How to Decarbonize Industrial Process Heat While Building American Manufacturing Competitiveness

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The world is in the midst of an energy transition: From 2022 to 2023 global renewable power capacity increased by 50%, and in 2023 84% of new power plant capacity in the United States came from clean sources. The economics now favor renewable generation over fossil fuel–based energy in most cases. As the grid decarbonizes, energy efficiency and electrification of combustion sources for buildings, vehicles, and industry deliver the most straightforward path to rapidly slashing a substantial portion of carbon emissions across our economy.

The industrial sector is likely to become the highest emitting economic sector, if new manufacturing investments are not also paired with rapid deployment of decarbonization solutions (Larsen et al. 2023). It is time for U.S. industry, long considered the "hard to decarbonize" sector, to take full advantage of clean electricity and to stop relying on fossil fuels. Technologically and economically, industrial decarbonization is feasible, but it will only occur with robust public policies.

In the following sections, we make the case for electrifying industrial process heat and lay out the challenges and opportunities, followed by key actions that can be taken by four major stakeholder groups, beginning on page 10: U.S. federal policymakers, U.S. state and local policymakers, utilities and system planners, and regulators.

The goal of electrifying 70% of all industry process heat by 2050 is both ambitious and achievable.

A resilient and competitive industrial sector is key to rebuilding U.S. global competitiveness. Electrification provides the most efficient technological route to clean manufacturing for most industrial process heating—particularly the low- to medium-temperature range (below 300°C)—but requires more upfront planning and in many cases a significant shift in operational strategies compared to continued reliance on fossil fuels of the past (Rissman 2022).

The economic case for electrification can be a winning one in the long term for industry. An estimated 40% of current industrial emissions can be addressed by deployable technology with net-positive economics by 2030, including electrification technologies within most of the major energy-intensive industrial sectors (Scott et al. 2023). However, the upfront logistical and financial challenges are formidable; they stem from supply chain complexity, industry inertia, limited adaptability in the workforce, and outdated electricity supply infrastructure. We will not overcome these obstacles without robust policy support—and the need is urgent.

We already have many of the commercially viable technologies we need for industrial transformation; substantial capital investments from both the federal government and private equity are fueling the rapid growth of domestic manufacturing; communities are hungry for economic development

opportunities—but they prefer factories powered by clean energy (e.g., Ye and Miller 2023; General Motors 2022).

The case for industrial electrification in the United States

The problem: The United States is currently falling behind other countries on investments into the clean manufacturing facilities of the future.

Without significant transformative changes, the United States risks forfeiting the opportunity to reclaim global leadership in industry. Manufacturing investments in the United States have steadily increased since 2020 but jumped 63% in 2023—the largest increase in manufacturing spending since 1951—driven in large part by over $256 billion in new investments in clean energy, semiconductor, and EV manufacturing facilities announced since the Creating Helpful Incentives to Produce Semiconductors and Science Act (CHIPS) and Inflation Reduction Act (IRA) were signed in August 2022 (Niquette 2024; Conness 2024). Despite this growth, China, the country with the largest manufacturing sector—93% of Chinese exports were manufactured goods in 2022 (World Bank Group 2024)—still invested more than twice as much as the United States into clean energy projects in 2023 (Catsaros 2024).

To restore the competitiveness of U.S. industry, we must invest in building new, modern factories while simultaneously upgrading aging existing ones. And we must invest in expanding our electric system to provide all new and renovated industrial facilities with clean power. Some industrial sectors in the United States are less carbon intensive and more efficient than in most other countries—for example, emissions intensity from the U.S. steel sector is quite low compared to most other major steel producing countries (Hasanbeigi and Springer 2019b). But in other industrial sectors, like aluminum and cement, production from U.S. facilities remains comparatively carbon intensive and polluting (McKenna 2022; Hasanbeigi and Springer 2019a).

All industrial manufacturing sectors have the technical potential to substantially increase process heating electrification. Process heat accounts for about half of all onsite energy use and represents about 30% of greenhouse gas (GHG) emissions in the U.S. industrial sector. Only ~5% of industrial process heat is currently electrified, despite the commercial availability of technology appropriate to electrify most needs (DOE 2022). Commercially available electrification technologies with applications to lower temperature heating needs include industrial heat pumps, electric furnaces and boilers, ultraviolet curing, and infrared heating. Low-medium temperature process heating demand accounts for approximately two-thirds of U.S. total manufacturing process heating demand (Rissman 2022; Renewable Thermal Collaborative 2022b).

Electrifying all process heat under 300˚C with clean electricity by 2050 would potentially allow for an approximately 30% reduction in total industrial GHG emissions, not factoring in the growth of U.S. manufacturing (Renewable Thermal Collaborative 2022b).

As new factories are built and the power sector continues to decarbonize, electrification must be deliberately prioritized as an efficient and sustainable pathway forward for all manufacturing sectors. Industrial electrification should be implemented in new facilities to avoid locking in additional GHG emissions from the expansion of fossil fuel–based process heating in the United States.

Industrial investments and associated electricity demand are already growing at an unprecedented pace, but the grid is not ready to accommodate these needs. The national energy growth forecast for the next five years doubled between 2022 and 2023, largely driven by industry and data center expansions (Wilson and Zimmerman 2023). The growth rate is likely to continue to rise as more industrial investments are announced and more industrial facilities break ground in the coming decade.

Industrial electrification loads will grow as new investments in clean energy manufacturing flow from both the private and public sectors. The growth is currently largely driven by semiconductors and batteries, followed by electric vehicles, wind, and solar. A snapshot representation of current patterns of investment is shown in figure 1. The Southeast, Southwest, and Midwest regions are most likely to experience industrial process heat electrification pressures first. If we were to electrify all existing industrial processes, electricity consumption could increase by at least 6,000 TWh—more than the current total national demand (4,300 TWh in 2022) and at least three times the demand from switching all cars to electric vehicles (2,000 TWh) (Rissman 2024). It is a tremendous challenge but also an enormous opportunity.

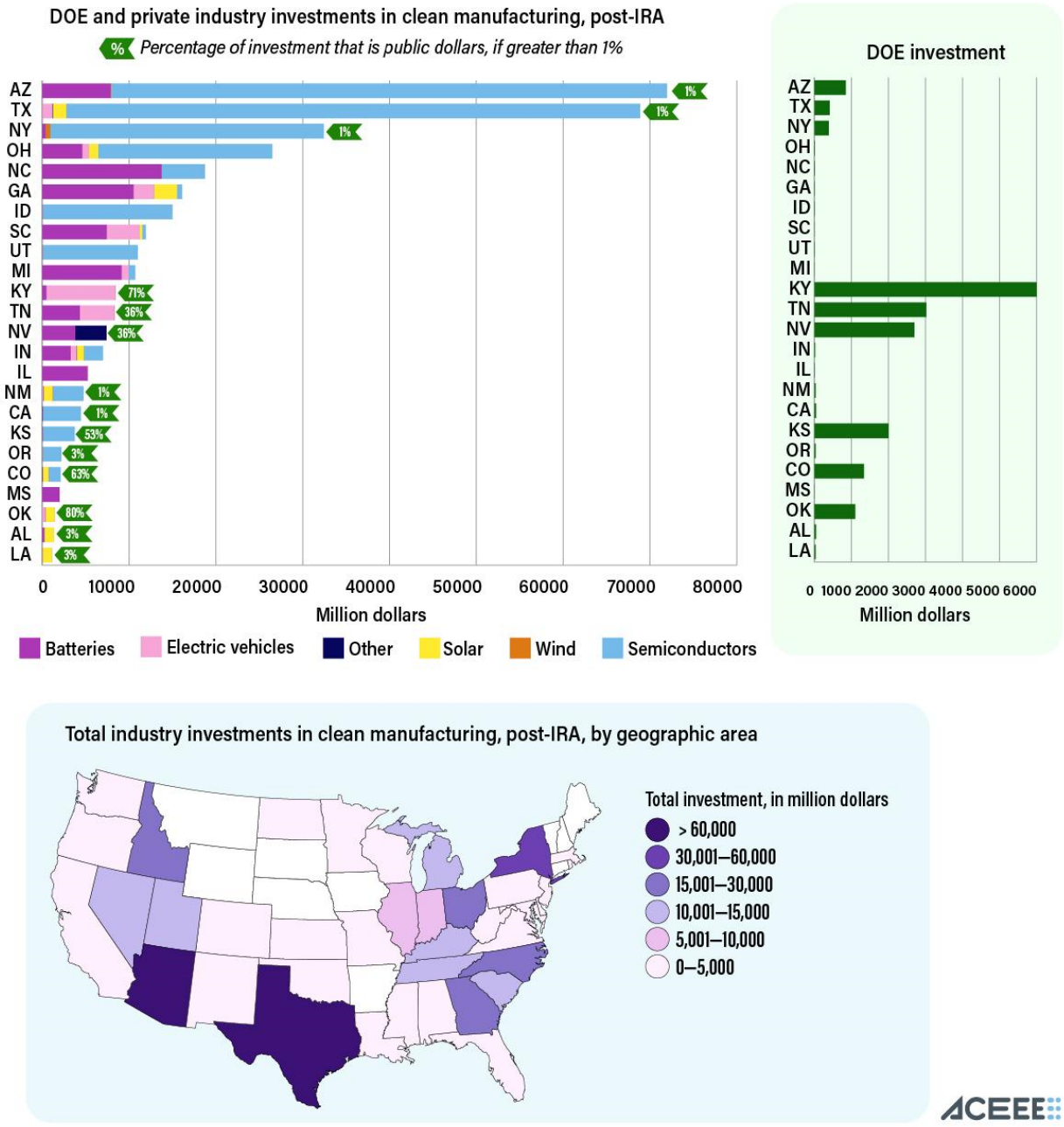

Figure 1. Representative DOE and private sector investments in clean energy manufacturing, announced between August 2022 and January 2024. Clockwise from top left, (1) total private and public dollar investments across clean manufacturing subsectors by state (percentages at the end of bars represent the percentage of investment that is public dollars, if greater than 1%), (2) the amount of public dollars invested per state, and (3) a map showing the geographic distribution of total investments in clean manufacturing. While not exhaustive, this dataset covers investments into the major energy and manufacturing supply chains receiving federal attention, as well as a selection of larger funding announcements from DOE. Additional large expected federal investments, however (e.g., $6.3 billion from the Industrial Demonstrations program), may alter the regional distribution of funds. *Source*: Conness 2024; Semiconductor Industry Association 2024; EERE 2024; LPO 2024.

The opportunities: Electrification can help build back the U.S. manufacturing sector to be cleaner, smarter, and more efficient while bringing jobs and prosperity to communities

Building a clean, efficient manufacturing sector in the United States is an essential step toward ensuring a resilient and secure economy in a decarbonized future. The manufacturing sector has a disproportionately large impact on the U.S. economy. For example, while the industrial sector directly employs 8% of the U.S. workforce, it accounts for 35% of productivity growth (Carr et al. 2022; Jarsulic 2023).

Industrial electrification makes industry smarter and more efficient

- **Greater intelligence:** Electrified industrial equipment (e.g., smart process controls, variable speed drives, or industrial heat pumps) can offer more precise controls that can lead to operational efficiency savings, especially when paired with information and communication technologies (ICT) that allow industry to communicate with the grid and respond to energy pricing signals (Johnson, Fraser, and York 2024).
- **Higher efficiency:** Even with waste heat recovery, burning fossil fuels within manufacturing facilities still generates a notable amount of waste: ~20% of the energy input is lost as waste, even from efficiently designed combined heat and power systems (Combined Heat and Power Partnership 2022). In contrast, an electric system boasts over 90% efficiency, significantly minimizing waste, and supporting continued progress toward reduced energy intensity of manufacturing (Bocca and Thomson 2023). In comparison to directly electrifying processes from renewable energy, burning green hydrogen is 50–80% less efficient as an energy source, not to mention its high generation cost and shipping constraints (St. John 2023). The higher value use of green hydrogen will be satisfying feedstock and very high temperature demands in a limited number of industries where electrification is infeasible.

Industrial electrification makes energy supply more reliable

- **Energy security:** Electricity can be generated from a diverse set of resources. An interruption of the supply of one resource can usually be made up for by others. Rapidly developing distributed energy resources (DERs), including long-term storage solutions, onsite generation resources, and microgrids can provide further system resiliency, making the electric grid an even more reliable power source for manufacturers than fossil fuels (NREL 2020)
- **Price stability:** Electricity prices are significantly less volatile than natural gas prices (Gruenwald 2021). They are also likely to decline in the long term as the share of renewable energy production continues to grow, especially if utility rate strategies are reformed and additional public investments support the scale of grid expansion needed. Furthermore, growth in demand for off-peak power can help to spread fixed costs over more sales, also contributing to electric rate declines. A more stable energy cost reduces uncertainties for industries.

Industrial electrification enhances grid and community benefits

- **Elimination of air pollution:** Fossil fuel combustion yields a range of air pollutants, posing significant risks to workers, public health, and the environment and disproportionately affecting frontline communities, which tend to be socioeconomically disadvantaged (Goforth and Nock 2022; Bistline

et al. 2022). As frontline communities become increasingly informed about the detrimental effects of these pollutants, they will seek to safeguard their neighborhoods, or move away from industrial areas, which may aggravate workforce shortages (Mahoney 2024). Consequently, industries will encounter even greater opposition when expanding their footprint, which means fewer jobs and less economic development opportunities for localities. On the other hand, clean, electricity-powered production offers an avenue for job creation and economic advancement without compromising the health and well-being of neighboring communities. This creates a win-win-win situation for manufacturers, residents, and local governments.

- **Enhanced grid stability and energy affordability:** Many industrial facilities operate around the clock, and so do not exacerbate peak demand periods. When combined with local storage and smart control technologies, industrial operation schedules can contribute to grid stabilization, especially in regions with a high proportion of renewable energy sources. By serving as a substantial load on the distribution network, industries can guarantee consistent demand for clean energy, absorb surplus generation that would otherwise be curtailed, and increase grid utilization rates, consequently improving overall system efficiencies and lowering energy expenses for all consumers connected to the network.

Momentum is building: Seven key factors are pushing the United States toward low-carbon, clean industry

The goal of running most or all industry processes on clean electricity seems ambitious, but it is achievable because a number of market conditions have made it an opportune time to invest in industrial electrification. These external factors helping to accelerate industrial electrification include:

- **Growing market demand:** Individual purchasers are demanding more zero-carbon products than are yet available (Falkenberg-Hull 2023), driving further commitments within supply chains to electrify processes and reduce emissions from manufacturing (Haggerty 2021). Public Buy Clean legislation allow governments to wield purchasing power to further ensure a market for goods with low embodied carbon (Office of the Federal Chief Sustainability Officer 2023).
- **Unprecedented federal investment:** The Bipartisan Infrastructure Law of 2021, Inflation Reduction Act of 2022, and CHIPS and Science Act of 2022 are helping to build domestic supply capacity through incentives (such as section 45X advanced manufacturing production tax credit, section 48C advanced energy project tax credit, and Defense Production Act (DPA) to accelerate domestic production of five key energy technologies). These bills also expanded loan programs (expanded the types of projects eligible for financing and increased lending authority), improving access to capital via DOE and EPA offices.
- **Emerging private-sector interest and increasing international investments in U.S. factories:** Since 2021**,** private companies have announced $649 billion in commitments to invest in 21st century industries, driven by federal investments (The White House 2024).
- **Regulation**: Direct electrification of industrial heat processes eliminates emissions from onsite combustion, helping industry to meet air quality regulations that protect the health of surrounding communities. For example, EPA has recently strengthened the annual health-based national ambient air quality standard for fine particulate matter (PM2.5) (EPA 2024). State and local governments have also passed additional regulations to reduce air pollution and GHG emissions from industry, such as new regulations on NO_x emissions from commercial ovens in the South Coast air quality district in California (Gallucci 2023). State carbon markets, such as California's cap-and-

trade program or the Regional Greenhouse Gas Initiative (RGGI) among eastern states, can also pressure companies to reduce carbon emissions, as can trade and border adjustment policies (Kennedy and Gangotra 2023; C2ES 2023). Industry is almost always able to meet new regulated emissions standards with lower costs than they initially project (Hodges 1997).

- **Grid decarbonization:** Decarbonizing the power sector is essential to decarbonizing the rest of the economy. On average, just 20% of energy in the United States was generated from clean sources in 2022 (Center for Sustainable Systems 2023). But 84% of new power plant capacity in the United States in 2023 came from clean sources (Spector and Olano 2023). Many utilities have commitments to meet 2035 net-zero goals and are rapidly scaling up renewable energy investments. Even so, the United States still lags behind the level of investment needed to achieve its ambitious emissions reduction goals (Holland et al. 2023). Demand for clean power is growing at an unprecedented rate in markets across the country and energy developers are struggling to keep up (Halper 2024). For the grid to rise to this challenge, a broader suite of clean energy strategies may need to be deployed alongside solar, wind, batteries, and company-sited distributed energy resources. This might include extending the life of existing clean assets (e.g., nuclear plants) or expanding the use of clean, dispatchable resources such as nuclear, hydro, or geothermal power to address the final ~20% of grid decarbonization (Denholm et al. 2021; Solomon 2023).
- **Technology development and demonstration:** The research, development, demonstration, and deployment (RDD&D) of innovative, low-carbon industrial technologies are being accelerated by multiple federal programs. For example, DOE's Industrial Efficiency and Decarbonization Office (IEDO) funded 104 new projects across 40 states, with a total investment of $304 million in 2023 (DOE 2024). In two years (2022–23), the Office of Clean Energy Demonstrations (OCED) stood up 9 programs and announced 18 funding opportunities with more than $21 billion (Office of Clean Energy Demonstrations, U.S. Department of Energy 2023). The office is on track to award $6.3 billion for a wide range of industrial demonstration projects in 2024. The Office of Manufacturing and Energy Supply Chains (MESC), which manages $20 billion in federal investments in communities across America, selected 17 new Industrial Assessment Centers (IAC) and 10 Building Training and Assessment Centers (BTAC) with a combined $40.8 million (DOE 2023). A $24 million opportunity for additional IACs will be awarded in 2024 (Office of Manufacturing Energy Supply Chains 2024).
- **Environmental and economic justice:** Industrial pollution is one of the major factors driving interstate migration of U.S. residents, especially the move away from industrialized midwestern communities (Mahoney 2024). Communities are increasingly pushing back against industrial investments that do not prioritize health and well-being alongside economics and job creation (Vellucci 2024; Lydersen 2024). When companies are able to come to mutually agreed upon community and workforce agreements with local groups, projects are more likely to be completed on time and on budget (Mangundayao, McNicholas, and Poydock 2022), providing benefits to communities but also to companies.

Overcoming Four Key Challenges to Accelerate Industrial Electrification

Industrial electrification projects are not being implemented at the speed and scale required to meet our ambitious climate, energy, and economic goals nor is carbon free electricity yet available at the scale or within the timeframe that industries demand (e.g., Karplus, Pistorius, and Tkacik 2023). U.S. companies are going to miss out and be left behind if they do not seize the benefits of clean energy.

Carefully targeted policy support and concerted market interventions can catalyze the market for industrial electrification projects in the United States by addressing four perceived barriers.

Pilots and demonstration are necessary to accelerate technology application and build expertise across industries

There is no shortage of commercial technologies appropriate for electrifying lower-temperature heat. However, industries are heterogeneous, and their adoption of electric technologies is highly customized; technological solutions established in one industry do not always directly transfer to others. For example, the application and integration of industrial heat pumps at an automobile factory do not directly translate to a dairy processor. Specific products designed to replace combustion processes (which have been established for over a century) in every applicable industry have not been standardized and produced at scale. Due to low demand, equipment manufacturers have also not yet prioritized bringing a substantial number of these products to market. Neither the supply chains nor a skilled workforce have been formed to support production at scale.

To help smooth over the early bumps in the market for industrial electrification equipment, industry-specific applications and expertise are essential. This necessitates pilot projects and demonstrations, supported by federal funds and technical assistance, to showcase the effectiveness of these technologies and accumulate field experiences and performance data from early adopters that can de-risk implementation for the rest of the sector. Intentional planning, coordinated efforts, and persistent action are essential to combat industrial inertia. Industries making early progress on process heating electrification pilots include the beverage sector, which is electrifying brewing and distilling (Renewable Thermal Collaborative 2022a; Temple 2023); the construction sector using industrial heat pumps to dry lumber for flooring;[1] and EV battery manufacturers that are increasingly demanding renewable power and electric heat for their manufacturing facilities (Ferris 2023).

Government incentives can counterbalance upfront costs and allow industry to access long-term benefits

While electric equipment can often demonstrate cost competitiveness with natural gas–fueled technologies, the capital costs associated with process changes for fuel switching remain significant barriers, especially as some technologies require broader plant modifications or heating system redesign to run optimally. Process redesign is comparatively simpler for new facilities than it is for retrofitting existing ones. For example, replacing an existing boiler steam system with a hot-water industrial heat pump can require re-piping the plant and replacing heat exchangers and control systems, in addition to replacing the boiler (Chen, Elliott, and Hoffmeister 2024). While these upfront costs may seem daunting, they can be offset by long-term operating and maintenance cost savings, resulting in a lower total cost of ownership—similar to electric vehicles (i.e., the estimated scheduled maintenance cost for a light-duty battery-electric vehicle totals 6.1 cents per mile, while a conventional internal combustion engine vehicle totals 10.1 cents per mile) (Burnham et al. 2021). Today, the levelized cost of heat (LCOH) for industrial heat pumps for low-temperature heating applications are competitive in price compared to natural gas fired heating equipment (Renewable Thermal Collaborative 2022b). Unfortunately, when executives weigh the long-term gains of market competitiveness and leadership against short-term costs and profit losses, many are motivated by the latter.

[1] Ton Mathissen, Nyle Systems, pers. comm., September 8, 2022.

To overcome these cost barriers, federal, utility, and state incentives as well as expanded sources of financing are essential to make financial risks manageable for early adopters. Furthermore, providing adequate technical assistance to facilities that are willing to lead is crucial to mitigate technical risks.

Modern rate structures that reward large, flexible loads lower operational costs while incentivizing industry to provide grid services

In the absence of policy interventions, operational costs continue to pose a significant barrier to industrial fuel switching, primarily because wholesale gas prices are lower than wholesale electricity prices per unit of energy in most regions. While electrifying with onsite renewable generation and energy storage can be competitive with natural gas in certain regions, this solution is not universally scalable across the nation. Additionally, transmission and distribution (T&D) fees can further increase the cost of delivered energy to an industrial facility with electricity, especially if increasing electricity demand requires connection upgrades or if demand charges drive large increases in industrial electricity bills. The dynamics of this equation could shift in the future, though, if fuel price risks are taken into account. Given historical instances of extreme gas-price fluctuations, it remains uncertain whether natural gas prices can remain low with a steady supply over an extended period. Eliminating fossil fuel subsidies could help electricity generated from renewable sources be cost competitive compared to natural gas (IEA 2023).

The average cost of electric heat could be reduced further by designing modern rate structures that incentivize industry facilities for their contribution to meeting grid-balancing needs and GHG targets. Many industrial facilities operate around the clock (on average, industrial power demand only drops by 17% at night during the workweek), thereby not exacerbating peak demand periods (Rissman and Gimon 2023). Industrial early adopters of electrification at scale do not have consistently fair and reasonable access to and valuation of the benefits that flexible large loads can provide to the grid. Unlocking these benefits at scale will require a few steps. Additional analysis can support efficient resource planning for increased electricity demand. Innovative new financial models can incentivize industry to absorb large volumes of renewable power that would otherwise be curtailed and to provide energy back to the grid during peak hours, thereby enhancing the utilization rate of the existing grid infrastructure. Flexible industrial loads, with assistance from local storage and smart control technologies, can help make clean, carbon-free electricity affordable and available to other customers on the utility network by serving as a “virtual power plant” especially in regions with a high proportion of renewable energy sources (Downing et al. 2023).

Industrial electrification challenges vary by region

The electricity system in the United States includes multiple market players and regulatory entities in what has been described as a Balkanized patchwork. The wholesale power and bulk transmission elements of the system are regulated at the federal level, while retail delivery and services are generally regulated at the state level. In some states, such as Ohio, Wisconsin, and North Carolina, governors, legislatures, and certain state agencies wield influence over utility regulations, while in others like Mississippi and Louisiana, elected commissioners operate independently of state governors. In addition, significant portions of the country are served by public power entities, including electric cooperatives, municipal power suppliers, and state and federal power authorities (e.g., New York Power Authority and Tennessee Valley Authority).

The actual costs and benefits of electrification of industrial processes today vary by region (Schoeneberger et al. 2022). In addition, the costs to manage the scaling up of electricity transmission

and distribution infrastructure will be intensely focused within some regions and less challenging in others (Wilson and Zimmerman 2023). Regionalizing industrial electrification strategies based on subnational regulatory environment, geographic clustering of industrial subsectors, and varying climate and natural resources will determine which portions of the country are most ready to lead the way on supportive industrial electrification policy, and most prepared to expand the grid with carbon-free energy sources to support growing demand for electricity.

A Path Forward through Concerted Market Interventions

Industry will need to be ready to collaborate with federal, state, and local policymakers; utilities and system planners; and utility regulators to overcome current obstacles to successfully implementing electrification technologies to decarbonize their operations. Although relationships between these groups may become more complex, there will also be many new opportunities for mutually beneficial wins (Johnson, Hoffmeister, and Rightor 2023). In the following sections, we list steps that key stakeholder groups can take to meet today's challenge of accelerating electrification solutions while simultaneously ensuring reliable, clean electricity is available to meet consumer needs and emissions reduction targets.

Three key actions for federal policymakers

Continue to invest in technology deployment, supply chains, and workforce: The DOE should ensure that federally funded pilots and demonstration projects are distributed across all industrial sectors and in different regions, while bolstering domestic supply chains and reducing financial and technical risks for early adopters of electric technologies. Consistent and lasting federal programs are important to ensure market stability until its maturity. The federal government should continue to identify gaps in the market and develop additional policy strategies to help essential technologies to scale successfully, while also working toward new legislative pathways for supportive industrial policy (e.g., Fischer 2023).

Conduct strategic planning for electrical system expansion and fossil fuel system contraction: Robust and credible analyses are needed to ensure industrial electric load growth potential is adequately incorporated into utility planning. At the same time, strategic planning will be necessary to maintain and/or downsize natural gas systems as demand switches to electricity and to ensure that infrastructure can still be safely and affordably maintained (Graves, Figueroa, and Lam 2021). For electrical systems, the objective of these analyses and pilot studies should be to demonstrate to utilities that the benefits of clean and distributed energy resources (DERs) outweigh any potential lost revenues. For utilities to embrace interaction with industry-side DERs and for regulators to support industry-side DERs, the value propositions must be conveyed to them with evidence from regional-scale analyses and pilots.

Implement more aggressive pollution regulations consistently: Implement stringent pollution regulations to accelerate the imperative for change toward cleaner technologies. Existing federal standards can be reviewed and enhanced, especially where improved standards can boost health and well-being while also providing more regulatory certainty for industry and better aligning U.S. policy with global standards.

Three key actions for state and local policymakers

Implement more aggressive carbon and pollution reduction policies: More states should consider developing industrial decarbonization plans in consultation with industrial firms and other stakeholders,

as have states such as California, Colorado, and Washington. At the state and local levels, there is more flexibility to address specific regional pollution concerns; for example, Southern California's recent NO_x regulations are meant to push commercial ovens to electrify and reduce emissions to comply with standards (Gallucci 2023). To ensure the availability of clean power when industry electrifies, states should also set ambitious state clean or renewable energy portfolio standards to drive investment in low-cost renewable energy supply, as well as demand-side management strategies that reduce energy use and increase demand flexibility of large energy consumers.

Invest in local workforce development: Work with local and regional organizations to build a local skilled workforce to meet the changing technical demands of electrified industry. Workforce support should be focused in communities where energy transitions will have the greatest economic impact on the industrial sector; for example, in oil and gas producing regions (Raimi and Whitlock 2023).

Align economic development goals with carbon reduction goals and foster financial innovation: State and local policymakers should provide incentives to attract private sector investment in necessary regional supply chains to support key electric technologies and expedite and streamline permitting for new industrial facilities. State and local governments should fully utilize federal industrial decarbonization funds and develop granting programs that incentivize electrification to address priority industrial sectors. State governments should also work with grid operators and regulators to support them in redesigning the economics of energy systems and how energy projects are financed.

Three key actions for utilities and system planners

Support technology demonstration and incentivize regional pilots: Utilities should partner with industry to implement electrification pilots that showcase benefits to the grid that accrue with efficient and flexible electrification of large industrial loads.

Plan electrical system expansion and fossil fuel system contraction: For utilities to embrace interaction with industry-side DERs and for regulators to support industry-side DERs, the value propositions must be conveyed with evidence from regional analyses and pilots. Utilities and regulators need to open dockets to study the costs and benefits of industrial flexible loads and design rate structures to reward grid-balancing services from large energy consumers and integrate expanding industry electric loads into the resource planning process.

Redesign cost structures to incentivize industrial prosumers and benefit other consumers: Just as electrification provides an opportunity for designing more efficient heating systems in industrial facilities, the scale of investment into electrical infrastructure is an opportunity to redesign the economics of energy systems and how energy projects are financed. This includes utility rate reform strategies, such as avoiding one-size-fits-all formulas for allocating T&D cost and demand charge and focusing on exact incremental costs to the system to serve these flexible industrial loads instead. Regulators and utilities can offer price advantages such as grid access charges proportional to transmission requirements. For example, CF Industries Holdings (the world's largest ammonia producer) and NextEra Energy Resources (the world's largest wind and solar generator) announced a green hydrogen project in Oklahoma. This joint venture shows how co-locating new generation and new electrified industrial loads "behind-the-meter" can drive clean power growth.

Three key actions for utility regulators

Direct utilities to incorporate industrial electrification into their integrated resource and system plans (IRP and ISP): The scope of industrial electrification is still emerging, but it is important for utilities to

engage their industrial customers, transmission operators, federal resources (e.g., Federal Energy Regulatory Commission, DOE, national labs), and other state agencies (e.g., departments of commerce and economic development) to develop realistic scenarios for size and location of electric loads. Regulators should direct utilities to update these IRP and ISP plans regularly as the market evolves.

Review utility rates to ensure that they encourage industrial electrification: Industrial rates can be very complex. Regulators should review rates to ensure that they fairly price electric service and consider the role of many industrial firms as prosumers. These rates should ensure that these customers are fairly compensated for the grid services that they can provide, including their ability to defer or avoid T&D upgrades through non-wires alternatives.

Review utility interconnection procedures and protocols: Industrial electrification projects can progress more quickly than the speed at which utilities are able to connect these customers to new or expanded service. Regulators need to ensure that interconnection occurs without delays and provide the customer with a reliable timeline for establishing service. This issue is already being addressed by some utility regulators for transportation electrification projects (e.g., CPUC 2023) but should also be addressed in the context of large industrial projects.

Act Now: To realize the multifaceted benefits of industrial electrification, we must power industrial processes with clean electricity and be prepared to embrace the next era of technology breakthroughs

Industrial electrification sits at the intersection of many of the big problems facing the evolving U.S. energy system. It is worrisome that a resurgent American manufacturing sector, producing essential clean energy technologies and green products like low-carbon cement or steel, may face headwinds from the limited ability of the nation's electricity systems to keep up with growing demand for clean power. There are real risks that some regions may miss out on economic development opportunities because the grid cannot keep up. The challenge is not just with generation and transmission, but also with final-miles delivery limits of substations and distribution systems.

Typically, a new load of 20 MW requires a new substation while a load of 10 MW may require a new bank of transformers in an existing substation: Both projects can take on the order of five years to plan, gain approval, and execute (Nadel 2023). Building new, nearby generation could result in capital investments of billions of dollars per GW of new load. Increasing transmission capacity to transfer power from one region to another costs less than new capacity but is still expensive and is not fast enough to meet accelerating near-term demand, even with expedited permitting. As a result, utilities continue to commit to new fossil gas plants to meet demand quickly, counteracting investment in renewable energy. Some utilities, such as Georgia Power, one of the largest beneficiaries of industrial investments under the IRA, are even exploring the need to keep some coal plants open to meet the demand. But the U.S. power system should not resort to locking in polluting options for years to come.

Recognizing this issue, policymakers at all levels should support utilities and industries to collaboratively explore solutions. Now is the time to design the U.S. power system of the future, rather than relying on outdated models. How do we get every electron out of every line and rely on our distributed energy resources on both the utility and the consumer side of the meter? To use our system most effectively, facilities with generation and storage capacities must be part of the solution. Industrial consumers'

deployment of grid enhancing technologies can help moderate grid congestion, manage peak demand, provide ancillary benefits (e.g., spinning reserves, reactive power support, grid stability), decrease curtailments of variable generation assets and need for peaking turbine operation for grid firming, and allow deferral or avoidance of T&D upgrade investments. Well-managed industrial energy loads can reduce T&D investment recovery fees, lower electric rates for all consumers, mitigate the risk of major outage events, and limit grid-related fossil fuel emissions.

A common misconception is that we lack the commercially available technologies to electrify industry. These technologies are rapidly being commercialized; we just have not demonstrated and deployed them at scale yet. The RDD&D of innovative, low-carbon industrial technologies are being accelerated by multiple federal programs. Industry needs to come to the table and seize this opportunity. Successful industrial electrification at scale will require policymakers to take action to incentivize early adopters and lower their technological and financial risks. Industrial electrification strategies need to be developed regionally based on subnational regulatory environment, geographic clustering of industrial subsectors, and varying climate and natural resources. Innovative new financial models or rate structures need to be developed to ensure that clean, carbon-free electricity is affordable and available to all, and costs are distributed equitably. A domestic manufacturing sector reliant on clean electricity for process heat will be cleaner, more resilient, more efficient, and more competitive. The time to take action is now.

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