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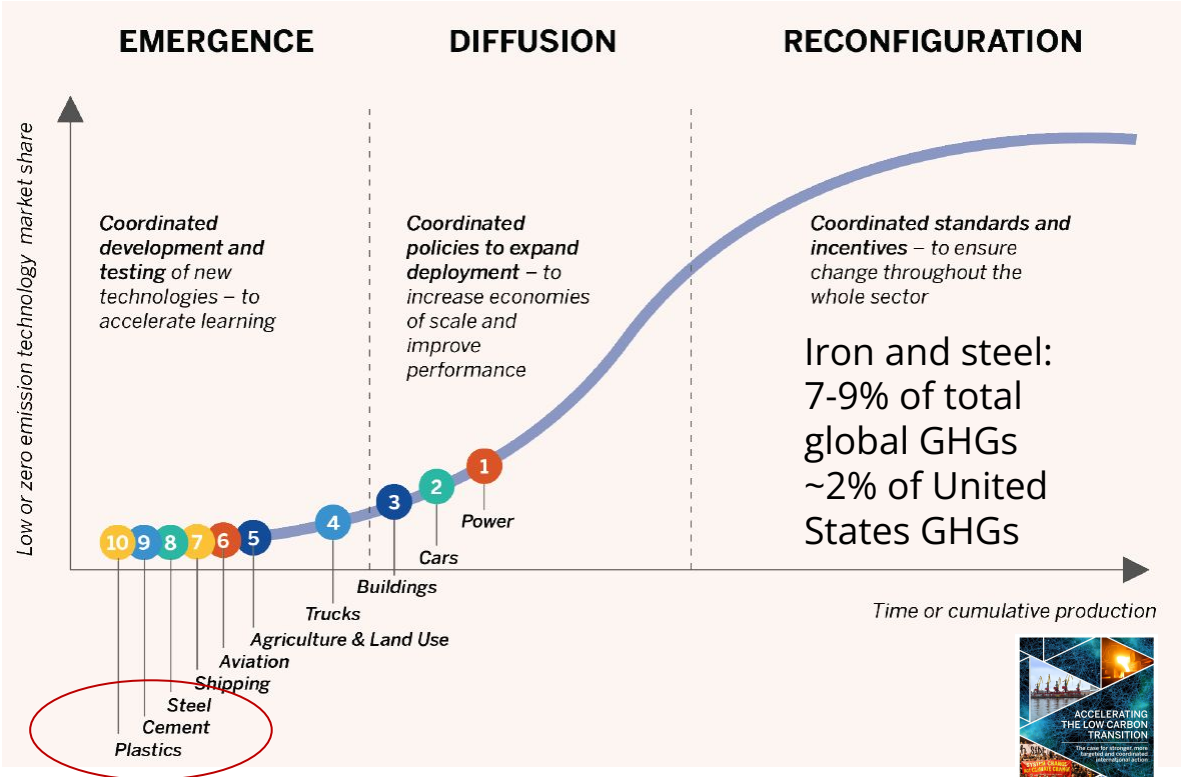
The Costs and Distributional Impacts of Decarbonizing the Iron and Steel Industry in the United States

NBER Industrial Decarbonization Preconference

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Efforts to address GHG emissions from industry are at an earlier stage than cars and electric power



Plastics, cement, and steel have few "consensus" solutions today.

Source: Geels, Victor, and Sharpe, (2019). *Accelerating the Low Carbon Transition*.

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This paper has three goals

1) To describe **technology composition and geography** of iron and steelmaking in the United States today.

2) To evaluate **pathways for deeply reducing greenhouse gas (GHG)** emissions from iron and steelmaking, including effectiveness, costs, and interactions with existing technologies and location-specific inputs.

3) To examine characteristics of the **workforce and communities** near blast furnaces operated in the United States at any time since 2000.





Photo credit: Pixabay, Wikimedia Commons

Iron and steel – Two major pathways in use today



Integrated route
2.2 t CO_2/tcs
72% of production
(~30% in U.S.)



Recycled/mini-mill route
0.5 t CO_2/tcs
20% of production
(+8% DRI)
(~70% in U.S.)

Coke, Limestone

Iron Ore

Natural Gas / Coal

Iron Production

Blast Furnace (BF)
1600-2300° C

Steel Scrap

Liquid Iron

Steel Production

Basic Oxygen Furnace (BOF)

Steel

Natural gas (future: H_2)

Direct Reduced Iron (DRI)
1100° C

Steel Scrap, DRI

Electricity

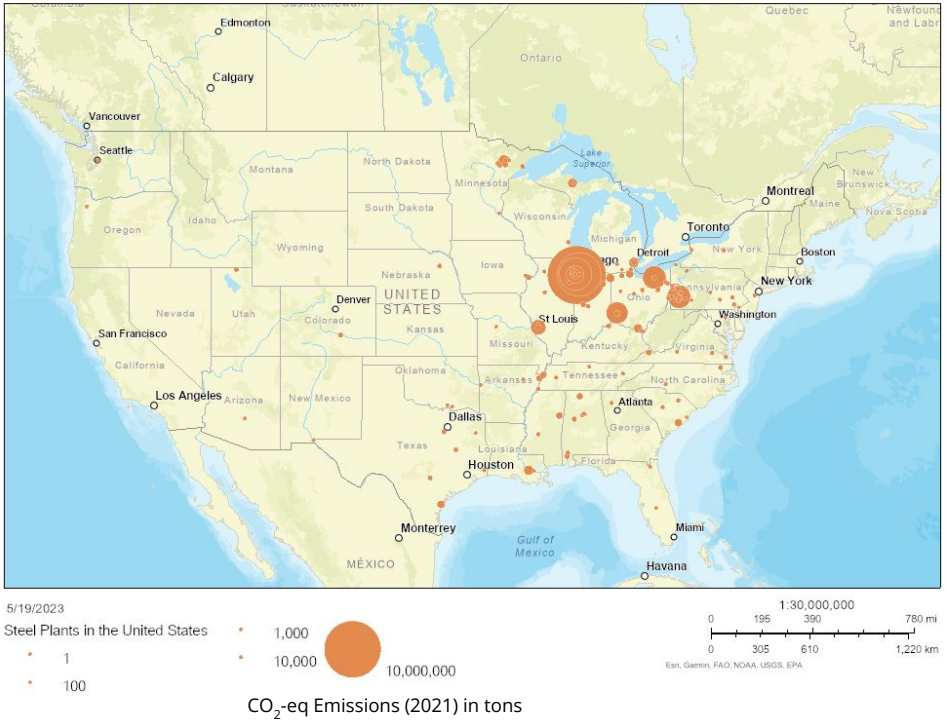
Electric Arc Furnace (EAF)

Steel

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Source: Images from Wikipedia, blast furnace and electric arc furnace.

Greenhouse gas emissions (CO_2-eq) from iron and steelmaking in the United States (2021)



CO_2-eq Emissions (2021) in tons

Source: U.S. EPA FLIGHT (2022) and GEM Iron and Steel Plant Tracker (2022)

9 blast furnaces

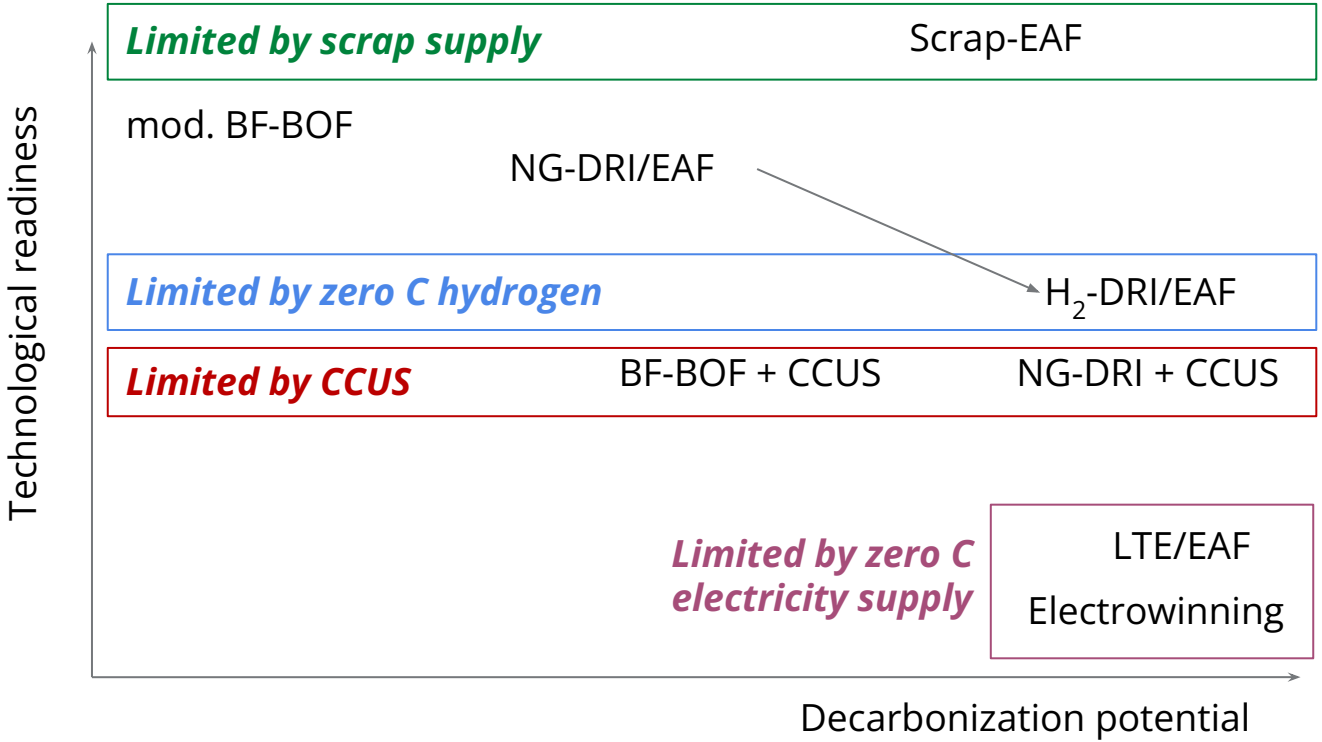
67 electric arc furnaces

3 DRI furnaces

Bubble size is 2021 CO_2-eq emissions in tons

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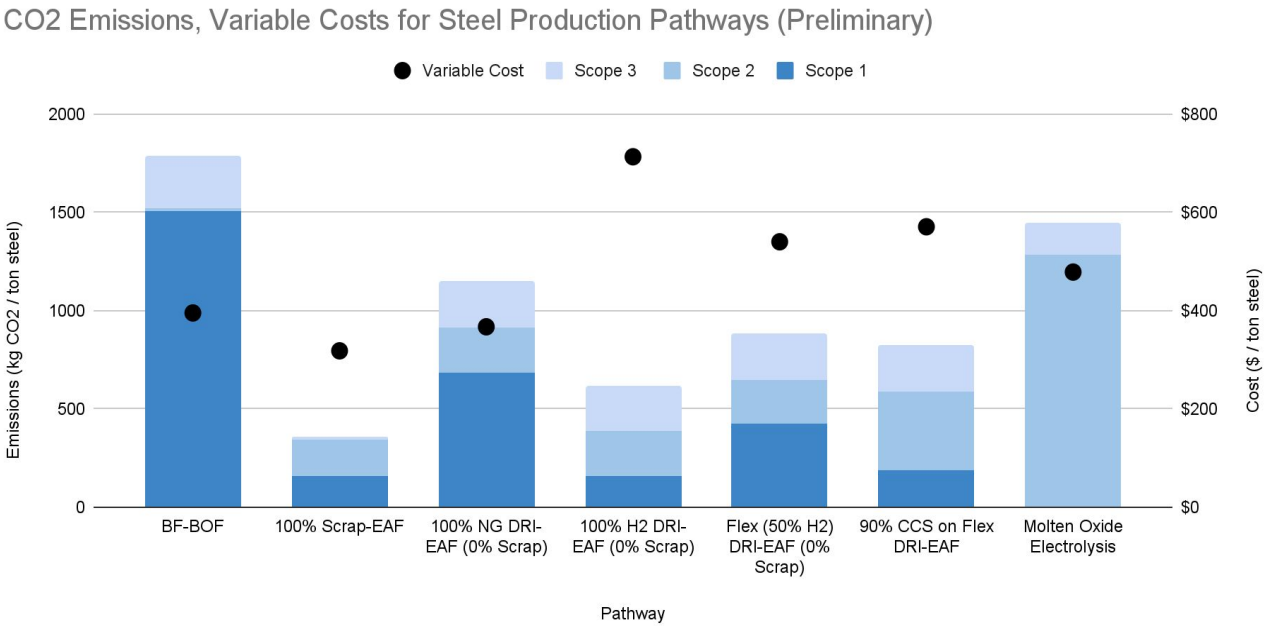
Multiple possible pathways for decarbonizing iron and steelmaking



CCUS - Carbon capture utilization and/or sequestration
LTE - Low temperature electrolysis

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Scope 2 (electricity) emissions grow in importance in all pathways - and flexible operation may be attractive



Notes: Techno-economic analysis by Elina Hoffmann and Katie Jordan (CMU Ph.D. students), based on various public and industry sources. BF-BOF represents Best Available Technology in 2023. Electricity CO_2 based on US 2021 average.
Not modeled: BF-BOF with CCS, incremental BF-BOF retrofits, aqueous electrolysis, biomass
H_2 is assumed to be produced from carbon-free electricity at $4.68/kg (Pistorius, 2022), electricity price of 7 cents/kWh.

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Workforce and Community Impacts

Workforce concerns: low carbon transition may further displace workers with specialized skills in production

Environmental Justice (EJ) concerns: polluting plant siting

- exposure to fine particulate matter <2.5 μm (PM2.5)
- PM2.5: 5th-highest risk factor for mortality globally

Colmer et al. (Science, 2020): absolute disparities in PM2.5 exposure have fallen, but relative disparities persist

- most polluted tracts in 1981 remained most polluted in 2016
- most exposed pops. in 1981 remained most exposed in 2016

Workforce and Community Impacts: Industry shrunk since the 1960-70s

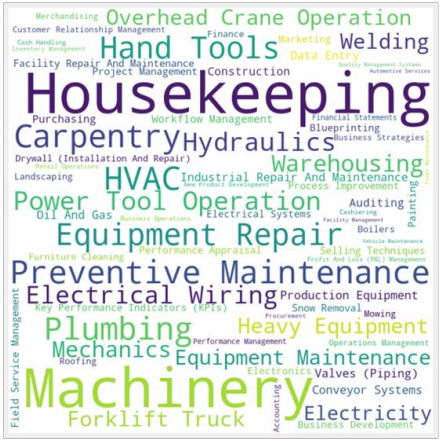
Census of Manufactures - Year	Number of Iron & Steel Companies	Number of Iron & Steel Establishments	Number of Establishments with 100+ Employees	Number of Employees (1,000)	Number of Production Workers (1,000)
1963	161	288	221	500.6	412.3
1967	200	329	216	533.1	434.0
1972	241	364	209	469.1	379.3
1977	395	504	205	441.9	350.2
1982	211	301	179	295.8	215.2
1987	271	342	155	188.1	147.0
1992	136	217	155	170.6	131.4
1997	191	273	162	146.2	114.9
2002	283	373	157	118.8	93.2

Worker specialization may make it challenging to re-employ iron and steel workers in other industries

Management Occupations



Installation, Maintenance, and Repair Occupations



Production Occupations



Source: Compiled from job postings in Lightcast by Jillian Miles (CMU Ph.D. student).

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Data

Location of U.S. blast furnaces in operation

• U.S. EPA's Facility Level Information on Greenhouse Gases Tool (FLIGHT)

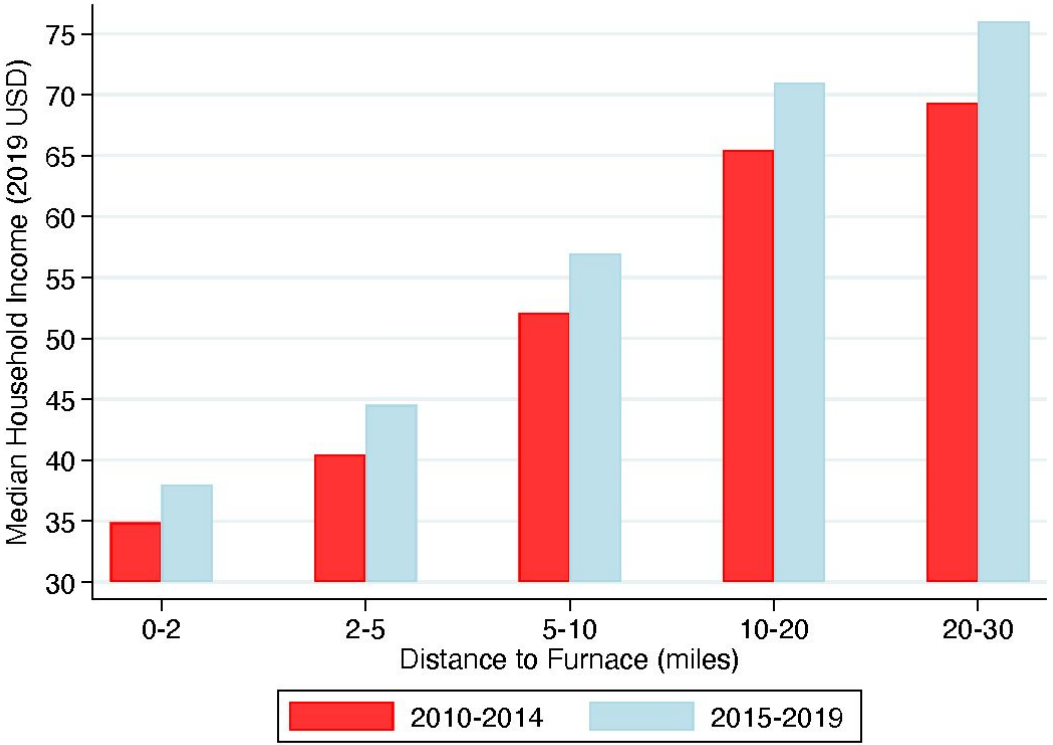
Demographic and socioeconomic variables

• American Community Survey (ACS)
    • 5-year averages: 2010-2014 & 2015-2019
• data at census block group level: 600-3,000 people

PM2.5: van Donkelaar et al. (EST, 2021)

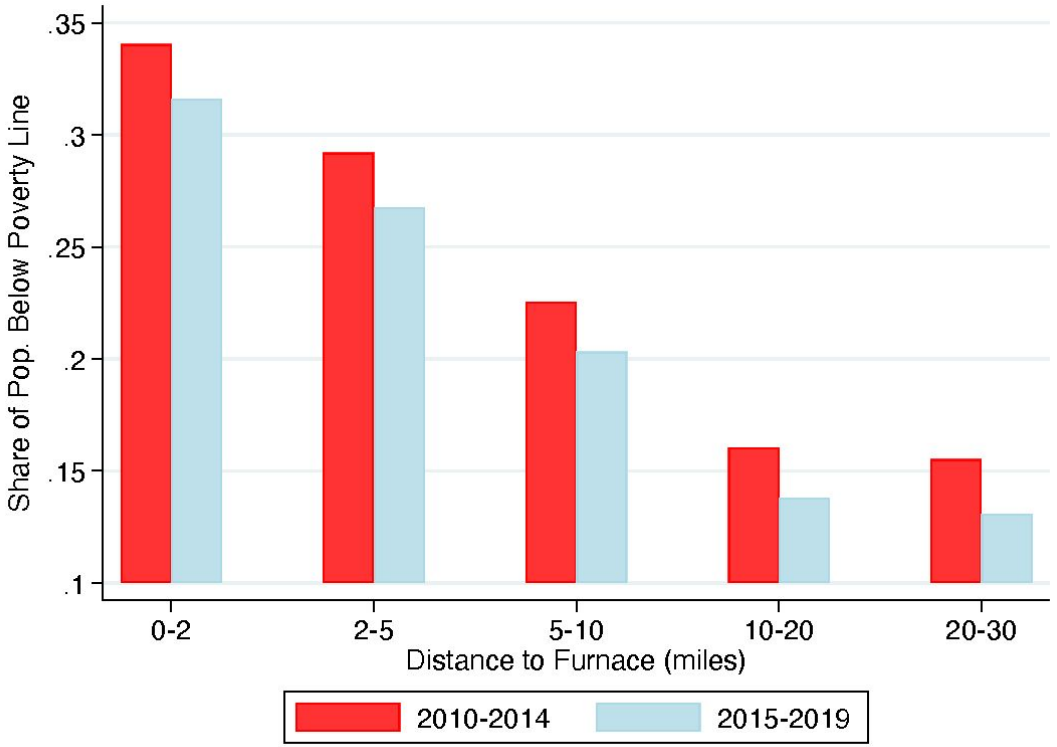
• annual mean in μg/m3 at 0.01° x 0.01° resolution (0.7 x 0.7 miles)
• satellite + chem transport model + calibration (ground-based obs.)

Median Household Income (1,000s)



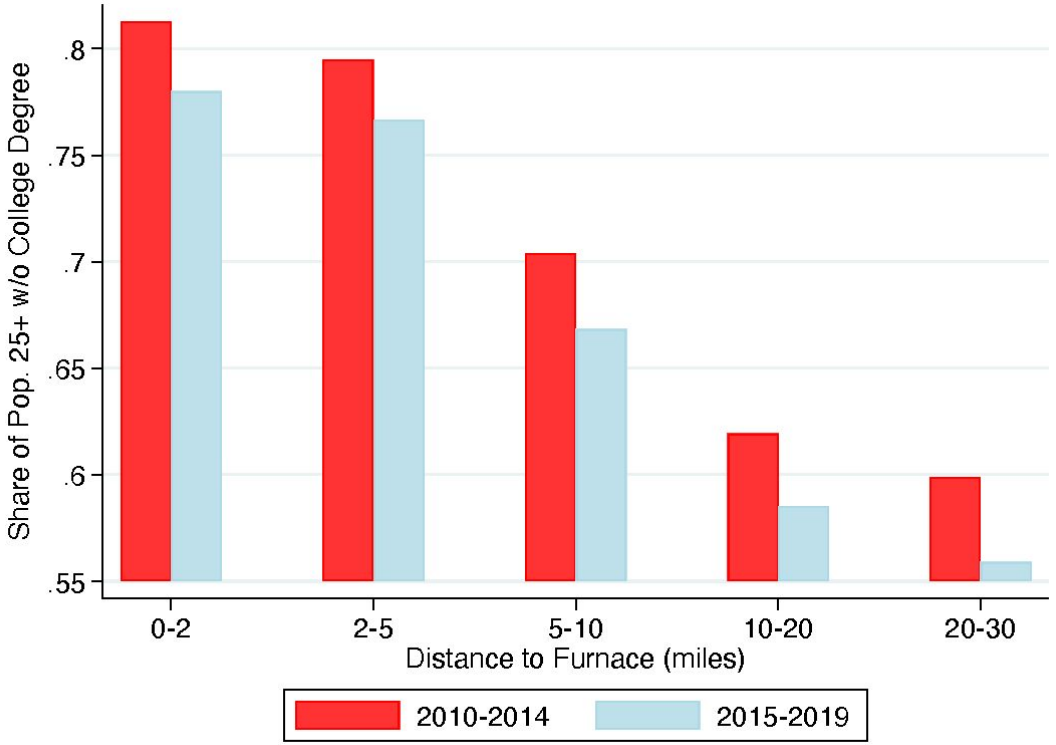
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Share Below Poverty Line



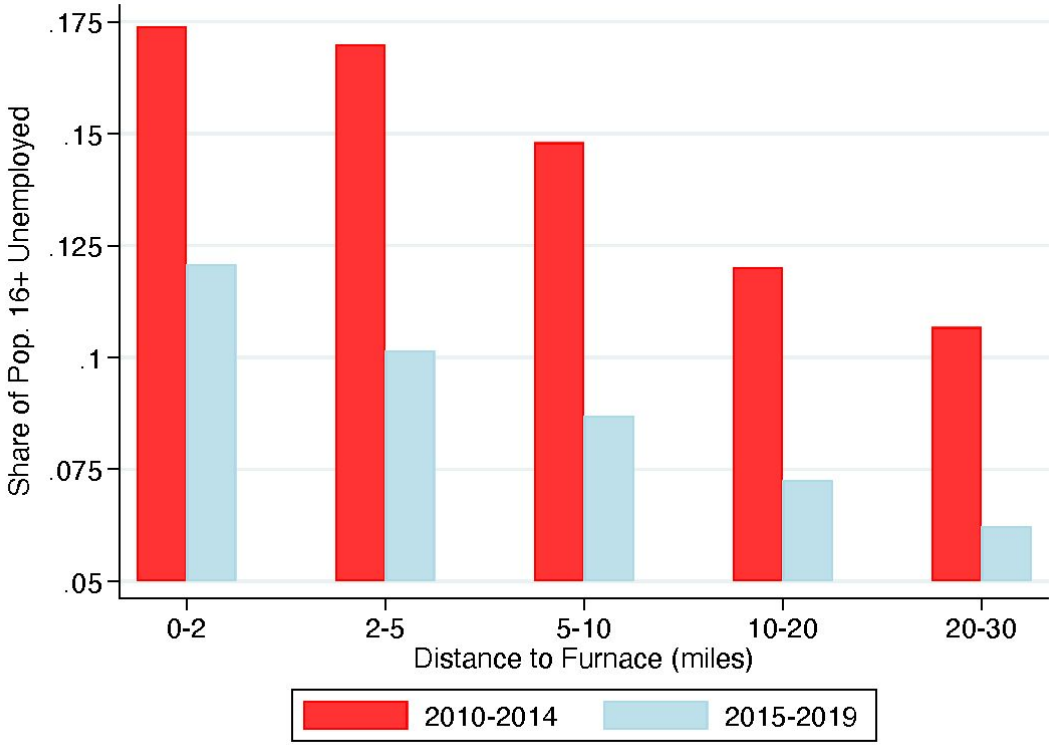
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Share of Pop. 25+ *Without* College Degree

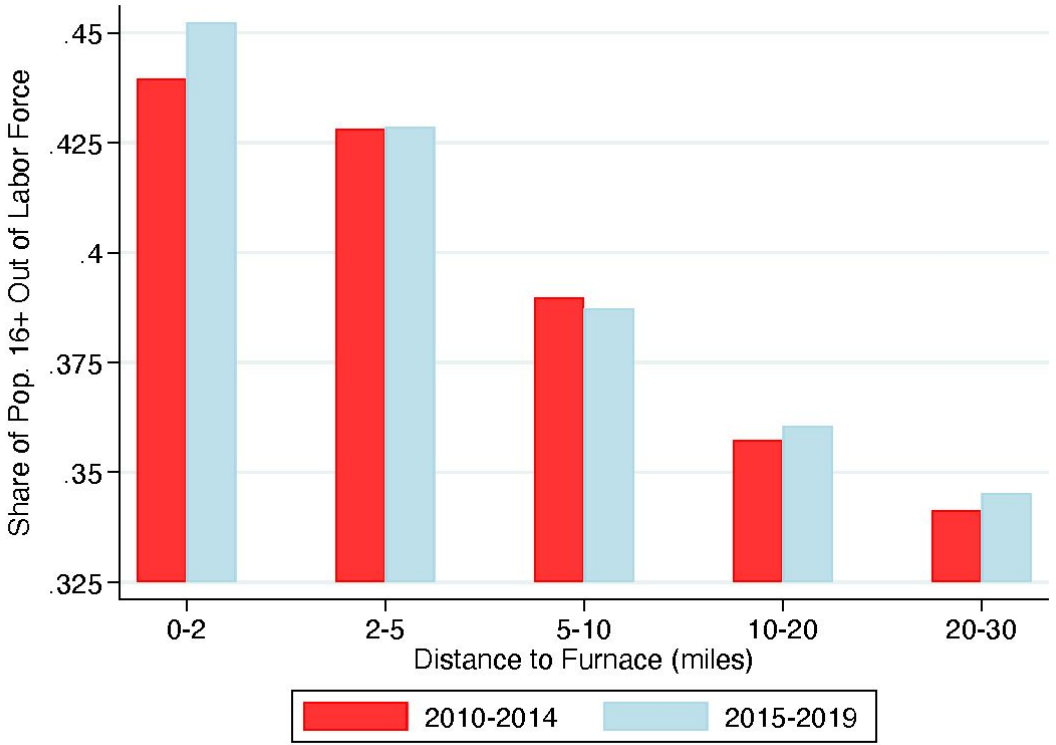


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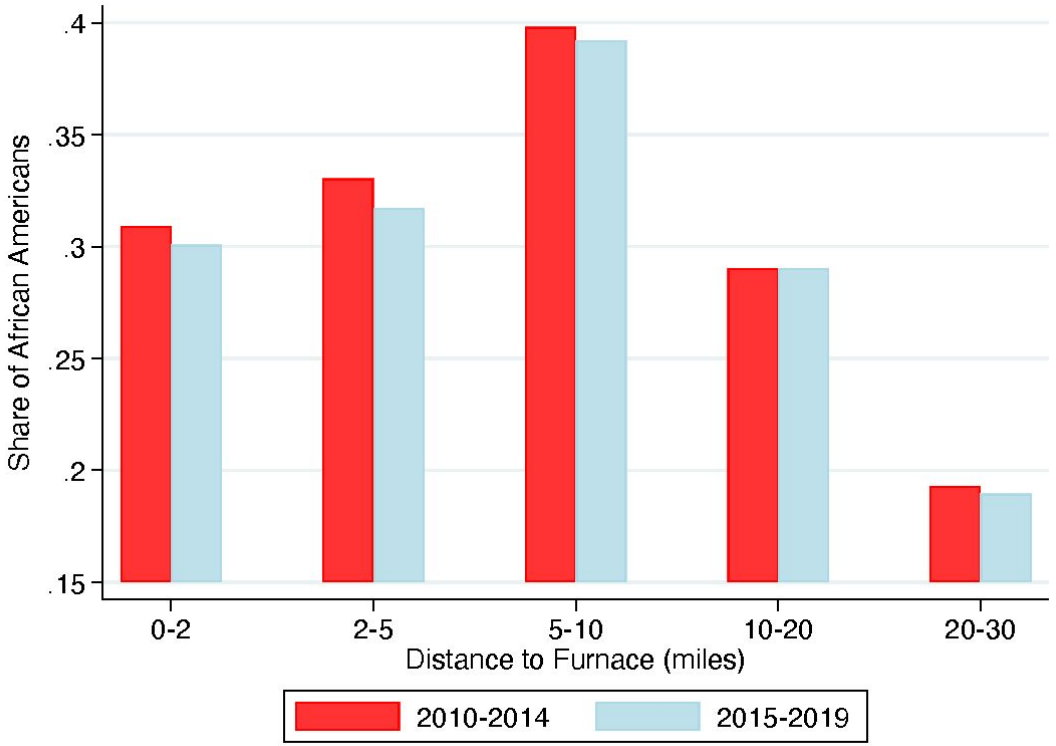
Share of Pop. 16+ Unemployed



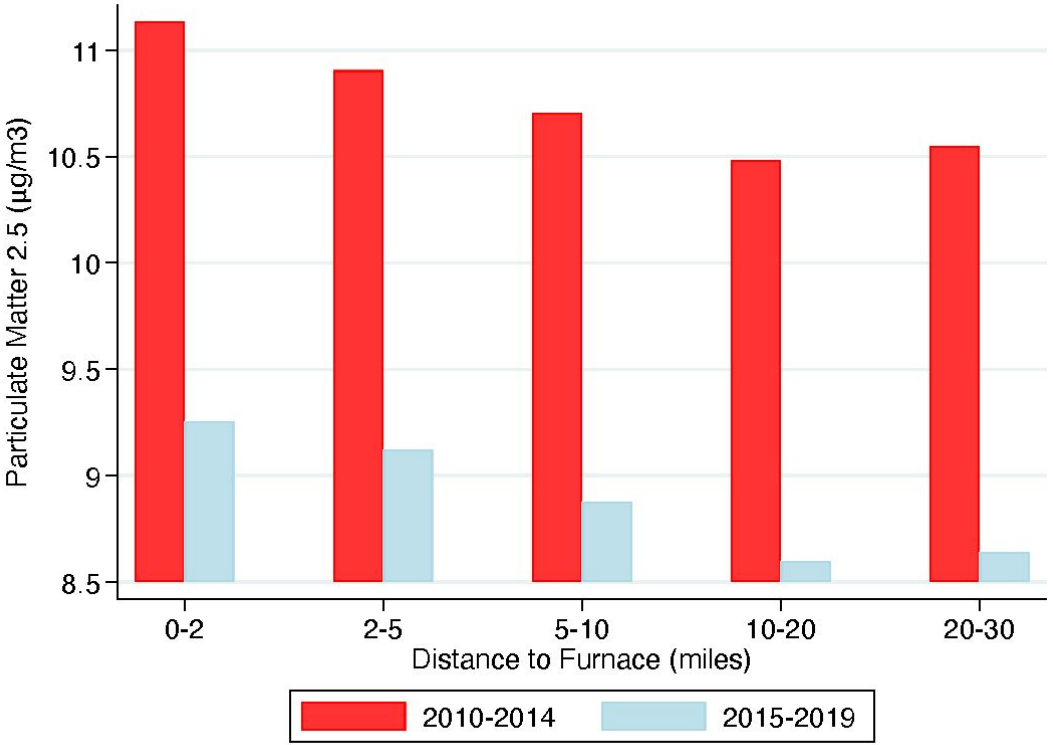
Share of Pop. 16+ Out of Labor Force



Share of African American Residents

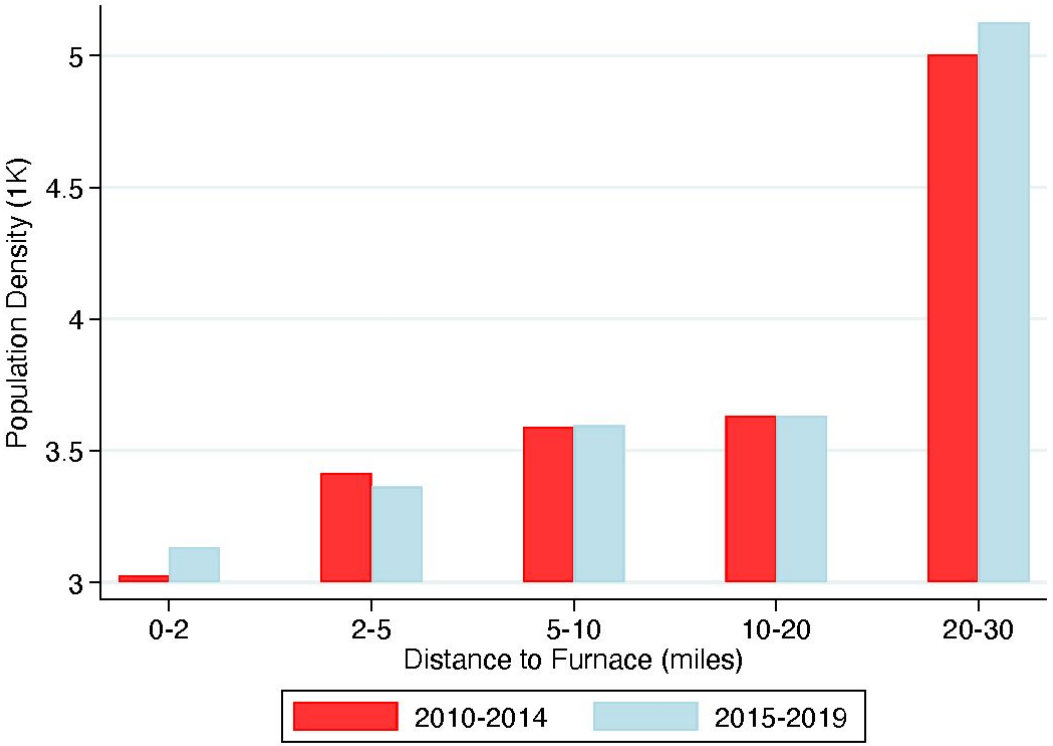


PM2.5 Exposure (Difference ~ Impacts of 1997 NAAQS)

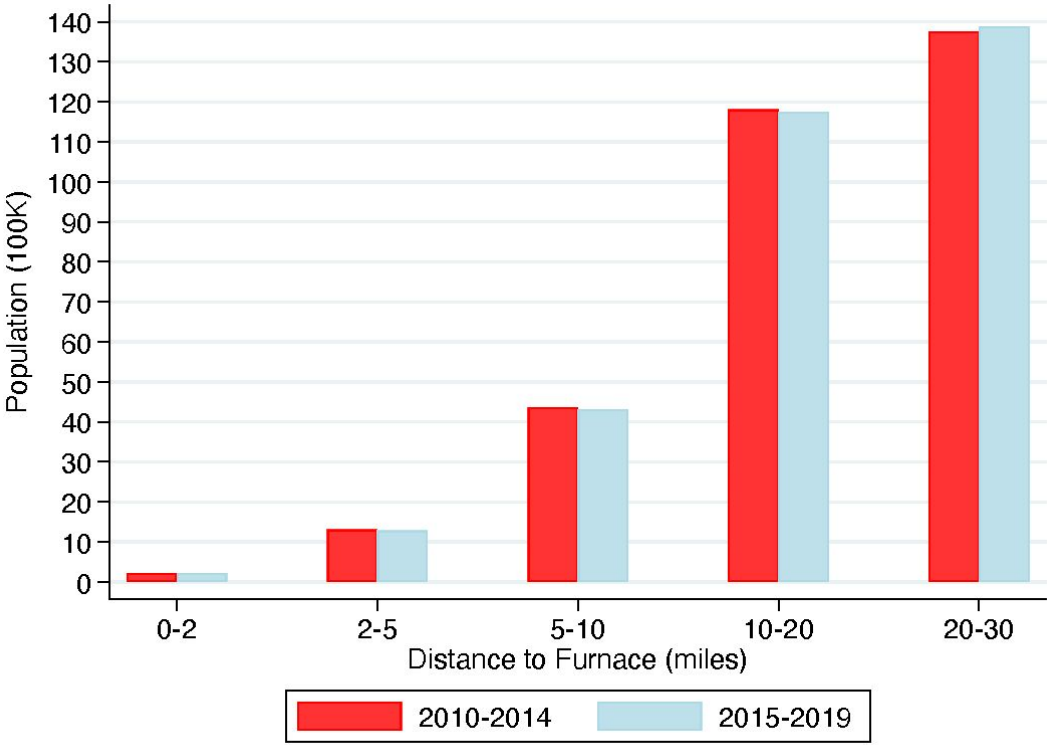


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Population Density



Total Population



Conclusions

There are already technologies/processes to reduce CO_2 emissions

- NG-DRI + EAF, Scrap + EAF, but scrap supply might be limited
- Deep decarbonization potential depends on zero-CO_2 electricity for iron and steelmaking processes, for H_2 production, and for CCS operation

New technologies and policies might accelerate decarbonization

- e.g., H2-DRI + EAF, BF + BOF + CCUS, infrastructure + IRA investments

Disadvantaged populations live around iron & steel plants

- Need to retrain workers and/or create wage insurance programs
    - *similar to programs for workers affected by trade shocks*
- Decarbonization might have important co-benefit of reducing $PM_{2.5}$

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Thank you!

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