean supports the creation and retention of good-paying American jobs. Because the products that Buy Clean applies to are often made in lower-emitting ways here in the United States, the implementation of Buy Clean will serve to support manufacturing jobs here at home and reverse decades of outsourcing. With Buy Clean, demand for lower-emitting, American-made products will grow, which can in turn support the creation of good union manufacturing jobs across the nation.[47] Buy Clean will make reducing climate pollution a business advantage, incentivising reductions in

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[42] Hasanbeigi et al., 2023
[43] Shah et al., 2022
[44] CRS, n.d.
[45] Allevi et al., 2017
[46] BGA, 2022
[47] BGA, 2022

	emissions through efficiency and fuel-switching for materials used in federally funded infrastructure including cement, concrete, iron, and steel.
Available Funding	Indirectly relies on funding for research, development, and deployment of low carbon technology. Both IRA and BIL apply.
Working Models or Pilot Projects	State-level Buy Clean programs.[48]

Iron/Steel	**Short Term** CO$_2$e Reduction	**Long Term** CO$_2$e Reduction
Estimate from literature[49]	20% reduction	50% reduction
CO$_2$e Reduction Nationwide	11,109,137 mt CO$_2$e	27,772,843 mt CO$_2$e
CO$_2$e Reduction in Energy Communities	3,452,341 mt CO$_2$e	8,630,852 mt CO$_2$e
CO$_2$e Reduction in Disadvantaged Communities	7,418,289 mt CO$_2$e	18,545,744 mt CO$_2$e

Cement	**Short Term** CO$_2$e Reduction	**Long Term** CO$_2$e Reduction
Estimate from literature[49]	30% reduction	50% reduction
CO$_2$e Reduction Nationwide	13,537,306 mt CO$_2$e	33,843,266 mt CO$_2$e
CO$_2$e Reduction in Energy Communities	1,071,165 mt CO$_2$e	2,677,913 mt CO$_2$e
CO$_2$e Reduction in Disadvantaged Communities	4,505,897 mt CO$_2$e	11,264,743 mt CO$_2$e

4.2.8 EPA Standards

Description	EPA Standards through the CAA would impose CO$_2$ emissions caps for high emitting industries. To implement these standards, permitting triggered by retrofits would require best available control technology (BACT), EPA databases and guidelines are built out to support permitting, and requirements are made stricter over time. Funding to the EPA for local staff and enforcement measures would be crucial in this intervention as well. A climate progressive, Democratic executive branch would be required for this intervention to be politically feasible.
Implementation Timeline	**Short term** - EPA imposes an emissions cap of 50% reduction from 2022 baseline.
	Long term - EPA imposes an emissions cap of 90% reduction from 2022 baseline.
Local Air Quality	Switching to low-carbon technology and electricity wherever possible will reduce both carbon and non-carbon pollutants.
Workforce and Economy	This intervention directly creates jobs at the epA and state agencies to develop and enforce standards, as well as an updated technology database and guidelines for permitting. This also indirectly creates private sector jobs in Environmental Services to help industry comply with

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[48] ACEEE, 2023

[49] These emissions reduction estimates are pulled from Hasanbeigi et al, 2021, who sets out several Buy Clean scenarios with the assumption that some, but not all, facilities will choose to achieve reduction targets in order to qualify for federal contracts, which results in conservative reduction estimates. The estimates used in this analysis do not account for spillover effects to non-federal cement and steel plants. They also differ from literature estimates that are derived from 2050 Net-Zero goals, e.g. Esau et al., 2023.

	standards. Without government subsidies, tax incentives, and other funding mechanisms like green banks, public-private partnerships, and advanced market commitment coalitions like First Movers, these standards could be extremely expensive for industry to comply with.
Available Funding	As stated above, funding such as gov. subsidies, tax incentives, and other forms of investment is a critical component of enabling the emission reductions estimated for this intervention.
Working Models or Pilot Projects	EPA standards for non-GHG pollutants have successfully reduced emissions while the U.S. economy continued to grow.

Iron/Steel	**Short Term** CO_2e Reduction	**Long Term** CO_2e Reduction
Estimate from literature	50% reduction	90% reduction
CO_2e Reduction Nationwide	27,772,843 mt CO_2e	49,991,118 mt CO_2e
CO_2e Reduction in Energy Communities	8,630,852 mt CO_2e	15,535,534 mt CO_2e
CO_2e Reduction in Disadvantaged Communities	18,545,744 mt CO_2e	33,382,340 mt CO_2e

Cement	**Short Term** CO_2e Reduction	**Long Term** CO_2e Reduction
Estimate from literature	50% reduction	90% reduction
CO_2e Reduction Nationwide	33,843,266 mt CO_2e	60,917,879 mt CO_2e
CO_2e Reduction in Energy Communities	2,677,913 mt CO_2e	4,820,243 mt CO_2e
CO_2e Reduction in Disadvantaged Communities	11,264,743 mt CO_2e	20,276,537 mt CO_2e

4.2.9 Low Carbon Fuels for Cement (Excluding Hydrogen)

Description	Divert non-recyclable, solid, and hazardous waste streams from landfills and use biomass to heat kilns where they reduce net energy a GHGs.
Implementation Timeline	**Short term** - Biomass and waste can reduce CO_2 by 1% and 7% in the short term, respectively.[50]
	Long term - Biomass and waste can reduce CO2 emissions up to 10% by 2050.[51]
Local Air Quality	Estimates that adopting low-carbon fuels would prevent thousands of deaths in California each year due to improved air quality. In economic terms, the total public health benefits were estimated to be approximately $20 billion annually.[52]
Workforce and Economy	Would be available for facilities that are not ready for major upgrades or retrofits.
Available	The IRA Section 45Y Tax Credit is a technology-neutral credit focusing on clean energy production

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[50] DOE, 2023b
[51] IEA, 2018
[52] Li et al., 2022

Funding	
Working Models or Pilot Projects	EU ETS and EU's Renewable Energy Directive[53]

Cement	**Short Term** CO_2e Reduction	**Long Term** CO_2e Reduction
Estimate from literature	8% of kiln emissions	10% of kiln emissions
CO_2e Reduction Nationwide	1,766,240 mt CO_2e	2,207,800 mt CO_2e
CO_2e Reduction in Energy Communities	139,757 mt CO_2e	174,696 mt CO_2e
CO_2e Reduction in Disadvantaged Communities	587,894 mt CO_2e	734,867 mt CO_2e

4.2.10 Low Carbon Fuels for Steel (Excluding Hydrogen)

Description	Divert non-recyclable, solid, and hazardous waste streams from landfills and use biomass to heat blast furnaces for ironmaking, in place of pulverized coal from fossil fuel sources.[54]
Implementation Timeline	Biomass application in the Iron/Steel industry is limited and suffers from strong competition from fossil fuels; challenges for implementation stem from both technical and economic factors.[55]
Local Air Quality	Estimates that adopting low-carbon fuels would prevent thousands of deaths in California each year due to improved air quality. In economic terms, the total public health benefits were estimated to be approximately $20 billion annually.[56]
Workforce and Economy	Would be available for facilities that are not ready for major upgrades or retrofits.
Available Funding	The IRA Section 45Y Tax Credit is a technology-neutral credit focusing on clean energy production
Working Models or Pilot Projects	EU ETS and EU Clean Steel Partnership [57]

Steel	**Short Term** CO_2e Reduction	**Long Term** CO_2e Reduction
Estimate from literature	28.1% to BF and BOF[58]	-
CO_2e Reduction Nationwide	5,103,204 mt CO_2e	-
CO_2e Reduction in Energy Communities	1,601,983 mt CO_2e	-
CO_2e Reduction in Disadvantaged Communities	4,267,134 mt CO_2e	-

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[53] Supino et al., 2016.
[54] Wang et al., 2015
[55] Mousa et al., 2016
[56] Li et al., 2022
[57] Eurofer, n.d.
[58] Wang et al., 2015

4.2.11 Circularity for Steel

Description	Steel is one of the most highly recycled materials in use today. Using steel scrap in the production process reduces CO_2 emissions by 58% compared to primary production. Recycled steel production from scrap is 72% less energy intensive than primary production from iron ore. Due to demand increase, recycling alone cannot fulfill requirements, but there is still opportunity to increase circularity by transitioning some primary steel production through the BF-BOF pathway to secondary steel production through the Scrap + EAF pathway.
Implementation Timeline	**Short-term:** Given that the U.S. already has extensive EAF infrastructure, an increase in recycling can be ramped up quickly, given that steel scrap as a feedstock is collected and distributed at sufficient rates to meet demand.
	Long-term: Replacing some BF-BOF steel production with EAF + Scrap steel making would be likely to happen by 2050.
Local Air Quality	Using recycled steel to make new steel reduces air pollution by 86%[59]
Workforce and Economy	The winding-down and replacement of BF-BOF production with EAF and scrap production would be disruptive to facility operations and the upgrades needed would require high capex, construction, and shut-down costs. However, an increase in circularity using existing infrastructure is highly feasible and would not be disruptive to the workforce. The secure supply of scrap steel as a feedstock is crucial to enable full deployment of this intervention. Policies to support collection and distribution of scrap steel will therefore be an essential component of success.
Available Funding	Indirectly supported by funding for EAF adoption.
Working Models or Pilot Projects	Thai steel recycling policy example[60]

4.2.12 Cap and Trade

Description	Modeled after California and Europe, the US creates a cap and trade system for companies to manage emissions. California's cap and trade program (which includes the Cement industry) sets a 2030 GHG Reduction Target of at least 40% below 1990 levels.[61]
Implementation Timeline	Dependent on congressional approval.
Local Air Quality	Case study: California's cap-and-trade program has yet to yield improvements in environmental equity with respect to health-damaging co-pollutant emissions, which could change as the cap on GHG emissions is gradually lowered.[62]
Workforce and Economy	Proceeds from cap-and-trade auctions can be used to fund investments in communities. However, note that cap-and-trade programs generally increase prices, which are passed onto consumers (e.g. higher gas prices).[63]
Available Funding	None
Working Models or	California's cap-and-trade system, managed by CARB.

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[59] EuRIC, n.d.
[60] Taghipour, et. al., 2022
[61] California Air Resources Board, n.d.
[62] Cushing et al, 2018
[63] Cushing et al, 2018

Pilot Projects	

4.2.13 Carbon Border Adjustment Mechanism

Description	A carbon border adjustment mechanism (CBAM) is a trade policy that applies tariffs on imports such as steel and cement based on their carbon emissions. This may be paired with a domestic carbon tax. For instance, the proposed MARKET CHOICE Act imposes a carbon fee on both domestic and international goods. This would impact domestic emissions by raising the price — and thereby disincentivizing purchase of — carbon-intensive products. Other proposals like the Foreign Pollution Fee Act would apply only to international imports; this would similarly enhance the competitiveness of low-carbon (especially American-made) goods, incentivizing their purchase.[64]
Implementation Timeline	Short-term, based on existing models domestically (as proposed bills in Congress) and in the EU (with application starting in 2026).
Local Air Quality	No impact. CBAM measures by definition would primarily impact emissions outside the local area, e.g. outside a particular state or country.
Workforce and Economy	Potentially negative effects. CBAM can lead to an increase in the prices of goods and commodities with high embodied impacts. They can also lead to shifts in labor as companies transition to low-carbon materials and production methods. Such impacts could occur both inside and outside the region where CBAM is implemented.
Available Funding	None
Working Models or Pilot Projects	EU CBAM has been implemented and will apply in its definitive regime from 2026, while the current phase lasts between 2003 and 2026.[65] Current U.S. congressional bills that have been introduced include the PROVE IT Act, the Foreign Pollution Fee Act, the Clean Competition Act, and the Market Choice Act.[66]

4.2.14 Fund EJ

Description	Increase direct funding or tax incentives to Energy and Disadvantaged communities, especially where the funding supports the development and deployment of industrial decarbonization projects. This would be an expansion to existing programs under the IRA and BIL.
Implementation Timeline	This intervention should be pursued in the short term, if based on a similar model to IRA/BIL..
Local Air Quality	High impact, especially where targeting remediation, water quality, air quality, and so on.
Workforce and Economy	Impacts are moderate to high, varying depending on how the policy is implemented. Funding for EJ communities can be especially effective when paired with Just Transition framework. This intervention is particularly important to address legacy issues like air/water pollution, and support local renewable energy.
Available Funding	Moderate amount of funding. Expert commentary indicates that current levels of funding are historic, but still not sufficient to completely deal with the issue of decarbonization. Benefits likely to flow to middle/upper income levels rather than lower income demographics.

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[64] Gangotra et al. 2023a
[65] European Commission, n.d.
[66] Gangotra et al., 2023

	Estimated that IRA offers $47.5 billion for EJ funding.[67] EPA funding sources include IRA ECJ block grants ($3 billion).[68] Greenhouse Gas Reduction Fund ($14 billion) for clean energy projects.[69] It is estimated that the IRA offers $47.5 billion for EJ funding.
Working Models or Pilot Projects	IRA/BIL

4.2.15 Just Transition

Description	This is a collection of policies that aim to decarbonize the economy in a way that is as fair and inclusive as possible to everyone concerned. A Just Transition involves maximizing the social and economic opportunities of climate action, while minimizing and carefully managing any challenges, especially those related to labor.[70]
Implementation Timeline	Implementation varies, depending on the specific policy implementation.
Local Air Quality	Low (indirect effects). E.g. Support for clean energy can reduce emissions from FF-burning electricity plants.
Workforce and Economy	Impacts to the workforce and economy are high: This is the central focus of the Just Transition framework: to alleviate potentially negative social and economic impacts of decarbonization. JT policies help to keep wages up, reduce unemployment, support unions, create tax revenue, ensure resilience, protect workers, promote local business, and lead to long-term economic growth
Available Funding	American Rescue Plan dedicates $300 million to coal communities IRA/BIL via Justice40. AMRF from BIL focuses not just on decarbonization but also job creation. CHIPS and Science Act includes billions to help rural and distressed areas create jobs in 21st-century economic sectors, including $11 billion for the U.S. Economic Development Administration to create regional technology and innovation hubs and to establish a Recompete Pilot Program for grants in persistently distressed regions.
Working Models or Pilot Projects	Many pilot policies have been implemented at the state-level in the U.S., including the formation of committees, worker funds for job training and education, data collection, timeline negotiation, equipment and infrastructure purchasing, environmental remediation, and strategic planning in states including Maryland, Maine, New Mexico, Oregon, and more.[71]

4.3 Policy Comparison

See Appendix C for a summary of our policy results, including how they rank in each of our quantitative and qualitative categories when compared to one another.

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[67] EPA, n.d.d
[68] EPA, n.d.d
[69] CRS, n.d.
[70] International Labor Organization, n.d.
[71] BGA, 2020.

5. Assumptions & Limitations

There are several major limitations to this project: Firstly, we have focused on policy proposals for federal action, as required by our client. Next, our analysis is limited to the Iron/Steel and Cement sectors. There are several reasons for this:

(a) *Significance*: Iron/Steel and Cement are two of the top three emitters among heavy industry sectors in the U.S.;
(b) *Data availability*: Both industries have been widely studied for decarbonization potential, ensuring a robust foundation of data for use in our project; and
(c) *Simplicity*: Existing production pathways are few and well-studied, unlike more complex sectors like Chemical (EPA, n.d.f).

We believe that this limitation does not diminish the validity of our work in developing a new methodology for analyzing decarbonization policies in the context of environmental, social, and economic impacts. In addition, although our analysis focuses on only 2 industries, the methodology is applicable to the remainder of industries present in the GHGRP database. Indeed, many of the policies discussed in this report apply generally to heavy industry, not just Cement and Iron/Steel. We encourage future researchers to perform similar analysis of the U.S. Chemicals industry and other sectors in order to evaluate which policies could have the biggest impact.

Additionally, our quantitative analysis is limited to Scope 1 (direct) carbon emissions only, with Scope 2 and 3 excluded. We have made no estimation or modeling of non-carbon pollutants like SOx, NOx, and particulate matter. As justification for this:

(a) Scope 1 emissions are reliably measured and reported in FLIGHT and other databases and do not require estimation through grid emission factors or other (especially in the case of Scope 3 emissions) still-developing methodology;
(b) Scope 2 (grid) emissions are expected to decrease over time as investments in renewable energy increase nationwide, independent of efforts to decarbonize Iron/Steel and Cement specifically; and
(c) unlike non-carbon pollutants, carbon emissions do not require advanced weather simulations to understand how their concentration impacts human health and well-being in surrounding populations, since the science of global warming is well-understood (IPCC, 2021).

While this is an important limitation of our project, we consider our work still to be valid in its ability to show a potential change in Scope 1 emissions that results from policy implementation. We have also indicated where policies can potentially impact Scope 2 and 3 in our qualitative analysis; for instance, Buy Clean procurement rules would impact not just Cement and Iron/Steel facilities but also their larger supply chain. In terms of non-carbon pollutants, our literature review indicates that technologies that cut carbon emissions also tend to reduce local air pollution (ACEEE, 2023). Thus we consider that our policies could have an impact not only on Scope 1 but also Scope 2 and 3 and non-carbon pollutants. We encourage future researchers to explore more fully the impacts of the policy proposals considered in this report on net carbon and non-carbon emissions.

We have also made a number of assumptions in our data and policy work in order to maintain a well-defined and manageable project scope. For example, our definitions of Energy & Disadvantaged Communities are based on legal or technical definitions from existing legislation (such as the IRA) and government agencies to align with federal policy going forward (The White House, n.d.). The map layers for Disadvantaged and Energy Communities are drawn directly from the DOE and CEJST websites (EDX, n.d.). We have also drawn quantitative estimates (for the emissions breakdown and reductions) from a variety of sources dating back to several years or even several decades ago; in the absence of updated figures, we have assumed that these numbers still apply to Iron/Steel and Cement industries today.

Our team considers these assumptions to be reasonable, realistic, and reflective of best practices for the analysis of decarbonization policies today. We have sought where possible to align our sources and methodology with those of federal agencies, who would be responsible for overseeing the policy implementations considered in this report. We believe this to have been the optimal approach for this project, increasing its utility to policymakers advancing heavy industry decarbonization and EJ goals.

A full list of additional assumptions and limitations of this project, along with relevant justifications, is provided in Appendix G.

6. Conclusions and Recommendations for Future Research

6.1 Conclusions

Our recognition of heavy industry's importance to modernization compelled us to address its negative impacts on climate and disadvantaged populations with urgency. While various organizations are already engaged in efforts to decarbonize heavy industry, existing interventions often could be improved in terms of the depth needed to tackle emissions at the individual facility level. This lack of spatial specificity hindered our ability to fully understand the localized impacts of carbon emissions and pollution on communities and to identify targeted strategies for emission reduction.

Our project took significant strides toward advancing research methodologies and generating fresh insights. Through meticulous modeling, we broke down industry-level emissions by process and end-use, shedding light on nuances not typically considered by the policy community. By categorizing facilities based on community characteristics, we gained a deeper understanding of how emissions distribution affects different populations, thereby facilitating more targeted interventions.

As our project concludes, we are proud to have delivered a comprehensive quantitative and qualitative evaluation of the major policy proposals for heavy industry decarbonization today. This evaluation included consideration of each policy's potential to reduce greenhouse gas emissions and improve the well-being of disadvantaged communities. This work, along with a comprehensive final report featuring impactful visualizations and a detailed database of facility-level emissions, stand as valuable tools for policymakers and advocacy groups alike. The value added by our collective output can be utilized by policymakers, researchers, and advocacy groups to further build upon the facility-level information and data analysis, especially when addressing EJ concerns related to heavy industry decarbonization. Altogether, we can leverage these resources to drive meaningful change, ensuring a more sustainable and equitable future for all.

6.2 Recommendations for Future Research

As described in Section 5 above, our research had significant limitations, leading to gaps in our analysis. We recommend that future research on the decarbonization of the Iron/Steel and Cement industries build on our methodologies and seek to address these gaps. Our recommendations for future research are listed below:

6.2.1 Scope 2-3 Emissions

Our project was limited to Scope 1 (direct) carbon emissions from Iron/Steel and Cement facilities due to time and data constraints. We recommend that future researchers seek to quantify not only the impact of policy proposals on Scope 1 carbon emissions but also on Scope 2 and 3 emissions, which make up about 20% and 33% of Cement and Iron/Steel embodied emissions, respectively.[72] Scope 2 emissions, for instance, could be targeted by policy proposals at the state or municipal level to increase local availability of renewable energy sources. Scope 3 emissions could be targeted by a carbon border adjustment mechanism (CBAM), which encourages a shift towards more sustainable practices both upstream and downstream in the value chain. Resulting emissions reductions may be domestic or international.

6.2.2 Detailed Cement Industry Modeling

In Section 3.1.4, we have explained that cement production tends to follow a simplified pathway in comparison to iron/steel production. This is not to say, however, that all cement facilities are the same. Cement facilities use a variety of fuel mixes that may impact emissions (e.g. using coal vs natural gas), and may have different types of kilns with different levels of efficiencies and ability to retrofit. We recommend that future researchers investigate facility-level equipment for simpler industries such as cement, too.

6.2.3 Other Heavy Industries

Significant work remains to quantify carbon emissions and model reductions for heavy industries beyond Iron/Steel and Cement. In particular, we recommend that future researchers explore policy proposals for decarbonization of the U.S. chemicals sector, which produces over 180 million metric tons of CO_2e each year, along with non-carbon pollutants that put disadvantaged populations at risk for health issues.

6.2.4 State Policy

Our project focused on federal-level policies; however, future researchers could use our research to inform state-level policies for industrial decarbonization. State-level interventions can be just as — if not more — effective as federal interventions, especially considering today's highly polarized political environment. Many federal policies also provide significant leeway for state implementation, including funding for projects in census tracts under Energy or Disadvantaged Community designations.

6.2.5 Environmental Justice

Policies that reduce carbon emissions may also reduce non-carbon pollutants (e.g. NO_x, SO_x, PM2.5). Building off the work of our project, future researchers could use facility-level emissions breakdowns to model industrial pollution in relation to

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[72] CDP, 2023

disadvantaged communities in order to understand the effects of decarbonization policies on air quality in the surrounding areas.

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Appendix A

List of data sources. The below table summarizes the primary data sources used in our project, including the specific types of data used from each source and their relevance to our methodology. Some data sources may have limitations, which are further noted in Appendix G.

Source	Data	Relevance/Usage
EPA Greenhouse Gas Reporting Program (GHGRP, via FLIGHT)[73]	Iron/steel and cement facility locations and GHG emissions (tonnes CO_2e)	Understanding baseline emissions & geographical distribution of industrial activity
EIA Manufacturing Energy Consumption Survey (MECS)[74]	Avg. energy consumption for industrial end uses (TBtu fuel)	Breakdown of current emissions by end use (e.g. process heat)
DOE Energy and Environmental Profile of the U.S. Iron and Steel Industry[75]	Avg. energy intensity for steel production processes (tonnes CO_2/tonne product)	Breakdown of current iron/steel industry emissions by process (e.g. casting, rolling)
CEQ CEJST Tool[76]	Census tracts labeled as “Disadvantaged”	Identifying facilities located in Disadvantaged Communities
DOE Energy Community Map[77]	Census tracts eligible for Qualifying Advanced Energy Project Credit (§48C) Program	Identifying facilities located in Energy Communities
DOE Liftoff Reports, IEA Technical Studies, & Other Sources[78]	Emissions reduction estimates	Calculating the results of policy interventions

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[73] EPA, n.d.g
[74] EIA, n.d.
[75] DOE, 2000
[76] CEQ, n.d.
[77] EDX, n.d.
[78] DOE, 2023a; DOE 2023b; IEA, 2018

Other Sources[79]	Qualitative criteria (listed in Table 4)	Evaluating qualitative impacts of policy implementation

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[79] E.g., BGA, 2023

Appendix B

Reduction estimates: The below table shows all policies considered in our project methodology and their associated emissions reduction estimates (as a percentage reduction). Data sources are also listed, along with any relevant limitations or considerations. Note that not all policies have associated reduction estimates; such policies were excluded from the Quantitative Analysis explained in Section 3.3.1.

Policy Name	Short Term	Short Term Scenario	Data Source(s)	Long Term	Long Term Scenario	Data Source(s)
CCS for Cement	90%	CCS on process heat and process emissions of priority plants (in energy and disadvantaged communities)	DOE, 2023a	90%	CCS on process heat and process emissions at all plants	DOE, 2023a
CCS for Steel	90%	CCS on BF + BOF and process emissions of priority plants (ISMs in energy and disadvantaged communities)	DOE, 2023a	90%	CCS on BF+BOF, EAF, and process emissions all plants	DOE, 2023a
Hydrogen for Cement	20%	Use as a fuel mix. Apply to process heat emissions for priority plants (ideally those co-located in other industrial h2-end-use-hubs but we didn't do that level of analysis so we chose facilities in EJ communities) because technology may be somewhat deployable within the next 5-6 years, but not safe to assume all facilities could access yet. Securing clean hydrogen at sufficiently low cost to compete with existing fuels is likely to be challenging. Clean hydrogen can likely be used as up to ~5–20% of the fuel mix without a significant overhaul of plant infrastructure	DOE, 2023a	20%	Use H2 as a fuel mix for all plants to process heat. Clean hydrogen can likely be used as up to ~5-20% of the fuel mix without a significant overhaul of plant infrastructure, but securing clean hydrogen at sufficiently low cost to compete with existing fuels is likely to be challenging.	DOE, 2023a
Hydrogen fuel blend for steel	21%	Transitional solution of blending hydrogen into the blast furnace with fossil-fuel reductants to improve GHG efficiency. Yilmaz et al. show that using H2 as an auxiliary reducing gas for BF to partly replace CO derived from either coal or	Yilmaz et al. 2017	N/A	Not long term	N/A

		coke can reduce CO_2 emission by 21.4%[80]				
HR-DRI/HBI for steel			Not short term	97%	Replace all BF-BOF with H2-DRI. H-DR emits only 2.8% of blast furnace CO_2.[81]	Vogl et al. 2018.
Energy efficiency for cement	7%	Energy efficiency gains based on BAT, modernizations, upgrades, machine learning, and artificial intelligence. 2030: Assumed based on modernizations, upgrades, machine learning, and artificial intelligence. PCA 2021 US roadmap(p. 30) documents planned decrease of 5-7%.	DOE, 2023a	30%	All cement facilities operate at current best available technology and best practice level using upgrades, machine learning, and AI. 2050: Assumed based on modernizations, upgrades, machine learning, and artificial intelligence. PCA 2021 US roadmap (p. 30) documents planned decrease of 20- 30%. Assuming all plants in 2050 would operate at the current best practice level, fuel efficiency could improve by 35%.[82]	DOE, 2023b
Clinker substitution for cement	10%	Clinker substitution with fly ash, steel slag, and limestone are available and deployed today. Portland Limestone Cements (PLCs), substitute up to 10–15% of clinker with materials such as ground limestone, driving 5–10% emissions reductions.	DOE, 2023b	50%	More ambitious approaches, like ternary blends and calcined clay cements (e.g Limestone Calcined Clay Cement, “LC3”), allow for substitution of ~30–50% of clinker in a cement mix by weight, driving emissions reductions of ~30–50%. Blends with steeper clinker substitution are technically proven and have strong economics but remain in limited use today.	DOE, 2023b
Energy efficiency for steel	11%	Short term energy efficiency gains of 11% fare, applied primarily to hot rolling and BOF. Not applied to process emissions which are primarily in BF / iron ore reduction and not affected by this intervention	Worrel et al., 2021		Fuel efficiency is not a long term solution	Worrel et al., 2021
Buy Clean for Cement	20%	Buy Clean reduces emissions across the section by 10% in the Low scenario and 20% in the medium scenario. Under the Low scenario for Buy Clean target for cement, annual emissions reduction of 3.6 Mt CO_2 can be achieved directly from government procurement of cement for construction. This direct annual CO_2 emissions reduction	Hasanbeigi et al., 2021	50%	Buy Clean reduces emissions by 50% in the Transformative Scenario (and 30% in the high scenario). Under the Low scenario for Buy Clean target for cement, annual emissions reduction of 3.6 Mt CO_2 can be achieved directly from government procurement of cement for construction. This direct annual CO_2 emissions reduction potential would	Hasanbeigi et al., 2021

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[80] Yilmaz et al., 2017
[81] DOE, 2023a
[82] Worrel & Boyd, 2022

		potential would increase to 11 Mt CO_2 and 18 Mt CO_2 under High and Transformative scenarios, respectively.			increase to 11 Mt CO_2 and 18 Mt CO_2 under High and Transformative scenarios, respectively.	
Buy Clean for Steel	20%	Buy Clean reduces emissions across the section by 10% in the Low scenario and 20% in the medium scenario. Under the Low scenario for Buy Clean target for steel, annual emissions reduction of 2 Mt CO_2 can be achieved directly from government procurement of steel for construction. This direct annual CO_2 emissions reduction potential would increase to 6 Mt CO_2 and 10 Mt CO_2 under High and Transformative scenarios, respectively	Hasanbeigi et al., 2021	50%	Buy Clean reduces emissions by 50% in the Transformative Scenario (and 30% in the high scenario). Under the Low scenario for Buy Clean target for steel, annual emissions reduction of 2 Mt CO_2 can be achieved directly from government procurement of steel for construction. This direct annual CO_2 emissions reduction potential would increase to 6 Mt CO_2 and 10 Mt CO_2 under High and Transformative scenarios, respectively.	Hasanbeigi et al., 2021
Low carbon fuels excl. hydrogen for Steel	28%	Biomass will reduce 28.1%. By replacing the injection completely with charcoal, the on-site emissions can be reduced by 28.1%; torrefied material and wood pellets can reduce a maximum of 6.4% and 5.7% respectively. The reduction is also substantial on an industry-level; replacing the coal used in this furnace alone, would cut the emissions of the whole industry by 17.3%.	Wang et al., 2015	N/A	Not a good estimate for LCF besides waste and biomass	N/A
Low carbon fuels excl. hydrogen for Cement	8%	Waste will reduce 7%, biomass with reduce 1%, so total 8%	DOE, 2023b	10%	Blend alternative fuels to replace fossil fuel can reduce 10%	Czigler et al., 2020

Appendix C

Summary table of results. The table below summarizes the results of our project, explained in detail in Section 4. Some notes on the creation of this table:

- **Quantitative Results:** We have included long-term (2050) emissions reductions where available. Otherwise, we have used the short-term (2030) emissions reduction value or marked the field as “N/A” (signifying that no reduction values are available).
- **Qualitative Results:** This table includes qualitative results only for qualitative criteria (see Table 4) for which we found robust information for all policies. Excluded are policies for which we were not able to find information for all policies, i.e. “Impact on other heavy industries” and “Political feasibility.”
- **Colors:**
    - The top 10 quantitative results in each community type are colored green; medium emissions reductions are colored orange; and low emissions reductions are colored red.
    - Qualitative results are colored green, orange, or red where they have positive/high, neutral/medium, or negative/low impacts.

		Quantitative Results: GHG Reductions (mt CO2e)			**Qualitative Results**				
Ref.	**Policy**	**Nationwide**	**Energy Communities**	**Disadvantaged Communities**	**Air & Water Quality**	**Social & Economic Impact**	**Cost**	**Existing Funding**	**Successful Precedent (Domestic/Intl)**
§4.2.8	**EPA Standards (Cement)**	60,917,879	4,820,243	20,276,537	Positive	Neutral	Neutral	Medium	Medium
§4.2.8	**EPA Standards (Steel)**	49,991,118	15,535,534	33,382,340	Positive	Neutral	Neutral	Medium	Medium
§4.2.4	**CCS (Cement)**	56,429,930	4,464,413	18,779,279	Positive	Neutral	Negative	High	Low
§4.2.3	**CCS (Steel)**	37,171,247	10,200,719	25,869,553	Positive	Neutral	Negative	High	Low
§4.2.2	**Hydrogen (Cement)**	12,537,984	992,091	4,173,272	Positive	Positive	Positive	High	Medium

§4.2.1	**Hydrogen (Steel)**	38,819,358	11,349,219	27,400,783	Positive	Positive	Positive	High	Low
§4.2.6	**Energy Efficiency (Cement)**	20,305,960	1,606,748	6,758,846	Neutral	Neutral	Neutral	High	High
§4.2.7	**Clinker Substitution (Cement)**	31,344,961	2,480,229	10,433,181	Neutral	Neutral	Positive	High	Medium
§4.2.5	**Energy Efficiency (Steel)**	634,622	202,199	340,349	Neutral	Neutral	Neutral	High	High
§4.2.8	**Buy Clean (Cement)**	33,843,266	2,677,913	11,264,743	Neutral	Neutral	Positive	Medium	High
§4.2.8	**Buy Clean (Steel)**	27,772,843	8,630,852	18,545,744	Neutral	Neutral	Positive	Medium	High
§4.2.10	**Low Carbon Fuels (Steel)**	5,103,104	1,601,983	4,267,134	Positive	Neutral	Neutral	Medium	High
§4.2.9	**Low Carbon Fuels (Cement)**	2,207,800	174,696	734,867	Positive	Neutral	Neutral	Medium	High
§4.2.11	**Circularity (Steel)**	N/A	N/A	N/A	Positive	Positive	Positive	High	Medium
§4.2.12	**Cap & Trade**	N/A	N/A	N/A	Neutral	Neutral	Negative	Medium	Medium
§4.2.14	**EJ Community Funding**	N/A	N/A	N/A	Positive	Positive	Positive	High	Medium
§4.2.15	**Just Transition**	N/A	N/A	N/A	Positive	Positive	Positive	High	High
§4.2.13	**CBAM**	N/A	N/A	N/A	Neutral	Negative	Negative	N/A	Medium

Appendix D

Description of GHGRP program:

The GHGRP (codified at 40 CFR Part 98) requires reporting of GHG data and other relevant information by large GHG emission sources, fuel and industrial gas suppliers, and CO_2 injection sites in the U.S (EPA, n.d.f).

Facilities and suppliers determine whether they are required to report based on the types of industrial operations, their emission levels, or other factors. Facilities and suppliers are generally required to submit annual reports under Part 98 if:
- GHG emissions from covered sources exceed 25,000 metric tons CO_2e per year,
- Supply of certain products would result in over 25,000 metric tons CO_2e of GHG emissions if those products were released, combusted, or oxidized, or
- The facility receives 25,000 metric tons or more of CO_2 for underground injection .

The GHGRP reporting program does not include emissions from the following sources or categories :
- Agriculture,
- Direct emissions sources that have annual emissions of less than 25,000 metric tons of CO_2e, unless the source is required to report regardless of their total annual emissions;
- Sinks of greenhouse gases; and
- Electricity purchases or indirect emissions from energy consumption (Scope 2 emissions).

Annual reports covering emissions from the prior calendar year are due by March 31st of each year. Once data are submitted, EPA conducts a multi-step verification process to ensure reported data are accurate, complete, and consistent. Data collected under the GHGRP is made publicly available unless the data qualifies for confidential treatment under the Clean Air Act (EPA, n.d.f).

Data reported through GHGRP (and available in FLIGHT):

Each facility reporting to GHGRP must submit specific emissions data, which is available to be viewed in FLIGHT. For the purposes of this project, we are concerned with direct emitters, which includes Cement and Iron/Steel facilities. Direct emitters must report both fuel combustion and process emissions, as described below:

- Fuel combustion emissions include carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) emitted from combustion of a fossil fuel (e.g., coal, natural gas, petroleum products) or biomass feedstock (e.g., wood, landfill gas). They are determined by facilities by using a CEMS, measured fuel composition data, or default emission factors (EPA, n.d.f).
- Process emissions generally include emissions from chemical transformation of raw materials and fugitive emissions. Transformation of raw materials includes processes like iron and steel production, cement production, petrochemical production, and nitric acid production, which can release CO_2, CH_4, and N_2O. Fugitive emissions refer to emissions of gases due to leaks or other unintended or irregular releases. Process emissions are determined by facilities using a variety of methods including a CEMS, a mass balance approach, or site-specific or default emission factors (EPA, n.d.f).

For more information on GHGRP reporting methodology, visit the EPA's GHGRP website at https://www.epa.gov/ghgreporting.

Appendix E

Sample questions from informational interviews. Below is a list of some of the questions we asked of experts in our informational interviews. Questions were tailored to each expert's area of expertise. The information gleaned from these interviews was used to determine our project scope (in terms of key industries and major policy proposals) and methodology (especially in determining availability of data inputs) and also served as starting points for our literature review (as experts pointed us toward particular online resources).

1. What are the major challenges to industrial decarbonization today?
2. What policies could make the biggest impact at the federal executive level?
3. What are existing policy gaps for decarbonization in the Cement and Iron/Steel industries?
4. What decarbonization policies have received support from the Cement and Iron/Steel industries?
5. Are there any countries with interesting/inspiring legislation or initiatives in heavy industry decarbonization?
6. How does industry view decarbonization as part of its business strategy?
7. What are some of the most promising technological solutions to decarbonization in the Cement and Iron/Steel industries?
8. How widespread is the use of carbon capture in the Cement and Iron/Steel industries?
9. What are the most important criteria to consider when evaluating policies for decarbonization?
10. To what extent do environmental justice considerations factor into industry decision making?
11. Does our approach to policy make sense? Any major concerns?
12. How do we balance the quantitative and qualitative aspects of our policy analysis?
13. How should we format our final policy recommendations for publication?
14. Anyone else we should chat with for additional insights?
15. What reading/resources do you recommend for further exploration?

Appendix F

Table of available funding for Cement or Iron/Steel decarbonization. The following table summarizes federal funding opportunities, including both direct grants and tax incentives, for projects that support industrial decarbonization goals.

Legislation	Title	Description
IRA Section 50161	Advanced Industrial Facilities Deployment Program.	Provides funding to DOE for financial assistance for clean energy demonstrations by eligible facilities, with priority to projects to achieve GHG reductions, provide the greatest benefit for the greatest number of people in the area, and participate in a partnership with purchasers of the facility's output.[83]
IRA Section 13204 (45V tax credit)	Clean Hydrogen Production Tax Credit	Provides a tax credit for the production of clean hydrogen at a qualified clean hydrogen production facility[84]
IRA Section 13104 (45Q tax credit)	Credit for Carbon Oxide Sequestration	Provides a credit for carbon dioxide sequestration coupled with permitted end uses within the United States[85]
IRA Section 60103	Greenhouse Gas Reduction Fund	Provides competitive grants to mobilize financing and leverage private capital for clean energy and climate projects that reduce greenhouse gas emissions, with an emphasis on projects that benefit low-income and disadvantaged communities[86]
IRA Section 60201	Environmental and Climate Justice Block Grants	Provides grants and technical assistance to community-based organizations, alone or in partnerships, to reduce indoor and outdoor pollution, including greenhouse gasses[87]
IRA Section 50161	Advanced Industrial Facilities Deployment Program	Provides competitive financial support to owners and operators of facilities engaged in energy intensive processes to complete demonstration and deployment projects that reduce a facility's greenhouse gas emissions through installation or implementation of advanced industrial technologies and

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[83] CRS (2023)
[84] The White House (2023b)
[85] The White House (2023b)
[86] The White House (2023b)
[87] The White House (2023b)

		early-stage engineering studies to prepare a facility to install or implement advanced industrial technologies
DE-FOA-0002922	Regional Clean Hydrogen Hubs Program	Provides $7 billion to establish 6-10 regional clean hydrogen hubs across the U.S.[88]

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[88] CED (n.d.)

Appendix G

List of assumptions and limitations. The following list includes all assumptions and limitations that apply to this project, aside from those already discussed more extensively in Section 5. We have organized them according to the part of the project methodology to which they apply. Key assumptions or limitations are highlighted in green, along with an explanation of how they impact our project. All other assumptions and limitations should be considered to have little impact on the validity of our research. Items are listed in no particular order.

Data Methodology:

- FLIGHT data is all self-reported, and verified by EPA.
- FLIGHT only includes facilities with emissions of >25,000 metric tons CO_2e per year. Smaller facilities are excluded. However, the bulk of total Iron/Steel and Cement emissions in the U.S. are captured by our analysis.
- Used FLIGHT data for 2022 (most recent reporting year).
- End-use/process breakdowns only apply to stationary combustion emissions (based on on-site fuel usage) and not to process emissions. This is a feature of the MECS and DOE data we used to generate these breakdowns which are based on fuel usage. Consequently, we did not perform an equivalent breakdown for process emissions from Iron/Steel and Cement facilities. We do not consider this to be a significant limitation to our analysis for the Cement industry: We are still able to model reductions to Cement process emissions, given that these process emissions come entirely from cement kilns (see, e.g., our modeled Clinker Substitution policy in Section 4.2.7). However, it is a limitation for our analysis of the Iron/Steel industry. Future research could improve the precision of our emission reduction estimates by breaking down Iron/Steel process emissions by their source.
- MECS data is only collected every 5 years. We used data from 2018 (most recent reporting year). Considering the slow stock turnover in heavy industry, we do not consider these figures to be out of date.
- MECS data is based on NAICS codes which did not always match up to FLIGHT categorizations. Our team had to manually match them up. This introduces some uncertainty into our NAICS classifications. However, our team has sought to ensure that our classifications are backed up by actual language from company websites that verify the activities taking place at their facilities.
- MECS energy data are reported in TBtu and associated emissions of tCO_2e had to be calculated via emissions factors from DOE.
- MECS values and emissions intensities are based on industry averages. The resulting breakdown may not be entirely accurate at the individual Cement facility level. For the purposes of our project, we assumed that facilities in the Cement

industry have similar energy consumption patterns. This assumption was confirmed in our literature review and informational interviews, and so we consider this approach to be valid.

- NAICS codes are very broad and not sufficient as a basis for emissions intensity breakdown for the steel industry. We had to manually double-check each Iron/Steel facility's activities and equipment with GEM, AIST, and other online sources to understand the particular industrial processes used. It is possible that we have missed some details of production at particular Iron/Steel production facilities. However, these emissions from any missed processes are likely to be insignificant. We successfully labeled each facility according to its main production pathway, such as BF-BOF or EAF; it is this pathway that is likely to have the biggest impact on the volume of facility emissions.
- Discrepancies between names/ownership reported for each Iron/Steel facility between FLIGHT, GEM, and AIST. Our team had to manually check each facility to verify correct information.
- DOE's 2000 report provided a range of energy intensities for each steelmaking process. We used the average value as a "typical" measurement of energy intensity for each process.
- DOE energy intensity values are from 2000, already 24 years ago. Based on our literature review and information interviews, however, we understand that heavy industry facilities have very slow turnover and are unlikely to have changed their production pathways in a way that would significantly change our results. For this reason, we consider these energy intensity values to be relevant still, and our methodology also to be valid.
- We assumed that the ratio of energy intensity values was equivalent to the ratio of emissions for each process.
- For Iron/Steel facilities, we assumed that the presence of equipment implied the presence of an associated process. We also assumed that each tonne of steel goes through all processes present. This follows from our assumption in the previous bullet, which requires normalization by mass. Since the facility processes were based on extensive research across multiple data sources (GEM, AIST, company websites), we believe that our process information is at least comprehensive. In addition, we have ensured that the information includes processes with the highest emissions intensities, such as Ironmaking. Thus any deviations from this are likely to make only a small difference, especially for facilities which include the ironmaking process (BF-BOF facilities).
- Facilities in FLIGHT that used a Continuous Emissions Monitoring System (CEMS) did not have an accurate way of reporting stationary combustion versus process emissions due to the nature of CEMS measuring the combined emissions. We had to apply a standard ratio to total emissions based on literature. We consider this approach to be valid since it uses the best available data; our

literature review indicated that the average ratios between emissions types are unlikely to change significantly between facilities.

Policy Research:

- We used informational interviews, compilation reports (like DOE's Liftoff Report), and DOE's Four Pillars to guide our research into current policy proposals. Not all possible policy proposals were considered, although we have tried to be as inclusive as possible and to evaluate at least the most widely recommended policy proposals today.
- Not all policies considered were appropriate for quantitative evaluation. Thus we have some policies with only qualitative evidence. For this reason, our team has sought to be as comprehensive as possible in collecting qualitative data, so that the full impacts of the policy can be shown even in the absence of quantitative data. We believe that this approach, while not complete, can still be useful to policymakers and advocacy groups in understanding which policies can be most effective for heavy industry decarbonization.

Intervention Modeling:

- Our team used reduction estimates from a variety of sources. Estimation methodology may differ from source to source. However, our team ensured that we were pulling information primarily from government sources, especially DOE publications, and secondarily from scholarly or expert sources. Government sources were generally aligned on their methodology, whereas other sources are still reputable. We consider these to be the best available data on emissions reductions.
- Could not find reduction estimates for all policies. Such policies were excluded from the quantitative analysis and evaluated only through qualitative analysis. For this reason, our team has sought to be as comprehensive as possible in collecting qualitative data, so that the full impacts of the policy can be shown even in the absence of quantitative data. We believe that this approach, while not complete, can still be useful to policymakers and advocacy groups in understanding which policies can be most effective for heavy industry decarbonization.
- Reduction estimates may apply to total emissions or to a specific part of the emissions breakdown.
- Some intervention scenarios used year-by-year reduction estimates. We used values (where available) from 2030 and 2050, or alternatively for short-term and long-term scenarios for specific facilities in order to model policy impacts more accurately. Our team selected these facilities according to their location — prioritizing facilities in Energy and Disadvantaged Communities as shown in Table 3 — in order to model how federal funding in these regions can accelerate decarbonization efforts in vulnerable communities. We believe this approach best illuminates the impact of decarbonization policies on environmental justice.

- Reductions are assumed to apply equally and instantaneously to each impacted facility within the given timeframe. Note that not all facilities are impacted by each policy, and some facilities are designated as being affected only in the short- or long-term, as stated in the bullet point above.
- Reduction values are high-end estimates, reflecting maximum emissions reductions achievable through a mature, broadly implemented policy program. We believe this approach to be valid because we are interested in the full potential of each policy; policies that have a greater potential for decarbonization should naturally be considered over policies with lesser potential. Our team has included both short- and long-term reduction estimates to show how these policies can continue to drive down emissions over time as they are implemented across all relevant facilities. We have also included qualitative evidence that supplements the quantitative data, for cases where the quantitative differences between policies are not clear.
- The CEJST map of Disadvantaged Communities partly utilizes data from EPA's EJScreen tool, which uses assumed, instead of measured, values for some census tracts. This is no solution to this issue; it is a data limitation of our project. However, given that this data set is being used across federal agencies seeking to implement Justice40 goals, we consider our approach at least aligned with leading efforts in this space.
- DOE's "Energy Community" program is new and may not yet be implemented in all eligible census tracts. For the purposes of our intervention modeling, we assume that all eligible census tracts will take advantage of government funding through the §48C tax credit.

Final Policy Evaluation:

- Qualitative criteria were (in part) negotiated with our client and may reflect our client's particular interests and goals.
- There was no weighting of qualitative criteria. However, we did try to rate the criteria roughly according to impact, as shown in Table 4. This produced the table in Appendix C, which shows a "heat map" of policy impacts, with "hotter" policies producing more positive impacts across all quantitative and qualitative criteria. This allows readers to understand roughly which policies can be considered more effective than others, according to their particular goals and interests.
- Our team used qualitative evidence from a variety of sources. However, our team ensured that we were pulling information primarily from government sources, especially DOE publications, and secondarily from scholarly or expert sources. Government sources were generally aligned on their methodology, whereas other sources are still reputable. We consider these to be the best available data.
- Our team did not attempt to rank policies according to the evidence compiled. While the purpose of this project is to identify top-performing policies for industrial decarbonization, we recognize that readers are likely to have different

constituencies, policy interests, and goals. Thus we have presented a compilation, instead of a ranking, of policies, so that our research can be utilized for a variety of policymaking contexts.

Appendix H

Simplified, step-wise summary of project methodology. A high-level, step-by-step summary of the steps taken in our project methodology is below. This summary is meant to supplement the overview and in-depth discussion of methodology in Section 3.

A high-level step-wise summary of our methodology is as follows:

1. Downloaded data from publicly available and gold-standard sources that apply to all industries:
    - GHGRP/FLIGHT data from EPA
    - MECS data from EIA
    - Disadvantaged Community census tract data from CEQ
    - Energy Community census tract data from DOE

2. Explored data using Excel and R studio, and narrowed down the databases to our industries of interest in R studio using industry NAICS codes.

3. Applied MECS end-use breakdown to stationary combustion emissions of FLIGHT data and explored the breakdown for each industry. MECS values were converted from energy consumption (in TBtu) to emissions (kg CO_2e) based on fuel-specific emissions factors.

4. We used our knowledge of what types of equipment/processes are present in each industry to match these equipment/processes to the end-use breakdowns. We found that the Cement industry was fairly uniform across facilities and simple in the equipment/processes present applied to each end-use and that the Iron/Steel industry was complex and variable. This led us to explore another way of breaking down Iron/Steel emissions: by process.

5. Researched and utilized a DOE report detailing energy intensities of different equipment/processes specific to Iron/Steel.

6. Used GEM and AIST reports detailing the types of equipment present in each facility to apply unique energy intensity breakdown based on DOE values to each facility based on equipment/processes present.

7. The final product is an inventory of GHG emissions broken down by their source, i.e. the processes/equipment that generated them, for the Iron/Steel and Cement industries. This allowed us to have a better understanding of the hotspots for

emissions in each industry and to more accurately apply emissions reduction estimates for new policies/technologies.

8. We used GIS to visualize our Iron/Steel and Cement facilities and label which facilities exist within an Energy community or Disadvantaged community. In some cases both distinctions applied to the census tract the facility is located in.

9. From our extensive literature review, we identified emerging technologies and promising federal policies in the industrial decarbonization space and pulled emission reduction potentials for each intervention.

10. We used R to apply these emission reduction potentials from each intervention to the current GHG emissions data at the facility level and found the total reduction nationwide, in Energy communities, and in Disadvantaged communities. This allowed us to estimate the impact of each policy and understand distributional impacts as well.

11. We worked with our client to define qualitative criteria for policy evaluation and then researched those criteria for each policy.

12. Quantitative results (from Step 9) and qualitative results (from Step 10) were compiled for each policy, as summarized in the Results section of this report.