Right Onsite: Accelerating deployment of onsite clean energy technology in the industrial sector

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ABSTRACT

Achieving net-zero emissions in the US industrial sector will require simultaneously pursuing technology solutions in energy efficiency, electrification, and low-carbon sources, as well as carbon capture, utilization, and storage. Among this portfolio of strategies, generating clean power onsite at industrial facilities combined with electrifying processes is critically needed to fully decarbonize industry. Although some industrial users have already installed such technology, various barriers exist that impede broad adoption. Based on stakeholder engagement activities performed in 2022, DOE identified significant barriers and needs for industrial end-users to install onsite clean energy solutions. Building on those activities, in 2023 the DOE's Industrial Efficiency and Decarbonization Office (IEDO) announced a new program focused on deployment of onsite energy to meet those needs and help industrial facilities and other large energy users to increase the adoption of onsite clean energy technologies. This paper will describe the current state of onsite clean energy generation in the U.S. industrial sector, perspectives from industry about their interest in onsite energy, barriers to wide adoption, and the technical assistance, tools, and training that industry needs in this space. It also describes strategies DOE is developing to meet these needs by supporting subject matter expertise, research, and analysis in onsite clean energy technologies. Industry needs tools and guidance that provide unbiased evaluations of multi-technology solutions, information about policy incentives and financial support, assistance engaging with communities and other stakeholders, and support for workforce development efforts.

Introduction

Human activities have indisputably caused the observed increases in atmospheric greenhouse gases since the 1750s, leading to increases in global surface temperatures and associated changes in the atmosphere, ocean, cryosphere, and biosphere. Mitigating the effects of human-induced global climate change requires reaching net-zero emissions of carbon dioxide and other greenhouse gases within the next 20 to 30 years (IPCC 2021). Although making the necessary changes requires significant public and private investments, these will also lead to substantial economic benefits, in terms of both jobs and gross domestic product (Burke, Davis, and Diffenbaugh 2018; Saha and Jaeger 2020; Lee and Howard 2021). Both global climate concerns and economic benefits motivate rapid efforts to decarbonize the U.S. economy. Recognizing these needs, the Biden Administration set goals for generating 100% carbon-emissions-free electricity by 2035 and net-zero greenhouse gas emissions by 2050 (Exec. Order No. 14008, 2022), which will require significant and swift efforts across all sectors of the economy.

Industry in the US is a large, complex, and difficult-to-decarbonize sector of the energy economy. As of 2021, the industrial sector represented 33% of US primary energy use and was responsible for 29% of energy-related carbon emissions (EIA 2022, Tables 2 & 18). Globally,

the industrial sector accounted for 24% of direct anthropogenic greenhouse gas emissions in 2019, second only to the energy sector (Bashmakov et al. 2022). Reaching net-zero emissions in the U.S. will require significant efforts to decarbonize the industrial sector. However, this faces both structural and technical challenges, due to the diverse array of energy inputs used across varied industrial processes and technologies, and different needs in different subsectors and locations. For example, carbon dioxide is a byproduct of chemical reactions involved in key industries, such as cement, steel, lime, glass. These industries also require high-grade heat input, which has conventionally been produced via combustion of fossil-based hydrocarbon fuels (Pisciotta et al. 2022).

The U.S. Department of Energy (DOE) recently released an Industrial Decarbonization Roadmap, which laid out four pillars to reach net-zero greenhouse gas emissions across the economy by 2050: energy efficiency; electrification; low-carbon fuels and feedstocks; and carbon capture, utilization, and storage (DOE 2022a). Using modeling of potential emissions-reduction strategies, the roadmap laid out how net-zero emissions can be achieved in the highest CO_2-emitting industrial subsectors: petroleum refining, chemicals, iron and steel, cement, and food and beverage. In addition, the roadmap identified cross-cutting barriers that apply to all subsectors: heterogeneity of industrial emissions, inputs, and processes; incumbent technologies and practices; and high costs.

Achieving net-zero greenhouse gas emissions in the industrial sector will require both fully decarbonizing the electric grid and producing low-carbon electricity and heat near industrial facilities—including onsite generation. Clean onsite energy generation and storage technologies provide a practical alternative to conventional fossil-fuel systems and grid electricity for facilities to directly produce flexible, reliable, and affordable heat and electricity to reduce emissions across the industrial sector. Although energy-intensive industries such as cement, steel, and glass face unique decarbonization challenges due to the inherent production of carbon dioxide in current chemical processes and the high heat required (Pisciotta et al. 2022), locations with convenient and/or inexpensive access to low-carbon fuel sources could instead use those for heating. Producing clean electricity onsite can also provide a cost-effective and reliable supply for electric kiln technologies and other processes that lend themselves to electrification (Deason et al. 2018). Similarly, clean onsite energy generation can support industrial drying processes (Piacentini 2022), and the chemical industry has significant opportunities for electrified processes powered by clean energy sources (Mallapragada et al. 2023).

Less energy-intensive industrial sectors may be able to decarbonize sooner and significantly reduce their direct and/or indirect emissions by developing onsite energy generation. For example, facilities in the wood/forest products sector have significant access to waste low-carbon fuels. Other industries may only need low-temperature heat/steam that can be more-easily generated using (onsite) electricity. A recent study showed that 5-35% of industrial sectors could produce all their current electricity needs using rooftop solar photovoltaic arrays, depending on location (Namin, Eckelman, and Isaacs 2023).

The rest of this paper presents perspectives on deploying onsite clean energy technology in the US industrial sector. Here, we use “onsite energy” to describe electric and thermal energy generation and storage technologies that are physically located at an end-user site and provide clean energy services directly to the end-user and/or other co-located companies, such as industrial clusters. Onsite energy encompasses a broad range of technologies suitable for deployment at typical industrial facility sites, including battery storage, combined heat and power (CHP), waste heat to power, district energy, fuel cells, geothermal, industrial heat pumps,

renewable fuels, solar photovoltaics, solar thermal, thermal storage, wind power, and others. Informed by stakeholder and partner feedback, we first discuss the current state of industrial onsite energy generation, level of interest, challenges to broad adoption, and the tools and resources needed by industry in this space. We conclude by describing the current resources that DOE offers to support companies, incentives and resources funded by recent legislation, and strategies DOE is developing to meet these needs by supporting subject matter expertise, research, and analysis in onsite clean energy technologies.

Current state of industrial onsite energy generation

Modern industry began with distributed, clean onsite power generation. The use of watermills and windmills stretches back globally nearly a thousand years for processing agricultural products such as grain and corn. In the 17th and 18th centuries, watermills spread over the young United States to process lumber, grain, and wool. The Industrial Revolution saw an explosion in using waterpower to produce iron, textiles, and paper, among other products, well into the 19th century. However, as technology advanced, steam engines powered mostly by coal began to replace watermills, and by the 20th century centrally generated electricity became cheap and widely available enough to make watermills practically obsolete for many purposes, with coal/coke fueling high-heat processes onsite.

Today, U.S. manufacturers rely on the grid to provide most of their electricity needs, self-generating just 15% of the electricity they used in 2018. Figure 1 maps the 1,514 utility-scale (i.e., ≥ 1 MW) onsite power generation systems installed at U.S. industrial facilities as of February 2023, showing both technology type (by color) and net summer capacity (by size) (EIA 2023b)[1]. In the technology names, "natural gas" refers to turbines, combined cycle, and internal combustion engine systems that run on natural gas; "biomass/waste" refers to systems that run on wood and wood waste, other waste biomass, municipal solid waste, and landfill gas; "petroleum & coal" refers to systems that burn petroleum liquids, petroleum coke, and coal; and "other" refers to systems involving batteries, other gases, and "all other" fuels (where no additional information was provided). Larger systems tend to run on natural gas, coal, and petroleum, and they are generally located along the Gulf Coast and in the Midwest. Many biomass/waste-fueled systems operate in the Southeast and Pacific Northwest. Unsurprisingly, solar photovoltaic systems are more popular in the Southwest and southern California in particular.

The most widespread form of onsite power generation in the U.S. industrial sector is CHP, or the cogeneration of heat and electrical power. CHP systems provided nearly all (96%) onsite industrial electricity production in 2018, mostly using natural gas and coal as fuel; these systems are used most heavily in larger facilities and in energy-intensive sectors like pulp mills, petroleum refineries, and paper mills (EIA 2018). As of 2020, waste byproducts fueled 9.3% of industrial CHP installations, with renewable fuels at 4.9%; waste-heat-to-power systems made up 1.3% of electricity generation capacity (DOE 2022b). In addition to CHP, some industrials have installed onsite renewable power generation systems, particularly solar photovoltaic and wind, and many legacy hydroelectric systems remain active.

As of February 2023, the industrial sector had total utility-scale electrical generation capacities of 168 MW from solar, 57 MW from wind, and 209 MW from conventional

[1] Although the EIA also collects data on onsite power generation at industrial facilities smaller than 1 MW, these data are not tied to facilities or locations and so not included in the map.

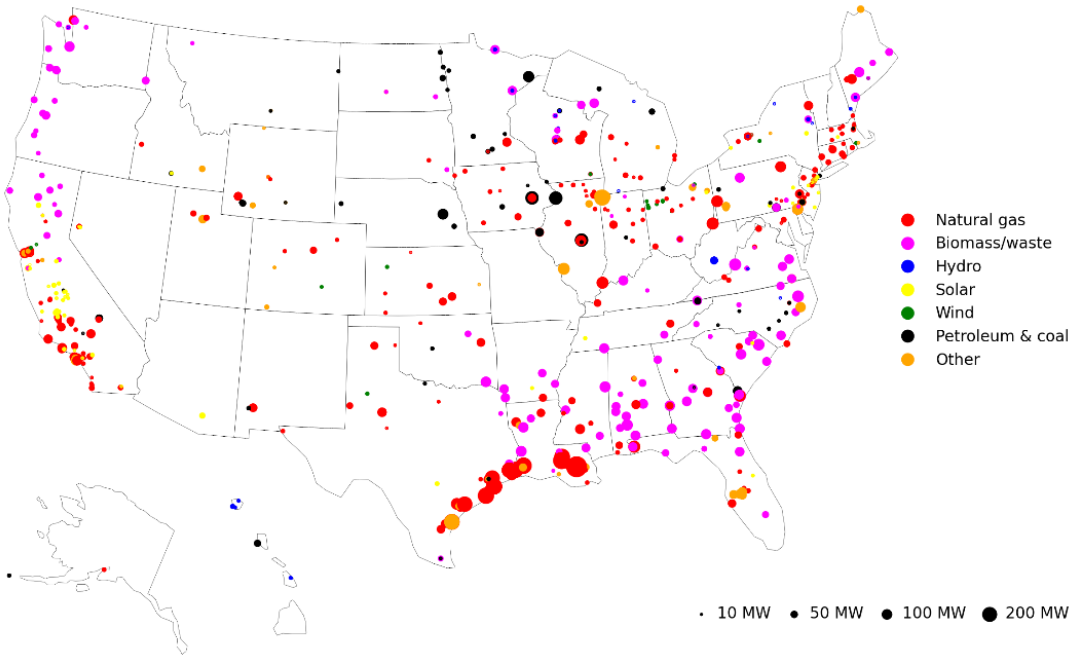
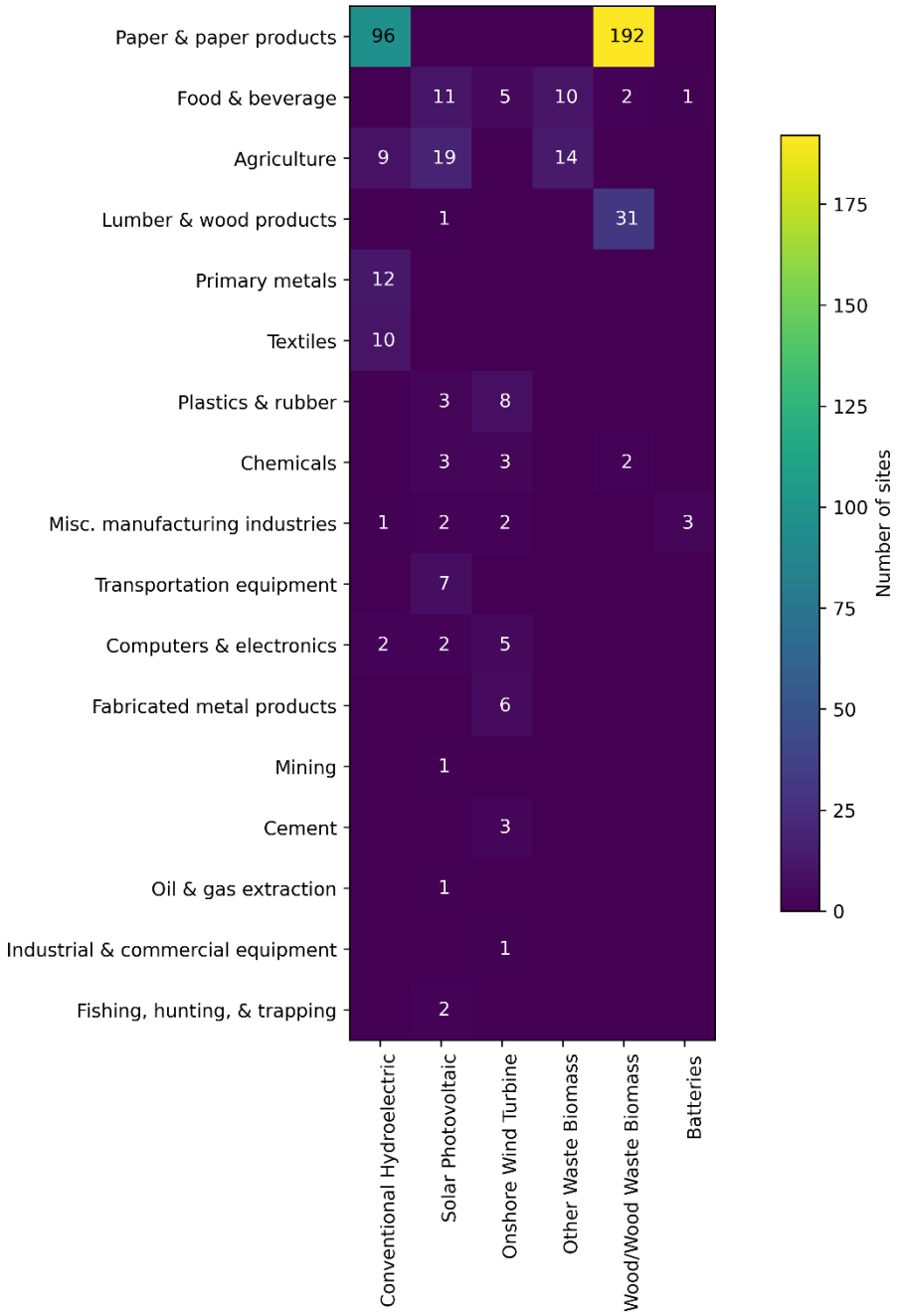


Figure 1. Map of the 1514 utility-scale (≥ 1 MW) onsite power generation systems at U.S. industrial facilities in February 2023. Size of circles scales with net summer capacity, and color indicates technology type. Multiple generators at the same site may overlap, and the map does not distinguish CHP from non-CHP systems. Source: EIA 2023b.

hydroelectric, along with 5.6 GW from combustion of wood and waste biomass—with very little installed battery storage (3.8 MW). Interestingly, solar photovoltaic systems smaller than 1 MW contributed an additional 2.4 GW of capacity across the industrial sector—much more by far than from the larger systems (EIA 2023a). Fossil-fuel-based power generation comprised 19.8 GW of capacity in the industrial sector, or 73% of the utility-scale total capacity (EIA 2023b). Industry currently relies more heavily on fossil fuels, mostly due to legacy CHP systems, than the U.S. electrical grid at large, where 59% of electricity was generated from the combustion of natural gas and coal in 2022 (EIA 2023a).

The last decade has seen small but steady interest from industrials in adding onsite renewable energy systems. Over 2014–2021, industrial facilities installed about 52 MW of distributed wind capacity, corresponding to 17% of all new installed capacity over that time; in some years, this was just 3.5% of new capacity installed, but in other years industry installed as much as 54% (Orrell, Kazimierczuk, and Sheridan 2022). This represents around half the available wind power capacity in the combined commercial and industrial sectors in 2022. The number and size of these new projects has remained relatively steady over the last eight years, with industrial customers representing the second-largest portion of distributed wind capacity installed in 2021. Similarly, commercial and industrial users have consistently installed around 1 GW of capacity per year in solar photovoltaic systems over the last eight years. However, utility-scale and residential installations make up a more-significant portion of the new capacity installed each year (Feldman et al. 2023).

Onsite clean energy systems are currently distributed quite unevenly across the U.S. industrial sector. Figure 2 shows numbers of the 470 utility-scale onsite clean energy systems operating at industrial facilities in 2021, organized by subsector and technology (EIA 2022a).



We combined various subsectors (based on NAICS code) for clarity[2]. The paper industry uses the highest number of onsite clean energy systems, which are exclusively hydroelectric and (unsurprisingly) wood/wood waste; the lumber and wood products sector also runs many wood-fueled systems. The food and beverage industry has fewer, but more diverse, systems that include all technologies but hydroelectric; the agriculture sector has the highest number of solar photovoltaic systems.

[2] "Paper & paper products" is everything under 322; "food & beverage" combines 311 and 312; "agriculture" combines 111, 112, and 115; "textiles" is 313 and 314; "chemicals" is everything under 325; "plastics & rubber" combines 325211 and 326; "mining" includes 212x; and "computers & electronics" combines 334 and 335.

While some industrials have already installed onsite clean energy generation technologies—particularly CHP and solar photovoltaic systems—various barriers exist that impede broad adoption, as we will discuss in more detail later. The EIA predicts that the generation capacity from small-scale solar photovoltaic systems will increase about 40% in the commercial and industrial sectors from 2022 to 2024; furthermore, 5–35% of manufacturing sectors could use rooftop solar photovoltaic systems to supply their entire electricity needs, depending on location (Namin, Eckelman, and Isaacs 2023). However, the EIA does not predict any substantial increases in electric generation capacity from other sources over this time (EIA 2023a). We aim to change this trajectory over the next 10–15 years by offering new technical assistance to industrial companies for deploying onsite clean energy generation technologies, in combination with new financial incentives through federal legislation.

Perspectives on onsite energy deployment in industry

This section describes perspectives from industrial stakeholders on deploying clean onsite energy technologies in three areas: (1) opportunities, (2) barriers, and (3) needs for tools and technical assistance. Perspectives primarily rely on direct feedback from industry via formal and informal stakeholder engagement activities DOE conducted in 2022, along with insights gained through interactions with partners in the Industrial Efficiency and Decarbonization Office (IEDO) Technical Assistance and Workforce Development programs.

Opportunities

Industrial companies have a strong interest in installing clean onsite technologies at their facilities, driven by a combination of factors: a desire to lower energy costs, improve energy resilience, meet shareholder and/or customer demands, and achieve corporate sustainability and decarbonization goals. For companies with decarbonization targets, onsite energy solutions can contribute to reductions in both direct scope 1 and indirect scope 2 greenhouse gas emissions.[3] For example, a facility that switches from a coal or gas boiler to generating heat with a renewable source of thermal energy—such as biomass, biogas, geothermal, solar thermal, or other alternatives—lowers its scope 1 emissions. A facility that invests in self-generating renewable electricity at their site reduces the amount of electricity purchased from the utility grid and lowers its scope 2 emissions. Companies recognize investments in renewable generation and storage as a significant opportunity for reducing greenhouse gases while also balancing the need to improve operational resilience and reliability.

In the near-term, most companies are focused on the lowest-hanging fruit, such as low-cost energy efficiency measures, and installing technologies with which they are most familiar like solar photovoltaic systems. Industrial companies tend to be most comfortable with technologies that are not overly complex, have been demonstrated and proven at scale, have short payback periods, and are well-suited for the location of the facility and the space available.

[3] For greenhouse gas inventory, accounting, and reporting, emissions are classified into three "scopes." Scope 1 emissions are direct emissions from sources owned or controlled by the company and include onsite fossil-fuel combustion in stationary sources (e.g., boilers, furnaces, turbines), vehicle fuel combustion, emissions from chemical processing, and fugitive emissions. Scope 2 emissions are indirect emissions resulting from generation of electricity, heat, or steam purchased from a utility provider. Scope 3 emissions come from sources not owned/controlled by the company, such as transportation of fuels, material extraction, and sold product use (World Resources Institute and World Business Council for Sustainable Development 2004).

These types of solutions often include recovering and using waste heat, replacing fossil fuels with renewable/low-carbon fuel alternatives, and installing renewables like solar photovoltaic and distributed wind systems. Companies tend to reserve more-costly or more-complex technologies that they have less experience with for longer-term plans, which can include solutions like geothermal, solar thermal, industrial heat pumps, energy storage, and other technologies.

Barriers

Industrial companies experience a variety of challenges with implementing onsite energy solutions at their facilities, most often citing cost concerns. Owning onsite energy systems typically requires significant upfront capital and additional costs to operate and maintain the equipment over its lifetime. Some global companies pursuing decarbonization strategies describe more favorable economics in Europe for self-generating with onsite energy. In U.S. markets, those same companies choose to prioritize purchasing renewable electricity, at least until onsite solutions become more cost-effective. For these companies, near-term plans are more likely to focus on lowering scope 2 emissions by purchasing renewable energy credits (RECs) or entering virtual power purchase agreements (VPPAs), and delaying strategies to generate renewable electricity or thermal energy onsite until later phases when capital costs may be lower.[4] Availability of incentives—federal tax credits for clean technologies passed in the Inflation Reduction Act, new grant programs to reduce greenhouse gases in the industrial sector established by the Bipartisan Infrastructure Law, plus state incentive programs—can significantly reduce the upfront capital requirements for installing onsite energy.

In addition to cost constraints, companies experience barriers associated with specific site characteristics, including geographic location and operational characteristics of their plant. Renewable energy resource availability depends highly on geography[5] (Lopez et al. 2012) and some technologies can require significant amounts of land and/or available space. Companies can also be limited by the operational requirements of their manufacturing process, including the need for high-temperature process heating. Low-emissions heat sources such as solar thermal and geothermal can deliver clean industrial process heating for low-temperature applications (e.g., pre-heating, drying, sterilizing) but are limited in their ability to meet high-temperature heating demands (Piacentini 2022; Pisciotta et al. 2022).

Regulatory challenges can also present barriers, such as working with utilities on interconnection and municipalities or agencies to navigate permitting processes. Utilities and regulators require distributed resources to follow a set of procedures for interconnecting to the electric grid aimed at ensuring the safety, reliability, resilience and power quality of the system. The process can cause delays in project schedules depending on how long the utility takes to process applications, and projects can experience significant increases in cost if they require detailed studies or expensive system upgrades or hardware. With the availability of new federal tax credits, already-backlogged interconnection queues are anticipated to grow (Penrod 2023).

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[4] VPPAs are financial agreements to purchase renewable energy credits by contracting to purchase energy for a period of time, and the actual renewable energy generation can be located offsite in other parts of the grid, other states, or other parts of the country.

[5] NREL has resource maps available for geothermal (https://www.nrel.gov/gis/geothermal.html), wind (https://www.nrel.gov/gis/wind-resource-maps.html), and solar (https://www.nrel.gov/gis/solar-resource-maps.html) energy.

Finally, the capacity and expertise of the existing workforce presents additional challenges for some companies. Becoming a power generator or managing complex dispatch strategies for stored resources may be outside the scope of what many companies view as their core business operations. Corporate executives may be reluctant to dedicate limited staff resources, training existing staff, or bring on additional expertise with knowledge and skills to manage onsite energy resources.

Needs for Tools and Technical Assistance

To accelerate adoption, stakeholders have shared key technical and non-technical needs that will help address barriers associated with integrating onsite clean energy technologies in industry. Needs mostly center around analysis, training and expertise, and engagement. Table 1 summarizes the needs DOE identified. Although substantial analysis and tools are available, DOE programs are often focused on single technologies (e.g., solar, water, geothermal, wind) and as a result analysis and tools also focus on single-technology solutions. In addition, many existing tools do not focus on industrial facilities.

Table 1. Summary of key technical and non-technical needs

Technical needs	Non-technical needs
Modeling technical, economic, and environmental performance of onsite energy technologies and equipment options	Information about policy, regulations, incentives, and other financial support available
Unbiased, technology-neutral feasibility assessments and evaluations of multi-technology solutions	Engagement between industrial energy users, utilities, policymakers
Resources to assist with reducing risk and ensuring commercial viability	Expanding career and technical education coupled with training and curriculum improvements
Support for optimizing, operating, and maintaining energy systems in industrial facilities	Engagement with local communities
	Connections and collaborations with peers
Support with electrical infrastructure upgrades & grid interconnection	Knowledge about successful regional demonstration projects

DOE strategies to increase onsite clean energy in industry

Technical Assistance

DOE has a variety of technical assistance programs that can assist the industrial sector with reducing greenhouse gas emissions. In 2023, the Industrial Efficiency and Decarbonization Office (IEDO) announced a new program focused on deployment of onsite energy to meet needs

identified by stakeholders, including those described above.[6] The program will include a regional network of Onsite Energy Technical Assistance Partnerships (TAPs) to provide manufacturers and large energy users with unbiased information that helps identify onsite technologies best suited to meet their needs and assists them during the implementation process.

In the past, DOE has supported a subset of onsite technologies through the Combined Heat and Power TAPs, including CHP, waste heat to power, and district energy technologies. With the dramatic decrease in costs for many other technologies appropriate for onsite deployment and the emerging familiarity of the industrial sector with integration of these technologies, IEDO is building on the successful model of the CHP TAPs with the goal of providing similar services for a broader set of technologies.

The Onsite Energy TAPs will operate by providing direct technical assistance to end-users and other stakeholders with identifying technology options for achieving clean energy objectives. For the program, "technical assistance" refers to the broad range of services in support of onsite energy project deployment from the beginning of the implementation process (e.g., pre-installation technology screenings) to the end (e.g., post-installation operation and maintenance). The Onsite Energy TAPs will also engage with policymakers, utilities, and other key stakeholders to address barriers and accelerate pathways for integrating onsite energy technologies. They will also develop publicly available analysis tools, share best practices and resources demonstrating successful installations at other U.S. facilities, facilitate partnerships, and perform other efforts that support decarbonization in the U.S. industrial sector.

The onsite energy program will closely coordinate with DOE programs to leverage subject matter expertise, tools, and resources across the agency's initiatives, including the Better Plants and Better Climate Challenge programs and the Industrial Assessment Centers.

The Better Plants program works with leading U.S. manufacturers and wastewater treatment agencies to set ambitious energy, water, waste, and carbon reduction goals and commit to reducing energy intensity by 25% over a 10-year period across all U.S. operations. Better Climate Challenge partners commit to reducing their scope 1 and 2 greenhouse gas emissions by at least 50% within 10 years (25% for energy-intensive industries). In 2023, Better Climate Challenge partners will offer an Onsite Renewable Energy and Storage Working Group, which will facilitate small group discussion about planning and deploying onsite energy systems. The Onsite Energy TAPs can assist Better Plants and Better Climate Challenge Partners with pursuing onsite opportunities identified in emissions reduction planning.

The Industrial Assessment Centers (IACs) help small- and medium-size U.S. manufacturers save energy, improve productivity, and reduce waste by providing no-cost technical assessments conducted by university-based teams of engineering students and faculty. After the site visit, the IAC team provides a comprehensive report with specific details on opportunities identified during the assessment, including applicable grants, rebates, and incentives. Traditional IAC assessments focused on energy efficiency measures. Future assessments will incorporate more opportunities associated with decarbonization, including recommendations related to onsite energy. The Onsite Energy TAPs can assist small and medium manufacturers with pursuing opportunities identified in IAC assessments and help connect them to implementation grant funding available from DOE's Office of Manufacturing and Energy Supply Chains.[7]

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[6] https://www.energy.gov/eere/iedo/onsite-energy-program

[7] https://www.energy.gov/articles/biden-harris-administration-announces-80-million-strengthen-american-manufacturing

Research and Strategic Analysis

Aside from technical assistance programs, additional research and strategic analysis activities are needed to support adoption of onsite energy in industry. This paper summarizes recent trends based on available data, but comprehensive data of existing installed capacity of onsite technologies in U.S. industrial facilities by sub-sector and state would help end-users and technical assistance providers better understand the technology options available. After establishing a baseline of how the industrial sector is currently using onsite energy technologies, additional analysis is needed to assess the technical and economic potential for deployment of onsite energy solutions, with an emphasis on the renewable resource potential based on geography and characteristics of the electric and thermal footprints of major industrial subsectors. Finally, there are many no-cost techno-economic analysis tools publicly available that can be used to identify and optimize distributed energy resources at the facility level. A review of these existing tools including their strengths, weakness, and primary use cases will help determine how these tools can be best applied in technical assistance programs.

Conclusions

The U.S. industrial sector has both a demonstrated need for and interest in onsite clean energy systems, which are necessary to achieve net-zero emissions. Over 1500 onsite energy systems operate at industrial facilities as of February 2023, but 73% of the capacity still comes from fossil fuels. A small number of industrial subsectors dominate installations of clean onsite energy technologies, with the paper, food and beverage, agriculture, and lumber/wood products sectors representing 83% of operating systems. Although industrials show strong general interest in adding onsite clean energy systems, challenges associated with capital cost, site/space requirements, regulations, and workforce expertise present barriers to rapidly deploying these technologies. Increasing adoption requires meeting needs that mostly center around analysis, training and expertise, and engagement. DOE offers a range of technical assistance programs that can assist the industrial sector with reducing greenhouse gas emissions, including the new Onsite Energy TAPs program. However, additional research and strategic analysis activities are needed to support industry in further adopting clean onsite energy systems to decarbonize the economy.

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