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EMBRACING CLEAN HEAT

Opportunities for Zero-Emission Industrial Boilers

Executive Summary

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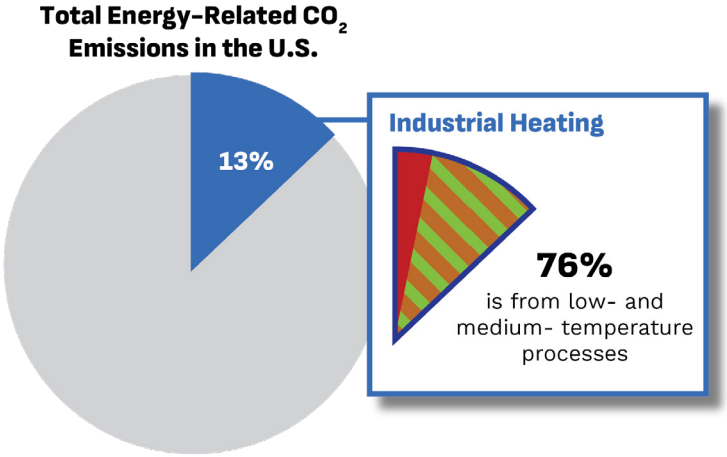
Executive Summary[1]

A strengthened domestic industrial base can invigorate the U.S. economy, revitalize many American communities that have suffered years of disinvestment, and help rebuild a robust, unionized American middle class. But the industrial sector's current dependence on oil and gas means that, in the absence of clean manufacturing technologies and practices, any growth will bring pollution that endangers public health, puts up hurdles to meeting international climate targets, and threatens international competitiveness. Phasing out fossil fuel combustion from industrial processes is therefore an increasingly urgent prerequisite to support responsible investment and sustainable economic growth.

While there is no silver bullet to tackle the staggering volume of pollution from American industry, there is one process element in the sector that contributes a far greater share of both greenhouse gases (GHGs) and conventional pollutants than any other: heat. The U.S. industrial sector encompasses everything from petrochemical production to paper-making, but across subsectors and processes, applying heat "to transform materials into useful products" (as described by the U.S. Department of Energy) is nearly universal. Phasing out fossil fuel combustion to generate industrial heat would cut pollution across the board– a critical opportunity for cross-sectoral emission reductions given U.S. industry's heterogeneity.



A recently published report from the Center for Applied Environmental Law and Policy (CAELP) found that combustion boilers alone across eight subsectors emit over 70 million metric tons of

1 This document is the executive summary of a larger report published by Evergreen Action and Sierra Club titled *Embracing Clean Heat: Opportunities for Zero-Emission Industrial Boilers*. The full report, plus appendices and a full list of cited sources, is available here.

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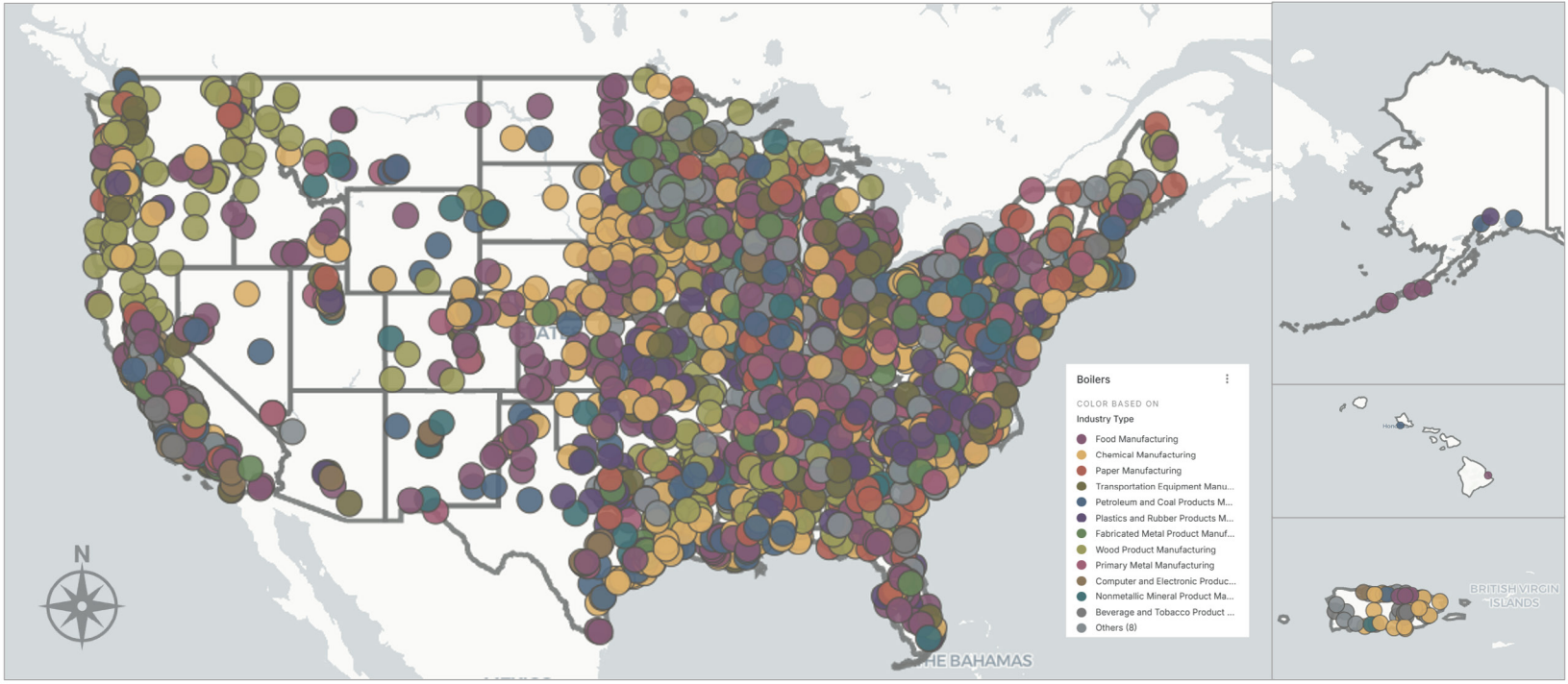
CO_2 annually and that thermal processes below 200°C account for 75 percent of all heat demand from industrial boilers. Because of combustion boilers' outsized pollution footprint, and because the most efficient electric alternatives are readily available in these key temperature ranges, **this report focuses primarily on electrifying fossil-fueled industrial boilers that operate at low and medium temperatures to deliver indirect process heat**. In a range of contexts, manufacturers can begin to replace traditional fuel-combustion boilers with commercially available electric equipment—including stand-alone or combined applications of industrial heat pumps for temperatures up to 200°C, conventional electric boilers for applications in the 200-500°C range (and in some cases much higher), and thermal batteries for a very wide range of temperatures (with added grid demand flexibility as a co-benefit).

The urgency to act on industrial emissions is growing, and in many states, the political and economic conditions are aligned to support long-term investments in clean, modern manufacturing systems. This report is designed to help regulators, advocates, and others help translate those conditions favoring clean industrial heat into a widespread, on-the-ground reality.

Emissions Impacts of the Current Industrial Boiler Fleet

Comprehensive and reliable data on industrial boilers, particularly with respect to emissions of criteria and hazardous air pollutants, have remained incomplete, and the data that exists has been difficult to utilize at the equipment level. Building on work from Energy and Environmental Analysis, Inc. (E3), CAELP, Northwestern University, and UC Santa Barbara, we have sought to fill those gaps by developing a first-of-its-kind emissions dataset for the full fleet of U.S. industrial boilers, with nearly 14,000 boiler units and the conventional pollutants they emit.

This refined dataset is visualized in an online interactive National Map of Industrial Boilers, designed to empower national, state, and local efforts to understand the geographically distributed environmental impacts of the current industrial boiler fleet as a first step in mitigating those emissions. The map's dynamic features allow users to filter and explore the data by various parameters such as state, fuel type, subsector industry, unit capacity, and proximity to environmental justice communities, facilitating targeted analysis of emission trends. For the purpose of this report, we highlight and explain several key findings from our analysis of the data:



Online Interactive National Map of Industrial Boilers (number of boilers by subsector)

1. Boilers generate 6 percent of all industrial nitrogen oxides (NO_x) pollution and 5-10 percent of all industrial carbon dioxide (CO_2) pollution in the U.S.
2. Nearly 40 percent of boilers across the U.S. are installed in 5 states: California, Illinois, Minnesota, Massachusetts, and Texas.
3. 25 percent of industrial boilers are located in areas that do not meet U.S. Environmental Protection Agency's (EPA) National Ambient Air Quality Standards (NAAQS) for one or more pollutants.
4. Just two companies—Westrock LLC and International Paper—operate nearly one-third of the nation's highest NO_x-emitting boilers.
5. NO_x data for boilers is heavily skewed due to high emitters, and 66 percent of the highest-emitting boilers are located in federally recognized disadvantaged communities (DACs).[2]
6. Boilers impose disproportionately higher pollution burdens on DACs, with the average DAC unit emitting nearly twice as much NO_x as the average non-DAC unit.
7. In the southern U.S., boiler units are disproportionately sited in DACs: the states with the highest concentration of reported units operating in DACs are Oklahoma (81 percent), Arkansas (75 percent), and South Carolina (69 percent).

2 We refer here to federally recognized disadvantaged communities as defined by the White House Climate and Economic Justice Screening Tool (CEJST) 2.0, as of December 2024.

Our analysis thus demonstrates not only the substantial scale of criteria and hazardous air pollution emitted by industrial boilers, but also identifies a number of concerning trends, including the disproportionate concentration of boiler facilities in particular states and underserved communities that are already heavily burdened by legacy pollution. Key boiler pollutants, including NO_x, particulate matter (PM), and volatile organic compounds (VOC) pose dire health risks; the pollutants emitted by industrial boilers are contributing to higher rates of lung and heart disease, cancer, and premature mortality in frontline communities across the country. Transitioning from fossil fuel-burning boilers to clean electric alternatives will therefore offer substantial and multifaceted public health benefits.

To further explore these trends and empower localized action, the accompanying interactive map offers a dynamic tool for stakeholders at the national, state, and local levels to investigate boiler emissions within their own jurisdictions.

Alternative Technologies

Technology exists now that can effectively mitigate industrial boiler pollution while revitalizing and future-proofing the U.S. manufacturing sector. Regulators, lawmakers, and advocates must prioritize the replacement of combustion-based boiler systems with clean, electric alternatives. Clean industrial thermal technologies can utilize energy provided from a variety of sources, such as the electric grid, geothermal, and waste heat recovery. This report focuses specifically on electric options, exploring opportunities to replace combustion boilers with industrial heat pumps, conventional electric boilers (i.e., electric resistance or electrode boilers), and/or thermal energy storage systems. However, other clean heat technologies exist as and may be attractive options at some sites.

Electric heat pumps typically operate at efficiencies three to four times greater than combustion-based boilers in low temperature ranges (60-200°C), which cover approximately 55 percent of industrial process heat needs. According to the American Council for an Energy-Efficient Economy (ACEEE), industrial electrification is gaining momentum across the nation. Manufacturers have successfully deployed heat pump technology across various industrial sectors, including pharmaceuticals, food processing, and pulp and paper. Conventional electric boilers can currently achieve higher temperatures than heat pumps without losing efficiency, though their operating costs are somewhat higher. Thermal energy storage can meet even higher temperature needs of up to 1,500-1,600°C while providing demand flexibility and improving grid stability. All three technologies have been deployed and demonstrated, and recent modeling demonstrates that heat pumps and conventional boilers can achieve significant reductions in pollution when standing in for combustion-based boilers.

Emissions Reductions and Economic Impacts of Industrial Boiler Electrification

Recent research shows that the substantial majority of industrial heat pumps installed today will be broadly cost-effective at reducing pollution over the course of their operating lives and, in some instances, can actually reduce facilities' operating costs. While the pollution abatement costs remain higher for applications at temperatures that exceed the current capabilities of heat pumps, electrification is still worth pursuing for many of these sources, particularly where thermal batteries can serve heat storage needs alongside the use of conventional electric boilers.

From our review of the published literature–which include reports issued by CAELP, the Renewable Thermal Collaborative, Energy Innovation, and two studies by the Lawrence Berkeley National Laboratory[3]–the following top-line points emerge:

- **Electric technologies pollute far less CO_2 than combustion boilers, even accounting for upstream emissions from generating electricity.** Considering reasonable projections of renewable energy growth in the electric power sector in the coming decades, the published research finds that the average lifecycle CO_2 emissions associated with newly installed heat pumps are approximately **45 to 80 percent lower** than natural gas-fired boiler emissions over the units' operating lives. For conventional electric boilers, average lifecycle CO_2 emissions are approximately **25 percent lower.**

- **Electric technologies generate far less conventional air pollution than combustion boilers.** The average lifecycle NO_x emissions associated with heat pumps and conventional electric boilers are approximately **80 to 95 percent lower** than gas-fired boilers' emissions over the course of their operating lives. Adopting heat pumps in particular, rather than gas-fired boilers, can save **thousands of lives per year** through reduced criteria and toxic air pollution.

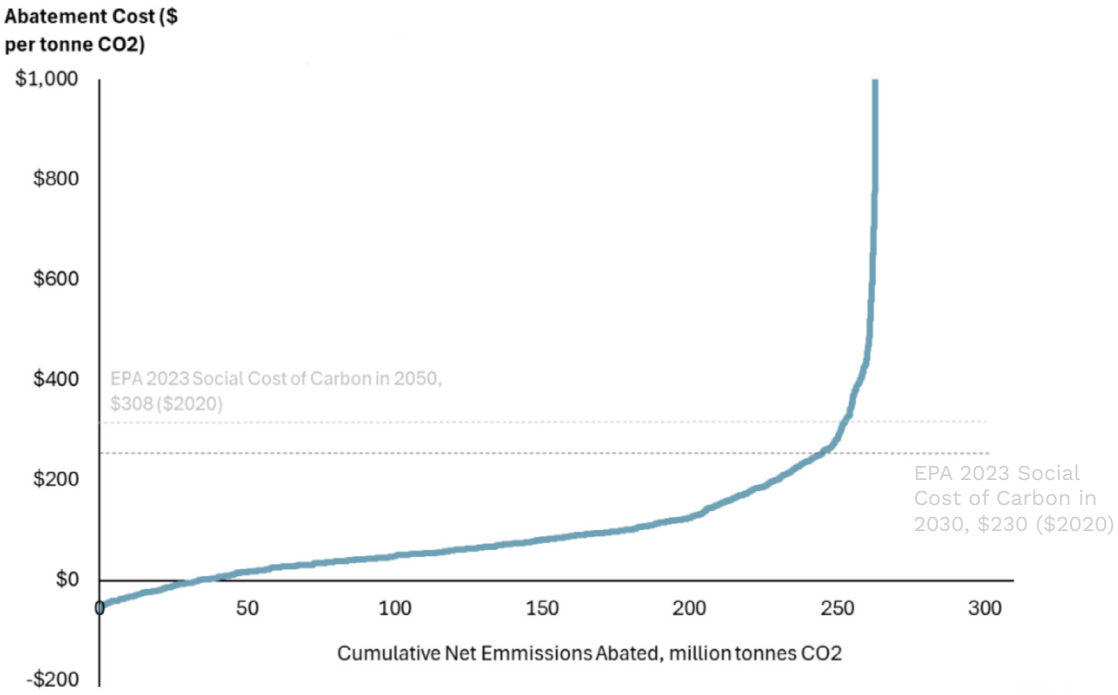
- **At present, the average overall cost of generating industrial heat through electric technologies is somewhat higher than it is for combustion boilers.** The studies reviewed in this report found that the levelized cost of heat—which estimates the overall cost of producing thermal energy from a particular technology—most often falls in the range of approximately **$10-30/million British thermal units (MMBtu) for heat pumps**. For conventional electric boilers, this figure is most often in the range of $20-25/MMBtu at lower temperatures and can extend into the **$30-50/MMBtu** range for higher temperatures. For gas-fired combustion boilers, the levelized cost of heat is lower—typically in the **$7-15/MMBtu** range–primarily because of the historically consistent cost differential between gas and electricity.

3 Specific citations to these studies are provided in our full report.

- **However, the lifetime emission reduction benefits from replacing gas-fired boilers with heat pumps already exceed the additional operating costs in the vast majority of cases.** Industrial heat pumps have such high efficiencies that the climate benefits of the CO_2 reductions they will provide over the course of their operating lives, when quantified in dollar figures, outweigh any additional operating or capital costs compared to gas-fired boilers for **over 90 percent of units.** This projection does not even account for the additional benefits of reduced criteria and hazardous pollution and avoided upstream emissions of methane that result from boiler electrification. All told, then, an industrial heat pump installed today will almost certainly provide net benefits even accounting for the possibility of higher operating costs compared to gas-fired units.

  The figure below is adapted from the CAELP report cited above, which modeled the costs and benefits of replacing gas boilers with heat pumps across a range of representative states. CAELP found that for the vast majority of modeled units, switching to heat pumps will provide CO_2 emission reductions at a cost that falls below (and in most cases well below) EPA's best estimations of the monetized benefits of those reductions.

Cost abatement figures for heat pump adoption (adapted from CAELP)



Source: adapted from CAELP, Decarbonizing Industrial Heat: Measuring Economic Potential and Policy Mechanisms, p.43 (2024)

- **The additional costs of switching to conventional electric boilers currently exceed the monetized value of their CO_2 emission reduction benefits in most cases, but multiple factors still favor their installation over gas-fired units.** While conventional electric boilers also provide substantial environmental and public health benefits compared to gas-fired units, they cannot on their own achieve the same level of efficiency as heat pumps. Because of this, the additional operational costs of replacing gas-fired boilers with conventional electric units will, in most cases, be greater than the monetized value of the lifecycle CO_2 emission reductions they will achieve—though this is expected to change as the electricity generation grid further decarbonizes. However, the additional benefits conventional electric boilers provide by reducing other pollutants and upstream methane emissions, as well as the opportunity to reduce costs by pairing them with thermal batteries where possible, should encourage their adoption where appropriate.

Policy Drivers for Boiler Electrification

A wide array of policy strategies are available to help encourage the adoption of clean thermal technologies like industrial heat pumps, conventional electric boilers, and thermal batteries. This discussion is not meant to be exhaustive, nor are any of the policy options discussed exclusive of one another. Instead, the options outlined below represent the kinds of regulatory or legislative tools that may help electrify industrial heating processes.

State-Level Emission Standards for Boilers. The Federal Clean Air Act (CAA) expressly preserves states' authority to adopt pollution controls for stationary sources like industrial boilers that are more stringent than parallel EPA requirements (or even where EPA has no such federal requirements). State governments therefore can and should take near-term action to clean up boiler pollution within their own borders and advance electrification efforts. In the full report, we provide some illustrative examples of states that either have already initiated regulatory efforts along these lines or are well-poised to do so. For instance, two air districts in California have already issued regulations that will phase in zero-emission requirements for small industrial boilers (i.e., up to 2 MMBtu/hr) later this decade, and California's Air Resources Board plans to develop similar requirements that will apply statewide. We also discuss Illinois and Minnesota, whose legal and regulatory tools and substantial boiler fleets make them prime candidates to adopt state-level standards geared toward boiler electrification.

Federal Clean Air Act Strategies. The CAA provides numerous opportunities for EPA—and, in some cases, states working cooperatively with the agency—to reduce industrial boiler pollution and incentivize electrification. These include the following three programs:

- **Section 111.** Section 111 directs EPA to issue standards of performance for stationary source categories such as industrial boilers. Subpart (b) of the program—which is not limited to any particular class of pollutant—covers new and modified sources, and is directly administered by EPA. Subpart (d), on the other hand, covers existing sources of pollution, and only authorizes emissions standards for pollutants (like CO_2) that are neither criteria nor hazardous air pollutants. Once EPA issues existing source guidelines for a category, states then issue and enforce standards through state plans that are subject to EPA approval and that must be no less stringent than the guidelines.

- **Section 112.** This CAA program addresses hazardous air pollutants (also known as air toxins), which includes those that cause cancer, neurological or birth defects, or similarly harmful outcomes. Under section 112, EPA must issue standards for both new and existing "major sources" of hazardous air pollutants within a listed category. Major source standards must reflect the "maximum available control technology" for those units. For sources in a listed category that fall below the major source threshold, EPA may issue similarly stringent standards, but may in many cases instead impose "generally available control technology" requirements. While the agency has regulated coal and oil-fired industrial boilers under section 112, it has issued no meaningful standards for gas-fired boilers.

- **The NAAQS Program.** The CAA's NAAQS program covers pollution caused by a diverse array of sources that linger in, and degrade the quality of, ambient air. EPA sets nationally applicable maximum concentration levels for ambient pollutants, and states then develop implementation plans that ensure that their air quality will not exceed these levels. States with areas not in compliance with the NAAQS must develop non-attainment implementation plans that, among other things, include requirements for "reasonably available control technology/measures" (RACT/RACM). States with NAAQS nonattainment areas for ozone, NO_x, or PM could adopt electrification requirements for industrial boilers in order to meet their RACT/RACM obligations.

Financial support programs. In addition to the "sticks" of regulations, policymakers can encourage boiler electrification through various financial "carrots," several of which we explore in the full report.

- **Tax credits.** Just as federal tax credits have been critical in helping expand wind and solar electricity generation, similar policies can be implemented at the federal and state levels to support clean industrial heat. The CAELP report described previously found that a clean heat production tax credit, which would apply to each unit of industrial heat produced by non-emitting technology, would be particularly helpful in advancing boiler electrification. An investment tax credit, which would apply to each unit of installed clean thermal capacity, would likely provide more modest benefits, but may still be worth pursuing in certain areas or sectors, particularly when paired with other programs.

- **Grants and financial incentives.** The Inflation Reduction Act included subsidies to encourage clean manufacturing, as have policies implemented in states like Colorado, New York, and Pennsylvania. They provide a precedent and framework for grant programs that are specifically designed to replace fossil fuel-fired boilers with heat pumps, conventional electric boilers, and other non-emitting options.

- **Loan programs.** Various loan programs—including loan guarantees and loans offered at low rates or long repayment terms—have often been used in the past to support emerging industries and technologies. Instituting similar programs at the federal and state level could help manufacturers switch to non-emitting industrial boilers. Because the operating costs—rather than upfront capital requirements—tend to be the biggest barrier to widespread boiler electrification, loan programs may be considered a lower priority than (for instance) a production tax credit, but could still help owners and operators shoulder the cost of upgrading their boiler fleets.

- **Workforce support.** Various labor-oriented policies, including union partnerships and investments that prioritize existing facilities and legacy workforces, can help ensure that a transition to clean industrial heat will work in favor of, and not against, working people to the greatest extent possible.

Other policies. Lastly, our report touches upon a host of other strategies to help electrify industrial heating processes, particularly when paired with the primary policy drivers described above. These include (but are not necessarily limited to) the following options:

- **Carbon price.** This option—which Canada and the EU have adopted—could take various forms, including the imposition of a fee on the CO_2 emitted by certain large sources or industries. It could also take the form of a carbon border adjustment

mechanism, which could help ensure that domestic manufacturers that electrify their boiler fleets do not face a competitive disadvantage from foreign manufacturers who do not similarly adopt clean industrial practices.

- **Permitting reform.** Federal regulations currently limit the extent to which air permitting authorities can require applicants to consider and adopt alternative clean technologies before building a new source. States, however, may impose more environmentally protective permitting requirements, and can design their programs to encourage or even require that new boilers use electric technology under certain circumstances.
- **Defense Production Act.** A federal administration interested in advancing industrial electrification could use the Defense Production Act to ramp up heat pump production by private companies, thereby supporting legitimate national security interests by mitigating climate change and supply chain vulnerabilities.
- **Roadmapping and technical assistance.** State leaders and policymakers can undertake planning and visioning processes that help maximize the benefits of boiler electrification while preparing for potential challenges. This could entail future-of-gas proceedings in state public utility commissions, the issuance of comprehensive climate action plans, or assistance programs that provide technical resources and facilitate communications across stakeholder groups.
- **Energy storage tariffs.** Specialty utility rates can help close the gap between electricity and gas prices that thus far has presented a challenge to more widespread adoption of clean industrial heat. These reforms could be particularly helpful in expanding the market participation opportunities for thermal storage technology, allowing operators to cost-effectively electrify industrial heat at much higher temperatures.
- **Utility reforms.** Various other utility reform policies have the potential to expand the use of clean industrial heat. These options could include electrification incentives for industrial customers provided by utilities themselves, dynamic pricing arrangements, or efficiency-based subsidies that, in practice, favor heat pumps over combustion units.

More detail on the need, opportunity, and legal tools to advance industrial boiler electrification is available in the complete version of this report, titled *Embracing Clean Heat: Opportunities for Zero-Emission Industrial Boilers*.