Technical opportunities for electrification of industrial units in the state of Louisiana

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Authors

Daniel Rodriguez, Amy Jordan, and Dane McFarlane

Carbon Solutions, LLC.

Executive Summary

The U.S. has set ambitious climate goals of achieving net zero emissions by 2050. Currently, the U.S. industrial sector accounts for 30% of CO_2 emissions and a third of primary energy consumption.[1,2] Much of this energy consumption is produced from fossil fuel combustion to make heat or steam, which is then used for specific industrial processes. The industrial uses of heat for processes ("process heat") include generating steam, drying product, melting metals, calcinating minerals, and improving combustion efficiencies within a unit. Nearly all industrial processes require energy in the form of heat or electricity, with the majority of these energy demands currently fulfilled by fossil fuels.

The electrification of industrial units is an opportunity to reduce emissions while maintaining the productivity and economic activity of the industrial sector. Electrification opportunities among industrial units are not homogenous. The units with the best electrification opportunities generally use lower temperature heat and have demonstrated applications of mature heating techniques. Additionally, combustion units that currently use byproduct or waste fuels will have lower potential due to the resistance from operators to stop using low-cost fuels or waste products. Industrial unit types are reported to the EPA Greenhouse Gas Reporting Program (GHGRP) while the electrification potential are defined in this study. The unit type and electrification potential are both reported in Table ES1. Unit types categorized as having "Poor to None" electrification potential are not necessarily impossible to electrify, but extenuating circumstances will preclude their inclusion as "Good" opportunities for electrification. These circumstances include requiring large quantities of high temperature heat (>800°C), lack of technological maturity, low efficiencies, poor economics, opaque data reporting to GHGRP, or impracticality of electrification.

Table ES1. Electrification potential of each unit type.

Unit Type	Electrification Potential
Boilers	Good
Process Heaters	Good
Hot Water heaters	Good
Line Heaters	Good
Comfort Heaters	Good
Ovens	Good
Furnaces	Good
Chemical Recovery Furnaces	Poor to None
Incinerators	Poor to None
Kilns	Poor to None
Thermal Oxidizer	Poor to None
Calciners	Poor to None
Turbines	Poor to None
Reciprocating Internal Combustion Engines	Poor to None

The state of Louisiana has a large industrial base with a variety of sectors, including prevalent petroleum refineries, pulp and paper, chemicals, and manufacturing. Fully electrifying units in Louisiana that have good opportunity would require an additional 49,183 GWh (electric capacity 21,381 MW) of electrical generation to account for the 225 trillion Btu (TBtu) used annually by those units (Table ES2). This additional electrical generation is 49% of the Louisiana's total electric power generation in 2021.[3] These increases take into account the increases in efficiency that electrified units realize compared to fossil fired units.

Table ES2. Estimated annual fuel use, emissions, equivalent electricity consumption and electric capacity for unit replacement in Louisiana

Industry	Facilities	Units	**2021 Fuel Used** trillion Btu	**2021 Emissions** $MtCO_2e$	**Equivalent annual electricity consumption** GWh	**Equivalent electric capacity** MWh
Boilers	**38**	**106**	**136**	**8**	**29,530**	**12,481**
Ammonia	1	7	11.6	0.60	2,514	718
Chemicals	2	5	2.3	0.12	501	246
Gas Processing	9	23	1.8	0.09	388	141
Metals, Minerals, and Other	2	6	9.5	0.49	2,062	544
Petrochemicals	8	20	20.1	1.19	4,371	1,589
Pulp and Paper	8	15	50.1	3.65	10,902	2,872
Refineries	7	29	40.0	2.33	8,700	6,342
Steel	1	1	0.42	0.02	92	29
Process Heaters	**22**	**106**	**77**	**5**	**17,074**	**6,808**
Chemicals	2	7	0.69	0.04	153	52
Gas Processing	9	26	7.6	0.40	1,684	460
Petrochemicals	6	32	25.3	1.44	5,622	2,768
Refineries	5	41	43.3	2.64	9,615	3,528
Hot Water Heaters	1	2	0.01	0.001	**3.42**	-
Waste	1	2	0.01	0.001	3.45	-
Line Heaters	**7**	**18**	**0.37**	**0.02**	**102**	**95**
Chemicals	1	1	0.003	0.0001	0.70	4
Gas Processing	5	10	0.09	0.005	25.4	24
Metals, Minerals, and Other	1	7	0.28	0.01	76.0	67
Comfort Heaters	**1**	**3**	**0.002**	**0.0001**	**0.38**	**1**
Refineries	1	3	0.002	0.0001	0.38	1
Ovens	**4**	**8**	**1.12**	**0.06**	**179**	**98**
Chemicals	2	4	0.17	0.01	25	24
Metals, Minerals, and Other	1	2	0.11	0.01	26	9
Pulp and Paper	1	2	0.85	0.04	128	65
Furnaces	**5**	**35**	**11**	**1**	**2,294**	**1,898**
Chemicals	1	1	0.03	0.001	5.40	3.00
Petrochemicals	4	34	11	1	2,288	1,895
Total	**78**	**278**	**225**	**14**	**49,183**	**21,381**

Emissions reductions from electrification occur if the carbon intensity of electrical generation is lower than that of fossil fuel combustion. Efficiency gains from electric equipment, compared to fossil fuel combusting units, can also reduce the carbon intensity of industrial users, even in cases when the electric grid still partially relies on fossil fuels for a portion of its energy generation. Louisiana's electrical grid, the Midcontinent Independent Systems Operator (MISO), has an assumed generation intensity of 365 g CO_2 equivalent (CO_2e) per kWh. Emissions reductions will only be experienced as the MISO generation intensity is similarly reduced; reductions of 50%, 75%, and 100% of Louisiana grid intensity would result in emissions reductions of 5.24, 9.73, and 14.22 million metric tons of CO_2e (MtCO_2e) based on electrifying units with "good" potential.

These emissions reductions and additional electrical capacity represent a logical minimum to electrification potential for Louisiana. Technological advances and increased grid decarbonization can compound on each other to provide synergistic benefits to electrifying industrial heat demand. Electric heating can be used to reduce the overall emissions impact for units that otherwise have poor or no electrified alternatives. Electric heaters can be used for preheating or hybrid heating configurations that use electric elements for quick-ramp additional energy demand, reducing the total quantity of fossil fuels needed. Applications that are entirely unsuitable for electrification can be further decarbonized through the usage of hydrogen-fuel switching and carbon capture, among other deep decarbonization techniques. Emissions reductions and operation optimization using hybrid heating schemes is not covered in this analysis.

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Introduction

Almost all industrial processes require energy in the form of heat or electricity. Industrial heating is used to convert raw materials into useful products; it can remove moisture, separate chemicals, create steam, and melt feedstocks for shaping, among many other uses. Industrial heating accounts for about 30% of U.S. emissions and the industrial sector consumes a third of the US primary energy consumption.[1,2] Many industrial sectors currently use fossil fuel-fired combustion units to fulfill these thermal energy requirements. Electrifying these units in tandem with grid decarbonization is an efficient way to reduce the carbon intensity of many industrial sectors with lower investment and infrastructure retrofit.

Some industries use byproducts or low-cost alternative fuels for combustion in their boilers. The share of byproduct fuel usage is not homogeneous and is most common in a few sectors, such as pulp and paper mills, petroleum refineries, chemical and petrochemical manufacturers, and steel mills. These fuels will generally be produced and used on-site or transported short distances to a local off-taker. This is exemplified by the use of black liquor, a byproduct of the kraft paper process, and biomass waste products as fuel for on-site steam generation and process chemical recycling in boilers and furnaces. Another common practice is the purchasing of low-cost non-traditional fuels (tires, railroad ties, waste products, etc.). Other byproduct fuels include refinery fuel gas from petroleum refineries and petrochemicals manufacturers, and coke oven gas and blast furnace gas from steel mills. Many of these industries produce price-sensitive commodities that depend on low energy costs. While many of these fuel types are more affordable, they will generally have lower calorific contents and will produce larger amounts of pollutants.

The quantity and temperature of process heat and steam needed by a facility will vary depending on its application within each industrial sector, and even between similar facilities in the same sector. The range of temperatures required for a variety of processes is shown in Table 1 below. [1] Many of the sectors have processes that use low-temperature heat, defined here as less than 300°C. By one estimate, approximately 35% of industrial process heat demand is less than 165°C, which is well-suited for electrification.[4] Even units and processes with high temperature requirements can be optimized using electric heaters, such as by preheating incoming feeds to reduce the amount of combustion heat required. Deployment of advanced electric heating units and configurations will allow further penetration into medium and high temperature heat requirements.

Table 1. Typical Temperature Ranges for Process Heat in Industrial Sectors

Industry	Process	Temperature Range [°C]*
Food & Beverage	Pasteurization	60 – 80
	Sterilization	60 – 120
	Concentration	60 – 80
	Cooking	60 – 100
	Blanching	75 – 90
	Drying	120 – 180
Textiles	Bleaching/Dyeing	60 – 90
	Drying	100 – 130
	Fixing	160 – 180
	Pressing	80 – 100
Paper & Wood Products	Cooking/Drying	60 – 80
	Bleaching	130 – 150
	Pulp Preparation	120 – 170
Petroleum Refining	Distillation	370 – 425
Chemicals	Steam Reforming	500 – 900
	Drying, distillation	170 – 230
Plastics	Preparation	120 – 140
	Distillation	140 – 290
	Separation	200 – 220
	Extension	140 – 160
	Drying	180 – 200
	Blending	120 – 140
Non-metallic Minerals	Preheating	200 – 750
	Calcination	750 – 1000
	Sintering	1200 – 1450
Primary Metals	Precipitation	200 – 300
	Annealing	300 – 500
	Ore Reduction	1000 – 1100

Source: Schoeneberger et al. (2020)[1]

* Temperature ranges are shaded by maximum temperature within the range: low (<300°C), medium (300°C–800°C), and high (>800°C).

The majority of fuel consumption and emissions are produced by a few industrial sectors. Table 2 shows Louisiana's estimated total fuel consumption and industrial greenhouse gas (GHG) emissions from 2021, using the approach described in the Methodology section of this report. This analysis removes all power plants and power generating units, assuming that electricity generation facilities are not electrifiable. Gas processing, refineries, and petrochemical facilities consume nearly 75% of primary fuel and produce more than 70% of industrial CO_2 emissions for Louisiana.

Table 2. Estimated fuel consumption and total emissions for Louisiana industrial sectors (excluding power plants) in 2021

Industry	Number of Facilities	Fuel Consumption TBtu	Total Emissions $MtCO_2e$
Gas Processing	228	347.67	18.51
Refineries	17	331.89	19.39
Petrochemicals	32	236.67	13.65
Pulp and Paper	9	129.42	10.48
Chemicals	36	77.79	4.14
Ammonia	4	70.59	3.75
Metals, Minerals, and Other	16	32.11	1.80
Steel	2	0.95	0.05
Waste	5	0.48	0.03
Total	**349**	**1,227.55**	**71.79**

There are a variety of equipment, or unit, types used by Louisiana industry. The list included in this analysis is not exhaustive of all industrial unit types used in the state and uses only those with GHG emissions greater than 25,000 tons CO2e per year which are required to report to the EPA Greenhouse Gas Reporting Program (GHGRP). Under this program, industrial operators must report a number of variables, including the fuel type used, the specific unit type, and emissions by fuel type, among other factors. Operators often report units as “Other Combustion Source (OCS)” if the unit type is not specified or the unit is part of a larger configuration and emissions cannot be separated to individual emissions streams. OCS units may be units that are classifiable by a specific definable unit type but operators may choose not to for undefined reasons. It can be impossible or impractical to investigate OCS units more closely in order to reclassify them into other unit categories due to the opaqueness of reporting and proprietary unit configurations. This analysis will exclude OCS from consideration for electrification for these reasons and only examine unit types that are electrifiable. The exclusion of OCS from this analysis does not mean that all units classified as OCS do not have electrification potential but is done for clarity and conciseness.

The contribution of total fuel use and emissions for each unit type in Louisiana in 2021 is shown in Table 3.

Table 3. Estimated total fuel use and GHG emissions for each unit type reported to the **GHGRP for Louisiana, 2021**

Unit Type	Number of Units	Total Fuel Use TBtu	Total Emissions $MtCO_2e$
OCS (Other combustion source)	467	707.63	39.16
SCCT (CT (Turbine, simple cycle combustion))	113	134.38	7.14
OB (Boiler, other)	95	98.11	5.70
PRH (Process Heater)	106	76.88	4.42
CCCT (CC (Turbine, combined cycle))	13	64.56	3.55
Chemical Recovery Furnace	11	60.11	5.57
S (Stoker Boiler)	11	37.61	2.99
K (Kiln)	15	13.94	1.21
F (Furnace)	35	11.03	0.64
RICE (Reciprocating internal combustion engine)	218	7.59	0.41
TODF (Thermal oxidizer, direct fired, no heat recovery)	46	4.84	0.26
Pulp Mill Lime Kiln	9	4.68	0.25
C (Calciner)	2	2.79	0.29
ICI (Incinerator, commercial and industrial)	14	1.59	0.08
PD (Product or intermediate product dryer)	3	1.01	0.05
HMH (Heater, heat medium for heat exchange)	12	0.34	0.02
RTO (Regenerative thermal oxidizer)	3	0.19	0.01
O (Oven)	5	0.11	0.01
II (Incinerator, institutional)	3	0.09	0.01
NGLH (Heater, natural gas line)	7	0.03	0.002
HWH (Heater, hot water)	2	0.01	0.001
FLR (Flare)	5	0.01	0.001
CH (Comfort heater)	3	0.002	0.0001
Total	**1,198**	**1,227.55**	**71.79**

The names of unit types in EPA GHGRP are often specific and this analysis combines several distinct unit types in Table 6 into general categories, such as “Boilers” or “Heaters.” The conversion of GHGRP-listed unit types to broader unit categories is given in Table 4. This list of unit types is inclusive of all units that will be considered for electrification in this analysis, although some units have greater electrification potential than others, as discussed in subsequent sections. Electricity generating units are excluded as they have no potential for electrification, as are flares and OCS.

Table 4. Categorization of unit types in GHGRP to broader industrial units

Unit Types	GHGRP Units
Boilers	OB (Boiler, other)
	S (Stoker Boiler)
Process Heaters	PRH (Process Heater)
Hot Water Heaters	HWH (Heater, hot water)
Heaters	NGLH (Heater, natural gas line)
	HMH (Heater, heat medium for heat exchange)
Comfort Heaters	CH (Comfort heater)
Ovens	O (Oven)
	PD (Product or intermediate product dryer)
Furnaces	F (Furnace)
Chemical Recovery Furnace	Chemical Recovery Furnace
Incinerators	ICI (Incinerator, commercial and industrial)
	II (Incinerator, institutional)
Kilns	K (Kiln)
	Pulp Mill Lime Kiln
Thermal Oxidizer	TODF (Thermal oxidizer, direct fired, no heat recovery)
	RTO (Regenerative thermal oxidizer)
Calciners	C (Calciner)
Turbines	SCCT (CT (Turbine, simple cycle combustion))
	CCCT (CC (Turbine, combined cycle))
RICE	RICE (Reciprocating internal combustion engine)

Conventional Combustion and Electrification Options

This section will discuss the common uses of each industrial unit type, electrification potential and options, as well as other considerations relevant to electrification.

Boilers

Combustion boilers are used across nearly all industrial sectors, accounting for around 41% of fuels combusted in industrial facilities in 2016.[5] In combustion boilers, various fuel types are used to produce steam or heated water above 100°C. These products can be used for process heat, electricity generation, and mechanical power.[6] Steam is an applicable heat transfer medium for uses between 120°C to 260°C, with the upper limit reaching in excess of 600°C for superheated steam applications.[7] Boilers can also be used for combined heat and power (CHP) to utilize of all available heat and mechanical energy. Some industrial processes may also require large quantities of steam within their production stream, such as petroleum refineries and pulp mills.[8] Hot water can be used as an extremely effective heat transfer medium, as its density is approximately 800 times higher than air with a heat capacity 4 times greater.

Combustion steam boilers produce hot water or steam for a variety of applications. Their energy demand is most often fulfilled by fossil fuels, biomass products (e.g., black liquor, wood residuals, etc.), and low-cost or byproduct fuels (e.g., tires, refinery fuel gas, etc.).[9] Combustion of these fuels will produce flue gases that are vented into the atmosphere. Many boiler configurations use heat exchangers to recover heat from the exiting flue gases to heat incoming water or fuel feeds. Although most heat is recovered, there will still be some heat lost to the surrounding environment, reducing the overall efficiency.

The reported design energy efficiency of different combustion boilers varies by the fuels used to heat the unit, its specific configuration, and the method used to calculate thermal efficiency. The design efficiency of combustion boilers varies from 83% for diesel and residual fuel oil fired units to 65% for liquor fired units, assuming an 80% heat recovery rate (Table 5).[10,11,12] Actual efficiencies will likely be lower due to inefficient operation or maintenance practices. Units that produce hot water, instead of steam, will be slightly more efficient, as the phase change from liquid to solid is mildly endothermic. The difference in efficiencies between hot water and steam boilers is described in Table 6.[13]

Table 5. Boiler design efficiencies by fuel type

Boiler Fuel Type	Efficiency	Reference
Natural Gas	75%	[8]
Coal	81%	[8]
LPG & NGL	82%	[8]
Diesel	83%	[8]
Residual Fuel Oil	83%	[8]
Coke & Breeze	70%	[8]
Liquor	65%	[8]
Agri-waste	64%	[8]
Pet-coke	70%	[8]
Waste Oil, Gas, Tar	70%	[8]
Wood & Wood Residuals	70%	[9]
Fuel Gas*	75%	[8]
Other Biomass Gases	68%	[10]

*Natural gas is used as an analog for fuel gas efficiency because of relatively similar combustion characteristics and a lack of information on fuel gas combustion efficiencies.

Table 6. Efficiencies of hot water and steam boilers according to their fuel type based on 10 CFR Part 431.86

Unit Type	Fuel	Heating Medium	Efficiency
Large Gas-Fired Hot Water	Gas	Hot Water	>96%
Large Gas-Fired Steam	Gas	Steam	>83%
Large Oil-Fired Hot Water	Oil	Hot Water	>89%
Large Oil-Fired Steam	Oil	Steam	>85.5%

Source: U.S. DOE.[13]

The distribution of energy demand by combustion boilers is not homogeneous across all industrial sectors. Pulp and paper mills, petroleum refineries, and petrochemical manufacturing account for the majority of energy consumption by boilers within the state of Louisiana. Pulp and paper manufacturing relies heavily on boilers to process virgin material into consumer goods and for thermochemical cycling to recover expensive chemical reactants. Petroleum refineries and petrochemical manufacturers use steam as an aid to break down larger hydrocarbons, increase mass within a reaction vessel, and to cool intermediary products.[14]

Electric boilers are the most mature electrified technology for industrial heat. Water within the boiler can be heated by a variety of methods, including resistance and induction heating. Resistance heaters run current directly through conductible material using the chemical properties of the material to produce heat. Induction creates a magnetic field around a an electrically conductive material, generating heat through the conductive material. Both heater types can be configured to have a heating vessel or to be flow-through boilers. Flow-through boilers will require much higher temperatures to ensure steam generation and longevity as water passes over the heating element.

Electric boilers are more thermally efficient than combustion boilers, as the heating element transfers all heat to the water, while combustion units will have some loss due to escaped energy with the flue gases. Most electric units use direct contact with the heating medium, leading to efficiencies close to 100%.[15] Some novel designs for high-efficiency, high-capacity flow-through induction boilers are estimated to have efficiencies of greater than 97%.[16] Electric heating units are more efficient operationally as well, requiring little downtime, minimal ancillary infrastructure (e.g., fuel storage tanks, pollution control devices, etc.), and having fast ramp-up times when compared to analogous fossil-fired units. Electric boilers can produce steam up to about 300°C.[1]

As electric boilers are already a mature technology, there is ample opportunity for electrification and this unit type is classified as having good potential. While the operation costs of an electric boiler may be higher than the combustion analog, a rising share of cheaper renewable energy is expected to reduce these costs in the coming decades.

Process Heaters

Almost all industrial sectors require heat to turn raw materials into a new product. This energy demand is called "process heat" and can be applied to many heat applications apart from primary energy production.[17] Industrial heat accounts for two-thirds of industrial energy demand and nearly one-fifth of global energy consumption.[18] While both boilers and process heaters are designed to transfer heat generated from fuel combustion, process heaters are often used in applications where boilers are inadequate, such as heating non-water working fluids (e.g., in petroleum refineries or petrochemical facilities) or heating solid materials.[19] Importantly, these process heaters will be distinct from other heating units, such as furnaces, kilns, ovens, etc. that may use heat in similar ways.

Thermal energy for process heat is classified based on its temperature. These categories vary broadly depending on the source and application, but are generally divided into low-temperature (<300°C), medium-temperature (300°C-800°C) and high-temperature heat (>800°C). The majority of heat used for industrial purposes falls in the low-temperature category (Table 1).[20] A few industrial sectors account for the majority of high-temperature process heat, including petroleum refineries, chemical manufacturers, and metal manufacturers. Petroleum refineries require large quantities of high-temperature heat to aid in the separation various component hydrocarbons from raw crude oil and to aid in chemical and thermochemical processes necessary to produce liquid hydrocarbon fuels and feedstocks. Similarly, petrochemical manufacturers will use process heat in a variety of ways, including modifying the chemical structure of hydrocarbons and increasing the chemical kinetics of a reaction. Metal manufacturing requires large quantities of high heat to turn raw ore into a usable metal product. Process heat is often used by metal manufacturers in furnaces, smelters, and other units.

Some applications of process heat can be decarbonized through electric process heaters or heat pumps. These heaters use similar methods to electric boilers to transfer heat to working fluids or gases.[21] Process heat can be applied to incoming feeds or directly to a unit (such as furnaces and crackers). Similar to electric boilers, electric heating units will have efficiencies nearing 100% as the heating element transfers nearly all available heat to the target process. Minimal loss in efficiency will occur due to electrical considerations, and radiative and conductive heat loss. Some electric boilers may be used to provide industrial process heat depending on the temperature needs of the industrial process.

Usage of electric process heaters is commonplace in some industrial applications. Similar to electric boilers, these electric process heaters are valued for their ease of maintenance, low ramp-up time, precise temperature control and distribution of heat, and smaller footprint than analogous fossil fuel-fired systems. Common industrial process heaters include flanged heaters, circulation heaters, over-the-side heaters, and screw plug heaters. Flanged and circulation heaters are commonly used to heat working fluids by chemical manufacturers, petroleum refineries, and petrochemical manufacturers. Each of these units may also be used to apply direct heat and heat gases.[22]

Temperature ranges for electric process heaters vary depending on the construction of the heater, how the heater is included within the configuration, and the fluid medium being heated. Existing high-temperature electric heaters can reach temperatures in excess of 550°C using high-powered heaters coupled with high-heat capacity fluids (such as molten salts), with some configurations reaching 650°C.[21] The heating capacity of electric units is diminished as power and working fluid heat capacity are lowered. Some novel designs can reach temperatures in excess of 800°C but are not yet commercially available.[23] Electric heaters can theoretically produce very high temperature heat if constructed with durable materials and supplied with large quantities of high-powered electricity. In one study, it is claimed that electric heaters could produce heat at temperatures greater than 1600°C.[1]

Heat pumps are another alternative to fulfilling low-temperature heat needs across industry. Heat pumps are bi-directional heating and cooling units that recover industrial waste heat that would otherwise be rejected to provide process heat or economize higher temperature processes.[24,25] Industrial heat pumps are generally used for very low-temperature applications (<100°C), but specialized units can achieve higher temperatures (150–200°C), with some new prototypes able to produce heat greater than 200°C.[26] Efficiencies for heat pumps, also known as the coefficients of performance (COP) vary widely depending on the incoming waste heat temperature, the end temperature demanded, and ambient conditions (e.g. temperature).[27] Optimal industrial heat pump performance is often realized when the unit must change the input temperature by 30–50°C, providing more than three times the thermal energy compared to the input electrical energy (COP greater than three).[28] Efficiencies are diminished when the temperature change is larger than this range.

Current electric process heaters and heat pumps are best suited for low- to medium-temperature industrial heat applications. Therefore, industries with thermal energy requirements in those ranges have high potential for the replacement of fossil-fuel fired units with electric alternatives, while advanced electric process heaters and boilers could be used to reduce fossil-fuel usage within industries that have high temperature demands. Table 1 shows the temperature ranges for process heat across a variety of industrial sectors. Based on these estimates, electric process heaters could replace fossil-fuel fired heaters in the food and beverage, textiles, paper and wood products, and plastics subsectors. Industries with high-temperature needs, such as steam reforming in chemical manufacturing and petroleum refining, calcination of carbonate minerals for cement, and reduction of ores for primary metal manufacturing, could see a reduction in fossil fuel use and emissions by adopting electric options wherever possible, particularly with innovations in high-temperature electric process heating.

Given the wide range of variables that affect temperature from these electric heating units, it is difficult to estimate the total electrical load necessary to replace fossil-fired process heaters. The electrification potential of process heaters is good as most process heat requirements fall within temperature ranges achievable by current electric heaters. There is less potential for high heat applications of process heaters due to thermal constraints of existing electric heating systems. Technological advancements in novel forms of electrical heating (i.e., electromagnetic, electric arc, etc.) and conventional systems (e.g., resistance) could lead to more potential for high temperature applications.

Hot Water Heaters

Hot water heaters are used for a range of industrial, commercial, and residential applications. Hot water heaters are similar to boilers and will have the same general configuration; they can be flow-through or tank designs with a suitable heating element. These units can be heated using combustion or electric elements. Hot water heaters will generally have slightly higher thermal efficiencies than boilers.[13] Boilers also tend to operate at much higher temperatures (>100°C) while hot water heaters will not exceed 100°C. These units can have several different configurations depending on the specific use case. Conventional hot water heaters will have a burner that heats a tank of water. More modern pass-through water heaters have a heating section where water is brought up to higher temperatures before distribution.

Within industrial facilities, hot water is often used for space heating, mixing, curing, and cleaning to facilitate product manufacturing and maintain sterile manufacturing environments. These applications are commonly found at mineral processors (i.e., concrete, gypsum, etc.), manufacturers of consumer goods (i.e., textiles, bottles, food, etc.), and high-volume service providers (i.e., hospitals, hotels, car washes, etc.).[29] Hot water heaters also have extensive use for commercial and residential applications from household heating to food preparation and sanitation.

Both conventional and pass-through configurations of hot water heaters discussed in this report can be electrified using mature technologies. Either can be heated using resistance, inductive, or microwave heating either directly or indirectly. Direct heating will have efficiencies close to 100% as the heating element will be fully immersed and all thermal energy is transferred directly into the water. Some heat may be lost through extensive ducting or distribution but electric water heaters will have zero heat loss due to flue gas, one of the largest sources of heat loss for combustion units.

Similar to electric boilers, electric water heaters have good electrification potential especially as they operate at lower temperatures and the technology is quite mature. This is especially true for units that require fast ramp-up times.

Line Heaters

Some industries require heat similar to, but distinct from, previously discussed applications. This specific usage of heaters is generally consolidated to line heaters but is reported as both natural gas line heaters and heat medium for heat exchangers in EPA GHGRP. These units use nearly identical configurations and are often found at upstream and midstream natural gas infrastructure.

Line heaters are generally found near natural gas wellheads or gas transmission lines. Their main purpose is to heat up the well-stream or pipeline fluid to prevent blockages. Gas and pipeline fluid will undergo a rapid pressure drop when exiting the wellhead, reducing the temperature enough to form solid hydrates in the line and blocking flow. A conventional line heater will have a similar configuration to a natural gas fired water heater, with combustion gases heating water, which will then heat the incoming well stream. These units are often fired using raw natural gas pulled directly from the wellhead. Some line heaters may add other compounds to the heated water to improve the heat exchange with the incoming well stream.[30]

These units may also be used at facilities that use large quantities of transmitted natural gas. Gases pulled from a large trunk line may be at a lower pressure and will need to be heated to prevent blockages that could impede facility operations.

Electrified line heaters are already used by industry today. Conventional gas fired line heaters can be electrified by replacing the gas-fired heating element within the heat exchange medium with a screw plug or flange mount immersion heater, or by complete replacement of the unit with a purpose specific circulation heater designed for heating flowing liquids and gases for industrial applications.[31] Each of these opportunities can be tailored to the specific needs of the gas line with specialized configurations able to reach 800°C.

Due to the relatively low-temperature heat requirement for heaters, this unit type is categorized as having good electrification potential. While this unit type has potential, the distributed locations of these units may preclude them from electrification, as they may be some distance from the local grid.

Comfort Heaters

Industrial facilities may need to heat indoor or outdoor spaces to provide tolerable working conditions. Comfort heaters can be permanent or mobile units that use electricity or fossil fuels to warm a working space. Industrial units may use low-cost byproduct or waste fuels such as residual fuel oils to produce heat spaces, producing hot air or working fluids. Industrial facilities often have additional safety requirements beyond what is required of residential or commercial applications, such as filtration of hazardous compounds or preventing accidental explosions. Comfort heaters may be a single component of a larger HVAC system or an additional unit solely responsible for heat. Industrial facilities can have large comfort heaters for large spaces or many small units to heat working spaces such as workshops, production lines, or administrative offices.

Comfort heaters operate similarly to other space heaters and can use a variety of techniques to produce heat. Some heaters may use combustion to warm incoming air or a working fluid that then warms the space. Other electric units may use resistance heating in a similar way, warming air or a fluid, while others use infrared radiation to only warm people in the space in order to increase the efficiency of the heating. Comfort heaters may draw in fresh air from outside, aiding in ventilation and circulation, or they may be placed in a space to heat that air with no new air added. Combustion-based heaters will require proper ventilation to vent flue gases and prevent potentially fatal indoor air quality while electric heaters do not require the same ventilation requirements.

Electrified comfort heaters are a robust technology that is used as additional heating in many residential, commercial, and industrial applications already. Comfort heating can also be provided using heat pumps on traditionally “low quality” waste heat (<100°C). Using heat pumps to provide comfort and space heating could virtually eliminate dedicated permanent combustion heaters and reduce the energy demand of the entire facility. Comfort heaters are not generally large units and will often have relatively modest emissions contributions compared to the larger facility. Some facilities with abundant low-cost waste or byproduct fuels may have less incentive to electrify comfort heating, as it is essentially “free” for them to produce heat in this way. While often dependent on waste or byproduct fuels, there are ample opportunities for comfort heaters to be electrified, allowing this unit type good potential.

Ovens

Industrial ovens are similar to other thermal processing units within industry, specifically furnaces. Ovens generally operate at lower temperatures than furnaces and heat is constantly applied. Ovens often use convection to circulate air and improve thermal efficiency.[32] Industrial ovens will generally produce heat between 120–450°C.[33] Units that produce more heat than this will usually be classified as furnaces instead of ovens.

Industrial ovens are used for a range of thermal processes. They can be used to heat treat parts, condition metals, remove moisture, cure coatings, and remove impurities from coatings. These units can be heated using combustion of fossil fuels, electric elements, or using a working fluid. Ovens may also use microwaves, UV or IR radiation, and high frequency waves. Ovens are also commonly used to process metals or other materials to get a desired chemical structure or composition. Ovens can further be used for baking, in order to remove moisture from materials such as in food manufacturing or preparing biomass fuels.

Electric ovens are already commonplace throughout industry. These ovens are favored for the reduced maintenance, lower construction costs, and customization while having higher operating costs due to the difference in cost between electricity and most fuels. For this reason, industry often favors fossil fuel combustion for large ovens while preferring electric ovens for smaller applications. Ovens have good electrification potential throughout industry due to the low-temperature heat demand and maturity of technology.

Furnaces

Certain industrial processes will require high temperature heat in large quantities or temperatures than can not be accomplished by ovens or process heaters by themselves. The dividing line between furnaces and ovens is not sharp and the nomenclature may rely on tradition or specific configurations rather than a specific definition.[34] Furnaces produce very high temperature heat, generally between 450–1000°C with specialized units able to achieve 3000°C.[35] The exact temperature range will depend heavily on the specific application of the furnace; cooking furnaces may require lower temperatures while melting and smelting require much higher temperatures.[36] These units are typically some of the highest temperature units found at industrial facilities and can be used for either process heat or as a reactor, providing heat for a reaction.

Furnaces are commonplace throughout many industries. They are used to smelt ore, melt metals and glass, bake ceramics, and break down chemicals, among other uses. While the name of the unit may vary, furnace-like units are found at steel mills, non-ferrous metal foundries, ceramic and glassworks, petroleum refineries, and petrochemical manufacturers. Each of these industries generally need large quantities of heat above 800°C.[37] Most combustion-based furnaces will have an average thermal efficiency above 50% and will vary depending on their specific type and function.[40]

There has been significant attention towards developing electric furnaces that can achieve the high temperatures required for process and reacting heating. These electrified units can hypothetically have zero flue gases, preventing a large source of heat loss and allowing very high efficiencies (>90%).[11] Depending on the specific process, electric furnaces may need circulating fans to assure temperature uniformity normally provided by flue gases and products of combustion. Heating can be supplied through mature resistance and inductive methods, or through novel techniques, such as radio frequency, microwave, and electromagnetic heating.[11] Furnaces that use electric heating elements will generally have a higher operating cost due to the higher cost of electricity compared to most fossil fuels.

Although furnaces will generally require large quantities of high temperature heat, the relevant heating technologies are relatively mature and there is a large amount of industrial research. For these reasons, furnaces are categorized as having good electrification potential. Chemical recovery furnaces, which are components of chemical recovery boilers, have poor electrification potential due to their use of biogenic byproduct fuels and are not considered in this analysis.

Incinerators

Incinerators are used to gasify waste products, typically for one of three purposes: hazardous waste destruction, municipal solid waste (MSW) removal, or so-called waste-to-power using MSW. In each of these applications, waste is heated to a very high temperature at which point the component chemicals become oxidized. For hazardous waste, this will often mitigate the toxicity of a compound or destroy it. Typically, incineration of hazardous materials will only be considered if there is an immediate threat to people or the environment, or if the wastes are predominantly liquids and gases. For MSW, this is a means to reduce the total volume and mass or waste for landfill storage or to extract energy from combustible components. These units usually operate from 850–1400°C to fully oxidize all materials in the combustion chamber.

Approximately 25 million metric tons (12%) of MSW is combusted in waste-to-energy plants in the U.S., producing 13.6 billion kWh of electricity.[38] These plants operate in a similar way to conventional coal boiler power generation. MSW will generally be mixed with another combustible fuel, such as natural gas or oil, and burned. This combustion produces steam which will produce electricity in a turbine. These waste-to-power facilities will have electrical efficiencies of about 44%. CHP and WHR can be used to enhance electrical efficiencies up to approximately 60%.[39]

Incinerators are generally used in few industrial sectors. The most common usage of incinerators is in the waste disposal industry, for incineration with power generation and without. The waste-to-power industry combusts MSW to extract power from organic and petroleum-based materials within the waste stream. Without power generation, waste incinerators generally seek to reduce the land-use requirements of MSW or to comply with pollution standards established by the Clean Air Act and other environmental regulations.[6] Incinerators can also be deployed within industrial facilities that produce large quantities of waste products that must be disposed of. These waste streams include detrital biomass from pulp and paper, tail gas from chemical manufacturing and petroleum refining, and various forms of hazardous and medical waste.[40] Incinerators are used in similar fashion to other disposal units (e.g., thermal oxidizers and flares) and labeling of these units may be interchangeable depending on the facility type and industrial sector.

While there is a lack of publicly available information of electrification potential, most incinerators could be electrified using existing technologies. The combustible component of MSW can still be ignited by heating those materials to their autoignition temperature, which will vary from material to material. Ignition of materials with cooler ignition temperatures can be achieved by using electric arcs or plasma. Further, waste could be heated using electric heating until all volatile components have been gasified, producing a high calorific value gaseous fuel that could be combusted for disposal or electrical generation. Incineration for disposal can be done in the same way, heating waste materials to high temperatures to destroy hazardous components. While electrification will diminish the demand for fossil fuels for incinerators, it will not mitigate greenhouse gas emissions from the waste itself. As feedstocks for consumer and industrial materials are decarbonized, the impact from the waste will be lessened but will need to be mitigated in other ways. Although incinerators may be electrified, the penetration of electrified units is unknown, and likely will not be pervasive, as the efficiencies of electric incinerators would likely be quite low and energy consumption very high. Incinerators are classified as having poor electrification potential for this reason.

Kilns

Kilns are very high temperature thermal processing units that can be used for a variety of products. Kilns will often be used for calcining minerals (e.g., turning limestone into cement), firing ceramics and glass, or for a variety of metallurgical processes (i.e., annealing, curing, sintering, quenching, etc.). Industrial kilns typically operate at temperatures in excess of 1100°C. Some lower temperature kilns may be used for industrial purposes (i.e., for wood product drying, etc.) which will be similar to ovens.

Industrial kilns can either be electric or fossil fuel fired. Smaller volume or specialty kilns will generally use electric arc or resistance heating while larger units rely on fossil fuel combustion. The cement industry will use very large rotary kilns to process limestone into clinker, an important intermediary in Portland cement. The efficiency of kilns will vary between specific use cases with the average below 60%.[41] Waste heat recovery can be used to improve system efficiencies, but the benefits will depend on the kiln and its intended use.

These units are used in several industrial sectors, generally in materials processing and manufacturing. Kilns are an important unit in cement manufacturing, metal treating, and glassmaking. Kilns in each of these sectors will operate in similar ways but the configurations will often be quite different. Rotary kilns used to process limestone for cement are large rotating compartments where a fuel air mix will be added directly to the raw limestone feedstock while most other fossil fuel-fired kilns will use indirect heating around the combustion vessel. Kilns can also be found in the pulp and paper industry or they may be replaced by a calciner.

Electrified kilns can have a lower thermal efficiency compared to their fossil-fired analogs. The lower efficiency is due to the difference in configuration between the two types of heating. In some large fossil-fired kilns, fuel is directly combusted within the heating chamber. This type of combustion will have a very high efficiency as nearly all thermal energy is transferred to the material. These kilns have refractory material surrounding the vessel which will reflect heat back into the vessel. For electrified units, heating elements must either be placed within the vessel or around the outside. Heating elements along the outside must transfer heat through the refractory panels into the process material, reducing thermal efficiency.

Electric kilns are generally not seen as having ample electrification potential due to the large quantity of energy needed to produce the high process temperatures these units usually operate within. Some applications, such as those used by bespoke ceramic or metals coating manufacturers, may use electrified units while larger industrial users will require larger combustion-based units. For this reason, kilns are unlikely to be electrified in the near term and are classified as having poor electrification potential.

Thermal Oxidizers

Emissions of some pollutants from industry must be destroyed using thermal oxidizers. These units heat exiting flue gases or process tail gas to temperatures sufficiently high enough to oxidize, and destroy, any harmful compounds. Thermal destruction of most organics will occur at temperatures between 400–1100°C.[42] Thermal oxidizers regularly operate at ~99% abatement efficiency, mitigating emissions of hazardous air pollutants and volatile organic compounds across a wide range of industrial sectors. These industrial sectors include chemical manufacturers, petroleum refineries, natural gas transportation and processing plants, metal producers, and pulp and paper mills. Thermal oxidizers may have identical or similar configurations to incinerators or flares but will be labeled as thermal oxidizers.

The specific configuration of a thermal oxidizer will vary somewhat but each will function in similar ways. Conventional thermal oxidizers use combustion, usually fueled by natural gas, to oxidize pollutants flue gases. There are three kinds of thermal oxidizers used in industry: regenerative thermal oxidizers, catalytic thermal oxidizers, and simple thermal oxidizers. Regenerative thermal oxidizers will utilize a heat exchanger to recover much of the heat from exiting flue gases to maintain the oxidative reaction. Regenerative thermal oxidizers may not require large inputs of fuel combustion to maintain the reaction as much of the heat can be recovered and additional energy is produced from the oxidation of volatile compounds. Catalytic thermal oxidizers use a catalyst bed in order to lower the oxidative temperature of pollutants and improve energy efficiencies for the system. Simple thermal oxidizers only use combustion without any waste heat recovery or efficiency improvements from catalysts. This type of thermal oxidizer will have the highest energy of the three types.

One of the configurations of thermal oxidizers, the catalytic thermal oxidizer, already gets the majority of its energy from electricity but requires some natural gas combustion for start up operations. Each of the configurations could be electrified using resistance heating, electric arcs, or a various other options, provided that the temperature within the unit reaches temperatures sufficient to oxidize the target compounds.

While technologically feasible, electric thermal oxidizers are not likely to be widely deployed except for specific niche applications and are seen to have poor electrification potential. Further technological advancements in catalysts and low-temperature oxidation of pollutant species will increase the penetration of electric thermal oxidizers.

Calciners

The most energy intensive equipment at many mineral processing facilities are calciners. These units process minerals by raising them to a high temperature in order to remove impurities and oxygen, thereby producing a refined product. The main component of the calciner is a furnace or reactor in which the raw mineral ore is processed. The exact configuration of a calciner will vary depending on the mineral being processed, the quantity processed, and other engineering considerations. Some types of units include rotary, fluidized bed, shaft, and multiple hearth calciners.

In nature, many minerals are oxidized by geologic processes and the interaction with water and atmospheric air over many millions of years. The additional oxygen atoms must be removed to produce a useful mineral product, such as the conversion of limestone ($CaCO_3$) to clinker (CaO) for usage in Portland cement. Thermally processing these minerals produces valuable mineral feedstocks and materials but can release large amounts of CO_2 as the minerals are converted to their reduced structure. These process emissions will typically compose about half of emissions from the calcination process, with the remainder coming from combustion for process heat.

Calciners are ubiquitous within the cement industry, and are common in other mineral processors (i.e., gypsum, lime, etc.), pulp and paper, and natural gas processors. Some facilities may use calciners even though they do not typically process ore. For example, the pulp and paper industry is a common user of calciners in order to process caustic materials used in the kraft paper process. These compounds will be used to break apart the paper fibers in the pulp in order to make paper but must be replenished. On-site calciners will recharge the chemicals so that they can be used again. Conventional calciners are often combined with kilns in order to optimize the calcination process.

The electrification of calciners is an opportunity to reduce the carbon intensity of manufacturing. For some calciners, electrification also presents opportunities for further emissions reductions by integrating carbon capture of process emissions. An electrified entrainment calciner at a cement plant could produce nearly pure CO_2 emissions that can be captured at low cost. Other electrified configurations, including rotary and fluidized bed calciners, are commercially available but are not widely deployed. Generally, each of these configurations uses resistance heating in or around the calcining unit to achieve proper temperatures for mineral processing.

The prospect of producing a nearly pure CO_2 stream from electrified calciners at cement plants is an attractive opportunity for emissions reductions of usually hard-to-decarbonize process emissions and an economic opportunity for plants who choose to electrify. Flue gases from conventional calcination operations will be composed of process CO_2 as well as the gases from combusting fossil fuels. The products of fossil fuel combustion will lower the purity of CO_2 in the flue gases, increasing the cost to capture CO_2 from that stream. As about half of these carbon emissions are a product of manufacturing the desired process, calciners must be decarbonized, at least in part, by carbon capture. The combination of carbon capture with electrification could completely reduce calciner emissions with a lower economic cost than carbon capture retrofit to a similar fossil fuel-fired unit.

Electrified calciners are not mature technologies and the large quantities of electricity needed to achieve high process temperatures makes electrification unlikely for most cases. For this reason, calciners are seen to have poor electrification potential in the near term.

Turbines

A turbine is generally defined as a device that extracts energy from a fluid flow using rotational energy. The exact configuration will vary between applications especially between fluids. All turbines will have a rotor, which is spun by moving fluid, connected to a generator which produces electricity. Gas turbines will combust gaseous fuel with compressed air to power a rotor which benefits from the expansive qualities of this type of reaction. Steam turbines use steam from a boiler to spin a rotor and produce electricity in a generator by expanding the hot steam.

Turbines are ubiquitous throughout industry as one of the most efficient ways to produce large quantities of power. Nearly all power generation will use a turbine to produce electricity, from gas and steam turbines in fossil fuel power plants to renewable generation from wind and hydroelectric turbines. Natural gas transportation and distribution infrastructure may rely on turbines to produce electricity in rural locations to power compressor stations. These stations siphon off a small quantity of raw gas from a pipeline or distribution network and use it to fuel a turbine.

There is little opportunity to electrify turbines as they are used to produce electricity. The electrification of these units would lead to a net loss of energy. Other applications, such as for natural gas compressor stations, could be replaced using an electric motor, but cannot be replaced by an electric turbine. This analysis will assume that turbines used to generate mechanical energy (i.e., pumps, compressors, refrigeration, etc.) will be electrified using an electric motor, eliminating the turbine completely.

It is very unlikely that combustion turbines as they are currently configured can be electrified. For this reason, turbines have no electrification potential but are assumed to be replaced by electric motors in this analysis. Even with the replacement of turbines with electric motors, electrification potential is assumed to be poor as there are additional considerations needed to fully quantify the potential that are not covered in this analysis.

Reciprocating Internal Combustion Engines (RICEs)

Reciprocating internal combustion engines (RICEs) are used across nearly all industrial sectors as electrical generators or to produce mechanical energy. These applications include backup generators (emergency, standby, peak shaving, etc.), small CHP units, pumps, compressors, and refrigeration. RICEs used for electrical generation may be used to maintain or safely spin-down operations during power outages, or to provide additional electrical generation during high-demand load peaking. Mechanical energy uses may be utilized to maintain pressure in feedlines, mitigate environmental considerations (e.g., flooding), and operate refrigeration units. Facilities that demand large quantities of mechanical energy will generally replace RICEs with turbines as they are more efficient at scale. These units are very similar to conventional vehicle engines but installed at a stationary location instead of onto a mobile platform.

RICEs will generally have higher efficiencies than gas turbines for smaller unit sizes with comparable generation capacity and fuel intake. The electrical efficiency of a RICE will vary depending on the size, configuration, and fuel considerations of the unit. As this category of engine is broad, the efficiencies vary and will likely be specific to each unit. Generally, large units will be more efficient than smaller units. Table 7 shows a range of efficiencies for several different RICE configurations.

Table 7. Efficiency of various RICE configurations by fuel type and electricity capacity[43]

Engine Type	Fuel	Capacity	Efficiency
Small stoichiometric engines	NG (spark ignition)	<100 kW	30%
Large lean burn engines	NG (spark ignition)	>3 MW	46%
Small high speed diesels	Diesel	<4 MW	30% (HHV)
Large bore slow speed engines	Diesel	<80 MW	42-48% (HHV)

RICE efficiency can be further optimized by the utilization of CHP and waste heat recovery (WHR). Most energy produced from combustion reactions is lost to heat energy, minimizing the amount of work from the combusted fuel.

Total energy efficiency of RICEs can reach 80% using CHP and WHR. RICE exhaust temperatures will typically reach 380–540°C and contain 30–50% of available waste heat from the system, producing hot water, steam, or hot air from the recovered waste heat.

Some applications of RICEs are unlikely to be replaced by electrified options while others are excellent candidates for electrification. Electric alternatives to RICEs are not a viable option for backup or additional electrical generators, as they demand electricity to operate. Electric motors could replace all other applications, including pumps, compressors, and other uses of mechanical energy. Many electric options of these unit types already exist and are being deployed. Although there are electric options for these units, RICEs are considered as having poor electrification potential due to the opaqueness in unit identification and lack of utility of electric units for some applications (e.g., backup and additional electrical generation). RICEs have good potential for mechanical purposes but can be nearly indistinguishable within EPA GHGRP.

Electrification Potential

Not all industrial units in the state of Louisiana are electrifiable. As described in the previous section, there are a number of unit types that cannot be electrified or have poor opportunities for electrification due to economics and technological considerations. Units with no or poor opportunity for electrification generally are electrical generating units (turbines, backup generators, etc.), require very high temperature heat (calciners, kilns, thermal oxidizers, etc.), or use a coproduced byproduct fuel (e.g., chemical recovery furnaces). This analysis categorizes each industrial unit type as having good potential for electrification or having poor to no potential for electrification. A unit categorized as having poor to no electrification potential does not mean that it cannot be electrified but the current technology readiness level is not sufficient to recommend economical electrification opportunities. Recent literature has indicated that high temperature heat applications are possible for some units that may be technologically and economically feasible in the near future but are not available currently.[59]

The present-day electrification potential of units as classified for this analysis is shown in Table 8.

Table 8. Electrification potential of unit types reported in EPA GHGRP.

Unit Type	Electrification Potential
Boilers	Good
Process Heaters	Good
Hot Water Heaters	Good
Line Heaters	Good
Ovens	Good
Furnaces	Good
Comfort Heaters	Good
Incinerators	Poor to None
Kilns	Poor to None
Thermal Oxidizer	Poor to None
Calciners	Poor to None
RICE	Poor to None
Turbines	Poor to None
Chemical Recovery Furnace	Poor to None

Methodology

To estimate fuel use and emissions for Louisiana facilities with boilers and process heaters in 2021, data were downloaded from the U.S. EPA Greenhouse Gas Reporting Program (GHGRP). Software code using the Julia language was used to interface with EPA's RESTful API to retrieve recent emissions data in the EnviroFacts database reported for industry Subpart C (Stationary Combustion), D (Electricity Generation), and AA (Pulp and Paper Manufacturing), as well as summary tables of facility information for emitters. A total of 11 files were obtained from EnviroFacts using this code for reporting year 2021.[44]

Next, the method of McMillan and Ruth[45] of the National Renewable Energy Laboratory (NREL) was used to estimate fuel use based on GHGRP-reported emissions for industrial facilities. This method was implemented using Python language source code made available on the GitHub distribution platform,[46] updated by this study team for recent changes to GHGRP data formatting and Python version differences. Other minor changes to the Python code provided by NREL included removing a filtering step by NAICS code that excluded certain industrial sectors, allowing facilities without a primary or secondary NAICS code to be included, and making changes to how general facility information is collected and used.

Within the NREL Python code, the method used to determine fuel use depends on the Subpart and Tier methodology under which the emissions were reported to the GHGRP.[47] Most commonly, fuel use is estimated using default emission factors for either CO_2 or CH_4, depending on the reporting Tier (1 through 4). If actual annual energy use is directly reported (i.e., under Part 75 reporting), this value is used. In other cases, custom emissions factors for particular facilities and fuel types are derived from more detailed information reported to the EPA.

The EPA provides an additional dataset ("Emissions by Unit and Fuel Type", referred to here as the GHGRP unit dataset)[48] which contains all of the units collected by the method above, as well as some additional units that are not captured by the NREL Python code. In total, this dataset provides an incomplete accounting of specific unit types; some are not reported because they do not meet a threshold for GHGRP, others are included in the "Other Combustion Sources" category, and some unit types (e.g., boilers) may be included within other unit types. Schoeneberger et al.[9] showed that industrial boilers in GHGRP represented a small fraction of total boilers in the U.S., by using county-level fuel estimates compared to fuel use estimates based on GHGRP alone. Therefore, this analysis for Louisiana is likely an underestimate of the numbers of units as well, although it will capture the largest fuel-using units and greatest emissions reduction potential.

For those units with emissions by fuel type reported in the GHGRP unit dataset[48] that are not handled by the method of McMillan and Ruth[45] described above, Julia code was used to estimate their fuel use and combine and collect the results of the NREL code and these calculations into a full dataset with all relevant information. For the units where fuel use is not calculated using the NREL code, it is estimated in the Julia code based on fuel type, reported emissions, and default EPA emissions factors for CO_2, CH_4, or N_2O, when available.[49] The equations for calculating estimated fuel use energy in million Btu (mmBtu) by emissions for CO_2, CH_4, and N_2O are:

CO_2: $E_f = GHG_f / EF_{CO2,f} \times 10^3$
CH_4: $E_f = GHG_f / EF_{CH4,f} \times 10^6 / GWP_{CH4}$
N_2O: $E_f = GHG_f / EF_{N2O,f} \times 10^6 / GWP_{N2O}$

Where

E_f is estimated fuel use energy for fuel type f [MMBtu],
GHG_f are reported emissions by fuel type f [tCO2e],
$EF_{CO2,f}$ is the CO_2 EPA emission factor for fuel type f [kg CO_2 per mmBtu],
$EF_{CH4,f}$ is the CH_4 EPA emission factor for fuel type f [g CH_4 per mmBtu],
$EF_{N2O,f}$ is the N_2O EPA emission factor for fuel type f [g N_2O per mmBtu],
GWP_{CH4} is the global warming potential of CH_4 [CO_2e], and
GWP_{N2O} is the global warming potential of N_2O [CO_2e].

The emissions by fuel type in the GHGRP unit dataset[48] are only reported for CH_4 and N_2O, with CO_2 available only for the breakdown by whole units. However, CO_2 emissions for some of these units by specific fuel types can be recovered from the files obtained from EnviroFacts above. In the Julia code, fuel use is estimated using each of the emissions types available, whether CO_2, CH_4, or N_2O. In the final step of selecting a "best estimate" for fuel use, CO_2 is used if available, followed by CH_4, and then N_2O. The values are generally similar.

The Julia code combines other information from the GHGRP unit dataset[48] with the fuel use estimates obtained by the NREL code. Unit maximum rated heat input (in mmBtu per hour) and biogenic CO_2 emissions are added to all units. Additionally, for cases where fuel use is estimated in the NREL code without a corresponding reported emissions value (e.g., under Part 75), emissions of CO_2, CH_4, and N_2O are estimated using the reverse of the above equations and default EPA emissions factors for the corresponding fuel type. A final facility information check is performed to fill in latitude, longitude, and parent company for as many facilities as possible based on all datasets.

There is uncertainty associated with estimates of fuel use and emissions using the above approach. Actual correspondence between fuel use and emissions are dependent on many factors. McMillan and Ruth[45] used facility-specific data to estimate custom CO_2 emissions factors and found that uncertainty was highest for fuel gas (±35%) and wood and wood residuals (±39%), two fuels that are significant for Louisiana facilities. Estimated uncertainty for natural gas was ±11%.[45]

The Louisiana facilities are assigned to industrial sectors based on a variety of factors including the purpose of their end product. Each facility type has its own considerations when reporting under various EPA Subparts and the specific unit configurations. There can be some error in the GHGRP reporting that is mitigated by the assignment of an industrial sector. The industrial sector classifications will also have similar flue gas emissions profiles, allowing comparison between different decarbonization strategies (e.g., CCS, hydrogen-fuel switching, etc.). These sectors may differ from the categorization found in GHGRP datasets.

Unit types (e.g., boilers, process heaters, etc.) are defined by the facility's reporting to the GHGRP. However, it is likely that many more boiler and process heating units are inaccurately classified as "Other Combustion Source (OCS)" in the GHGRP dataset. Therefore, the quantitative analysis described in the following sections represents a lower bound on the actual numbers of specific unit types.

Louisiana Facility Fuel Use and Emissions

A summary of boiler units with non-zero fuel use at Louisiana industrial facilities reported to the GHGRP in 2021 is provided in Table 9. Boilers were identified in the dataset by unit types of S (stoker boiler) and OB (other boiler). In 2021, there were 45 facilities containing a total of 114 boiler units with active fuel use, ranging from one to 10 boilers at a given facility.

Table 9. Summary of Louisiana facilities containing boiler units, 2021

Industry	**Facilities**	**Boilers**	**Fuel Use** trillion Btu	**Total Emissions** $MtCO_2e$	**Biogenic CO_2 Emissions** $MtCO_2$
Ammonia	1	7	11.55	0.60	0
Chemicals	2	5	2.30	0.12	0
Gas Processing	9	23	1.78	0.09	0
Metals, Minerals, and Other	2	6	9.48	0.49	0
Petrochemicals	8	20	20.09	1.12	0
Pulp and Paper	8	15	50.11	3.66	2.46
Refineries	7	29	39.99	2.33	0
Steel	1	1	0.42	0.02	0
Total	38	106	135.72	8.69	2.46

Using the methodology described above, estimated fuel use and greenhouse gas emissions for boilers in 2021 at Louisiana facilities is also given in Table 10. The industrial sectors with the greatest estimated fuel use and total emissions for boilers in Louisiana for 2021 are pulp and paper, refineries, and petrochemicals.

Emissions from fuel types of "Wood and wood residuals" and "other biomass gases" (both found in the pulp and paper industry) have CO_2 emissions that are considered biogenic, and may be unlikely candidates for electrification. However, boiler natural gas use by the pulp and paper industry in Louisiana is substantial (larger than any other industry in the state) and these remain a target for electrification.

Table 10. Estimated fuel use and emissions by fuel type for Louisiana boilers, 2021

Industry	Fuel Type	**Fuel Use** Trillion Btu	**Total Emissions** $MtCO_2e$	**Biogenic CO_2 Emissions** $MtCO_2$
Ammonia	Natural Gas	11.55	0.60	0
Chemicals	Natural Gas	2.30	0.12	0
Gas Processing	Natural Gas	1.78	0.09	0
Metals, Minerals, and Other	Natural Gas	9.48	0.49	0
Petrochemicals	Fuel Gas	8.90	0.53	0
	Natural Gas	11.19	0.59	0
Pulp and Paper	Natural Gas	20.87	1.09	0
	Other Biomass Gases	0.06	0.003	0.003
	Tires	0.94	0.08	0
	Used Oil	0.001	0.0001	0.000
	Wood and Wood Residuals	28.24	2.49	2.48
Refineries	Fuel Gas	33.53	1.99	0
	Natural Gas	6.45	0.34	0
Steel	Natural Gas	0.42	0.02	0

Process heater units by sector for Louisiana in 2021 are shown in Table 11. There were 106 process heaters across 22 facilities in the state with reported emissions. The industrial sectors with the greatest estimated fuel use and emissions were refineries and petrochemicals.

Table 11. Summary of Louisiana facilities containing process heating units, 2021

Industry	Facilities	Process Heaters	**Fuel Use** trillion Btu	**Total Emissions** $MtCO_2e$
Chemicals	2	7	0.69	0.04
Gas Processing	9	26	7.58	0.40
Petrochemicals	6	32	25.32	1.42
Refineries	5	41	43.30	2.57
Total	22	106	76.88	4.41

Table 12 shows fuel use and emissions by fuel type for Louisiana process heaters in 2021. Natural gas is the predominant fuel type in all sectors except refineries, where fuel gas dominates usage and emissions.

Table 12. Estimated fuel use and emissions by fuel type for Louisiana process heaters, 2021

Industry	Fuel Type	Fuel Use trillion Btu	Total Emissions $MtCO_2e$
Chemicals	Natural Gas	0.69	0.04
Gas Processing	Natural Gas	7.58	0.40
Petrochemicals	Fuel Gas	10.54	0.63
	Natural Gas	14.78	0.78
Refineries	Fuel Gas	43.09	2.56
	Natural Gas	0.20	0.01

There were only two hot water heaters at a single waste facility in Louisiana 2021 (Table 13). These two units were both entirely fueled by distillate fuel oil (diesel).

Table 13. Summary of Louisiana facilities containing hot water heaters, 2021

Industry	Facilities	Furnaces	Fuel Use trillion Btu	Total Emissions $MtCO_2e$
Waste	1	2	0.012	0.001
Total	1	2	0.012	0.001

There were 19 natural gas line and heating medium heaters at seven Louisiana facilities reported to GHGRP in 2021 (Table 14). Each of these units were entirely fueled by natural gas likely siphoned from extraction or transportation infrastructure as both unit types are often located at or near gas wellheads or petroleum processing facilities.

Table 14. Summary of Louisiana facilities containing line heaters, 2021

Industry	Facilities	Heaters	Fuel Use trillion Btu	Total Emissions $MtCO_2e$
Chemicals	1	1	0.003	<0.001
Gas Processing	5	11	0.1	0.004
Metals, Minerals, and Other	1	7	0.03	0.015
Total	7	19	0.4	0.02

Table 15 shows the fuel use and emissions of natural gas line and heating medium heaters in Louisiana in 2021. All units within this cohort were fueled entirely by natural gas. These units likely used raw gas extracted straight from the wellhead as both unit types are often located at or in close proximity to the wellhead or petroleum processing facilities.

Table 15. Estimated fuel use and emissions based on fuel type of Louisiana heaters, 2021

Industry	Fuel Type	Fuel Use trillion Btu	Total Emissions $MtCO_2e$
Chemicals	Natural Gas	0.003	<0.001
Gas Processing	Natural Gas	0.92	0.004
Metals, Minerals, and Other	Natural Gas	0.28	0.015

There were three comfort heaters at one facility reported to EPA GHGRP in Louisiana for 2021 (Table 16). The sub-tropical climate of Gulf Coast states, such as Louisiana, allows facilities to operate fewer comfort heating units than similar facilities in temperate zones. These units were entirely fueled by natural gas.

Table 16. Summary of Louisiana facilities containing comfort heaters, 2021

Industry	Facilities	Comfort Heaters	Fuel Use Trillion Btu	Total Emissions $KtCO_2e$
Refineries	1	3	0.002	0.01
Total	1	3	0.002	0.01

Ovens are fairly common throughout industry with only two types of ovens reporting to EPA GHGRP. These two kinds of ovens are general ovens and product drying units. In 2021, there were four facilities in Louisiana operating eight ovens of various types, as shown in Table 17. There were five reported ovens and three product dryers in 2021.

Table 17. Summary of Louisiana facilities containing ovens, 2021

Industry	Facilities	Ovens	Fuel Use trillion Btu	Total Emissions $MtCO_2e$
Chemicals	2	4	0.17	0.01
Metals, Minerals, and Other	1	2	0.11	0.01
Pulp and Paper	1	2	0.85	0.04
Total	**4**	**8**	**1.12**	**0.06**

Table 18 shows fuel use and emissions for ovens in 2021. All units of both types were fueled exclusively by natural gas. Product dryers accounted for the majority of fuel use (1.0 TBtu) and emissions (0.05 $MtCO_2e$). The two largest product drying units are operated by pulp and paper mills which contribute more than 80% of emissions and fuel use.

Table 18. Estimated fuel use and emissions based on fuel type of Louisiana ovens, 2021

Industry	Fuel Type	Fuel Use trillion Btu	Total Emissions $MtCO_2e$
Chemicals	Natural Gas	0.17	0.01
Metals, Minerals, and Other	Natural Gas	0.11	0.01
Pulp and Paper	Natural Gas	0.85	0.04

There were 35 furnaces operating at 5 facilities throughout Louisiana in 2021, as seen in Table 19. Many of these units were at petrochemical facilities which also account for the majority of the estimated fuel use and emissions. This list does not include chemical recovery furnaces, a type of furnace used at pulp and paper mills to recycle process chemicals, due to the high rate of byproduct biogenic fuels used by those units.

Table 19. Summary of Louisiana facilities containing furnaces, 2021

Industry	Facilities	Furnaces	Fuel Use trillion Btu	Total Emissions $MtCO_2e$
Chemicals	1	1	0.03	0.001
Petrochemicals	4	34	11.00	0.64
Total	**5**	**35**	**11.03**	**0.64**

Fuel use for furnaces in Louisiana in 2021 is broken down in Table 20. Fuel gas has the largest contribution to both estimated fuel use and emissions followed by natural gas. Fuel gas is a byproduct of processing petroleum products and is often combusted on-site, sold to a local off-taker, or flared.

Table 20. Estimated fuel use and emissions for Louisiana furnaces, 2021

Industry	Fuel Type	Fuel Use Trillion Btu	Total Emissions $MtCO_2e$
Chemicals	Natural Gas	0.03	0.001
Petrochemicals	Natural Gas	2.35	0.12
	Fuel Gas	8.65	0.52

Incineration units by sector for Louisiana in 2021 are shown in Table 21. There were 17 incinerators operating at seven different facilities in the state that reported emissions. The refining sector had the largest number of units, estimated fuel use, and emissions, followed by petrochemicals. Incinerators include units used for institutional and commercial and industrial purposes.

Table 21. Summary of Louisiana facilities containing incinerators, 2021

Industry	Facilities	Incinerators	Fuel Use trillion Btu	Total Emissions $MtCO_2e$
Petrochemicals	3	4	0.46	0.024
Refineries	4	13	1.23	0.065
Total	7	17	1.69	0.0896

Table 22 shows fuel use and emissions by fuel type for Louisiana incinerators in 2021. Natural gas was the most commonly used fuel type for both refineries and petrochemicals. Refineries had a small contribution from fuel gas.

Table 22. Estimated fuel use and emissions by fuel type for Louisiana incinerators, 2021

Industry	Fuel Type	Fuel Use trillion Btu	Total Emissions $MtCO_2e$
Petrochemicals	Natural Gas	0.46	0.024
Refineries	Natural Gas	1.14	0.061
	Fuel Gas	0.08	0.005

There were 19 kilns operating at 14 facilities within Louisiana for 2021 which are shown in Table 23. The petrochemical sector had the greatest estimated fuel use and emissions. Pulp and paper had more units but fewer emissions. Units included in this section are general lime kilns and pulp mill lime kilns.

Table 23. Summary of Louisiana facilities containing kilns, 2021

Industry	Facilities	Kilns	Fuel Use trillion Btu	Total Emissions $MtCO_2e$
Metals, Minerals, and Other	1	3	3.03	0.16
Petrochemicals	6	12	10.9	0.86
Pulp and Paper	7	7	4.68	0.25
Total	14	19	18.6	1.28

Table 24 shows fuel use and emissions by fuel type for kilns in Louisiana for 2021. Petroleum coke has the largest contribution to estimated fuel usage and emissions followed by natural gas.

Table 24. Estimated fuel use and emissions by fuel type from Louisiana kilns, 2021

Industry	Fuel Type	Fuel Use trillion Btu	Total Emissions $MtCO_2e$
Metals, Minerals, and Other	Natural Gas	3.03	0.16
Petrochemicals	Natural Gas	2.94	0.15
	Petroleum Coke	7.96	0.71
Pulp and Paper	Natural Gas	4.16	0.22
	Petroleum Coke	0.52	0.03

Thermal oxidizers by sector for Louisiana in 2021 are shown in Table 25. There were 20 facilities reporting emissions operating 49 thermal oxidizers. The industrial sectors with the greatest estimated fuel use and emissions were gas processors and petrochemicals. Thermal oxidizers include both conventional units and regenerative thermal oxidizers.

Table 25. Summary of Louisiana facilities containing thermal oxidizers, 2021

Industry	Facilities	Thermal Oxidizers	Fuel Use trillion Btu	Total Emissions $KtCO_2e$
Chemicals	2	7	0.14	7.5
Gas Processing	4	13	2.64	140.0
Metals, Minerals, and Other	1	3	0.05	2.6
Petrochemicals	4	12	1.19	67.6
Pulp and Paper	2	2	0.16	8.2
Refineries	6	11	0.40	23.8
Waste	1	1	0.46	23.8
Total	20	49	5.03	273.5

Table 26 shows fuel use and emissions by fuel type for Louisiana thermal oxidizers in 2021. Natural gas is the predominant fuel type for all sectors, except petrochemicals and waste, which fulfilled the majority of energy needs with fuel gas and landfill gas, respectively.

Table 26. Estimated fuel use and emissions for Louisiana thermal oxidizers, 2021

Industry	**Fuel Type**	**Fuel Use** trillion Btu	**Total Emissions** $KtCO_2e$
Chemicals	Natural Gas	0.14	7.5
Gas Processing	Natural Gas	2.64	140.0
Metals, Minerals, and Other	Natural Gas	0.05	2.6
Petrochemicals	Natural Gas	0.38	20.3
	Fuel Gas	0.80	47.7
Pulp and Paper	Natural Gas	0.16	8.3
Refineries	Natural Gas	0.23	12.5
	Fuel Gas	<0.001	0.04
	Motor Gasoline	0.12	8.3
	Naphtha	0.002	0.2
	Propane	0.05	3.1
Waste	Natural Gas	0.01	0.5
	Landfill Gas	0.45	23.3

A summary of calciners at Louisiana industrial facilities in 2021 is in Table 27. There was one petrochemical facility with two calciners. The estimated fuel use and greenhouse gas emissions for these units are also given. These two units are fueled entirely by petroleum coke and all estimated fuel use and emissions are attributed to combustion of that fuel.

Table 27. Summary of Louisiana facilities containing calciners, 2021

Industry	**Facilities**	**Thermal Oxidizers**	**Fuel Use** trillion Btu	**Total Emissions** $MtCO_2e$
Petrochemicals	1	2	2.79	0.28
Total	1	2	2.79	0.28

There were 119 turbines at 35 facilities in Louisiana reporting for 2021 (Table 28). The majority of these turbines (106) were simple cycle turbines which are often used to power compressors and refrigeration units. Combined cycle turbines, the other type of turbine, is often used for cogeneration of heat and power within a facility.

Table 28. Summary of Louisiana facilities containing turbines, 2021.

Industry	**Facilities**	**Comfort Heaters**	**Fuel Use** Trillion Btu	**Total Emissions** $MtCO_2e$
Chemicals	2	5	32.70	1.74
Gas Processing	27	110	119.22	6.33
Metals, Minerals, and Other	1	2	2.76	0.15
Petrochemicals	4	8	41.11	2.31
Pulp and Paper	1	1	3.15	0.17
Total	35	126	198.93	10.69

Table 29 shows the estimated fuel usage and emissions of turbines in each sector by fuel type. Natural gas was the most important fuel for turbines in 2021, accounting for about 90% of both energy consumption and GHG emissions for Louisiana turbines. Turbines also used fuel gas, often co-firing with natural gas.

Table 29. Estimated fuel use and emissions for Louisiana turbines, 2021.

Industry	**Fuel Type**	**Fuel Use** Trillion Btu	**Total Emissions** $MtCO_2e$
Chemicals	Natural Gas	32.70	1.74
Gas Processing	Natural Gas	119.22	6.33
	Distillate Fuel Oil No. 2	<0.001	<0.001
Metals, Minerals, and Other	Natural Gas	2.76	0.15
Petrochemicals	Natural Gas	21.73	1.15
	Fuel Gas	19.38	1.15
Pulp and Paper	Natural Gas	3.15	0.17

RICE units by sector for Louisiana in 2021 are shown in Table 30. There were 108 RICE units throughout 21 facilities in the state with reported emissions. The industrial sector with the largest fuel use and emissions was gas processing facilities. This analysis will only consider the subset of RICE units that are eligible for electrification and selects only those units on-shore that are explicitly labeled as units using mechanical energy (i.e., pumps, compressors, cranes, etc.). This selection may exclude some eligible units but provides a best estimate as to the electrification potential of RICEs in Louisiana.

Table 30. Summary of Louisiana facilities containing RICE units, 2021

Industry	**Facilities**	**RICEs**	**Fuel Use** trillion Btu	**Total Emissions** $KtCO_2e$
Chemicals	3	4	0.002	0.182
Gas Processing	11	55	5.32	278.2
Metals, Minerals, and Other	3	38	0.013	0.93
Petrochemicals	3	10	0.010	0.75
Refineries	1	1	<0.001	0.002
Total	**21**	**108**	**5.34**	**280.1**

Table 31 shows fuel use and emissions by fuel type for RICEs in Louisiana in 2021. Natural gas is the predominant fuel type for RICEs while distillate fuel oil no. 2, otherwise known as diesel, is more commonly used by all other industries.

Table 31. Estimated fuel use and emissions by fuel type for Louisiana RICE units, 2021

Industry	Fuel Type	Fuel Use trillion Btu	Total Emissions $KtCO_2e$
Chemicals	Distillate Fuel Oil No. 2	0.002	0.18
Gas Processing	Natural Gas	5.316	278.158
	Distillate Fuel Oil No. 2	0.001	0.037
Metals, Minerals, and Other	Distillate Fuel Oil No. 2	0.013	0.929
Petrochemicals	Distillate Fuel Oil No. 2	0.010	0.750
Refineries	Distillate Fuel Oil No. 2	<0.001	0.002

Louisiana Electrification Impact

The grid impact of electrifying all of Louisiana's industrial units is calculated based on the fossil fuel use estimated above, conventional unit efficiency by fuel type given in Table 32, and typical efficiency of the replacement electrical unit. Where a range of values is given for efficiencies found in the literature, the average value is used for all calculations. For unit fuel use E in mmBtu, the estimated mmBtu actually delivered as heat (after losses) is E times the combustion unit efficiency. Converting to MWh yields the equivalent electrical requirement, which is divided by the electric unit efficiency to get the estimated annual electricity consumption required for the unit once electrified. If multiple fuel types are used for a unit, the conventional efficiency is assigned based on the primary fuel type (greatest fuel use). Efficiencies for the electric units are also shown in Table 32. Unless otherwise stated, these the electric replacement unit is assumed to be of similar configuration to the combustion unit (e.g., an electric boilers replaces a combustion boilers).

Table 32. Combustion and electrified unit efficiencies as found in literature

Unit Type	Efficiency (Combustion unit)	Efficiency (Electric unit)	Source
Boiler	64-83%	99%	13, 16
Process Heater	75%	97%	Assumed
Hot Water Heater	89-96%	99%	13, 13
Line Heater	89-96%	99%	13, 13
Comfort Heater	75%	99%	Assumed
Oven	56-95%	99%	50
Furnace	52-65%	70-85%	51,52
Incinerator	47-62%	80%	53, 54
Kiln	60%	72%	55
Thermal Oxidizer	60-95%	96%	56, 57
Calciner	28%	40%	58,59
Turbine	10-40%	70-90%	60
RICE	40%	85%	61

Table 33 shows the estimated annual energy consumption by industrial sector in Louisiana, assuming 2021 industrial unit fuel use for feasible options (based on unit types rated "Good" in Table 8) are replaced by electrified options. Table 33 also shows the equivalent electric capacity (in MW) based on reported fuel capacity of units in mmBtu/hr to GHGRP.

Table 33. Estimated annual electricity consumption and electric capacity for Louisiana

Industry	**2021 fuel used** TBtu	**2021 estimated TBtu delivered**	**Equivalent annual electricity delivered requirement** GWh	**Estimated annual electricity consumption** GWh	**Capacity** mmBtu/hr	**Estimated equivalent electric capacity** MW
Boiler Replacement						
Ammonia	11.6	8.5	2,489	2,514	2,457	720
Chemicals	2.3	1.7	496	501	838	246
Gas Processing	1.8	1.3	384	388	473	139
Metals, Minerals, and Other	9.5	7.0	2,042	2,062	1,854	543
Petrochemicals	20.1	14.8	4,328	4,371	5,427	1,590
Pulp and Paper	50.1	36.8	10,793	10,902	9,803	2,873
Refineries	40.0	29.4	8,613	8,700	21,639	6,342
Steel	0.4	0.3	91	92	100	29
Boiler Totals	135.7	99.8	29,235	29,530	42,592	12,483
Comfort Heater Replacement						
Refineries	0.002	0.001	0.4	0.4	2	1
Comfort Heater Totals	0.002	0.001	0.4	0.4	2	1
Furnace Replacement						
Chemicals	0.03	0.01	4	5	11	3
Petrochemicals	11.0	6.1	1774	2288	6475	1898
Furnace Totals	11.0	6.1	1778	2294	6486	1901
Heater Replacement						
Chemicals	0.003	0.002	1	1	13	4
Gas Processing	0.1	0.1	25	25	82	24
Metals, Minerals, and Other	0.3	0.3	75	76	232	68
Line Heater Totals	0.4	0.3	101	102	327	96
Hot Water Heater Replacement						
Waste	0.01	0.01	3	3	1	0.4
Hot Water Heater Totals	0.01	0.01	3	3	1	0.4
Oven Replacement						
Chemicals	0.2	0.1	24	25	80	24
Metals, Minerals, and Other	0.1	0.1	26	26	31	9
Pulp and Paper	0.8	0.4	124	128	221	65

Oven Totals	1.1	0.6	174	179	333	97
Process Heater Replacement						
Chemicals	0.7	0.5	148	153	181	53
Gas Processing	7.6	5.6	1,633	1,684	1,572	461
Petrochemicals	25.3	18.6	5,454	5,622	9,447	2,769
Refineries	43.3	31.8	9,326	9,615	12,042	3,529
Process Heater Totals	76.9	56.5	16,562	17,074	23,242	6,811
All Units Totals	**225.1**	**163.3**	**47,854**	**49,183**	**72,983**	**21,389**

The emissions avoided by electrification depends on the carbon intensity of the local grid. Table 34 shows estimated emissions reductions for industrial units for 50%, 75, and 100% (net zero) reductions in carbon intensity of the Louisiana electric grid. The electric grid emissions carbon intensity was assumed to be 365 g CO_2e per kWh, based on 2022 estimates for the Midcontinent Independent Systems Operator (MISO) local resource zone 9, which includes Louisiana.[62] This is in comparison to the average US electric grid mix, which is 388 g CO_2e per kWh.[63] Given the grid intensity of the MISO local resource zone 9, electrification of industrial units results in an increase in estimated greenhouse gas emissions over current fossil fuel usage. However, with an increased share of renewable and low-carbon energy, emissions reductions from electrification become apparent at 50% and 75% lower electric grid carbon intensity, as seen in Table 34. Louisiana's net zero carbon goal by 2050, established by executive order JBE 2020-18,[64] will implement increasing renewable energy electric generation capacity, industrial electrification, and low-carbon fuel switching. The Louisiana Climate Action Plan sets a goal of 100% renewable or clean energy by 2035 with at least 80% generated from renewable sources.[65] Under a net zero scenario, 100% of greenhouse gas emissions from electrified units would be offset. Additionally, electrification of industrial process heat reduces emissions of other pollutants generated by the combustion of fossil fuels, including particulate matter, nitrogen oxides, and sulfur oxides.[66]

The total emissions reduction for a fully decarbonized grid is 14.22 MtCO_2e per year. Reductions in grid intensity by 50% and 75% would provide 5.24 and 9.73 MtCO_2e fewer annual emissions for these units.

Table 34. Estimated annual emissions reduction by electrification for Louisiana based on 50%, 75%, and net zero energy grid assumptions.

Industry	**Annual 2021 Emissions** MtCO_2e	**Estimated emissions, LA Electric Emissions Intensity 2022*** MtCO_2e	**Estimated emissions reduction, 50% grid**** MtCO_2e	**Estimated emissions reduction, 75% grid**** MtCO_2e	**Estimated emissions reduction, Net zero grid** MtCO_2e
Boiler Replacement					
Ammonia	0.60	0.92	0.14	0.37	0.60
Chemicals	0.12	0.18	0.03	0.07	0.12
Gas Processing	0.09	0.14	0.02	0.06	0.09
Metals, Minerals, and Other	0.49	0.75	0.12	0.31	0.49

Petrochemicals	1.19	1.60	0.39	0.79	1.19
Pulp and Paper	3.65	3.98	1.66	2.65	3.65
Refineries	2.33	3.18	0.74	1.53	2.33
Steel	0.02	0.03	0.01	0.01	0.02
Boiler Totals	8.49	10.78	3.10	5.80	8.49
Process Heater Replacement					
Chemicals	0.04	0.06	0.01	0.02	0.04
Gas Processing	0.40	0.61	0.09	0.24	0.40
Petrochemicals	1.44	2.05	0.41	0.92	1.44
Refineries	2.64	3.51	0.88	1.76	2.64
Process Heater Totals	4.51	6.23	1.39	2.95	4.51
Hot Water Heater Replacement					
Waste	0.001	0.001	0.0003	0.001	0.001
Hot Water Heater Totals	0.001	0.001	0.0003	0.001	0.001
Line Heater Replacement					
Chemicals	0.0001	0.0003	0.00001	0.0001	0.0001
Gas Processing	0.005	0.01	0.0003	0.003	0.005
Metals, Minerals, and Other	0.01	0.03	0.001	0.01	0.01
Line Heater Totals	0.02	0.04	0.001	0.01	0.02
Comfort Heater Replacement					
Refineries	0.0001	0.0001	0.00002	0.0001	0.0001
Comfort Heater Totals	0.0001	0.0001	0.00002	0.0001	0.0001
Oven Replacement					
Chemicals	0.01	0.01	0.004	0.01	0.01
Metals, Minerals, and Other	0.01	0.01	0.001	0.003	0.01
Pulp and Paper	0.04	0.05	0.02	0.03	0.04
Oven Totals	0.06	0.07	0.03	0.04	0.06
Furnace Replacement					
Chemicals	0.001	0.002	0.0004	0.001	0.001
Petrochemicals	1.14	0.84	0.72	0.93	1.14
Furnace Totals	1.14	0.84	0.72	0.93	1.14
All Units Total	**14.22**	**17.96**	**5.24**	**9.73**	**14.22**

* Louisiana 2022 estimated grid carbon intensity of 365 gCO_2e/kWh[62].

** Assuming 50% and 75% reduction in grid carbon intensity from LA 2022 scenario.

For low- and medium-temperature process heat in the industrial sector that is currently provided by point-source fossil fuel combustion, electrification is a key solution for greenhouse gas emissions reductions. The total potential on-site displacement of currently-used fuels, by industry, assuming full electrification of units with excellent opportunity, not accounting for electric generation, is given in Table 35.

Table 35. Fuel displacement potential from electrification of Louisiana boilers and process heaters

Industry	Fuel Type	Fuel Use trillion Btu
Chemicals	Natural Gas	2.42
Gas Processing	Natural Gas	7.68
Metals, Minerals, and Other	Natural Gas	0.38
Petrochemicals	Fuel Gas	19.19
	Natural Gas	17.13
Pulp and Paper	Natural Gas	13.06
Refineries	Fuel Gas	43.09
	Natural Gas	0.20
Waste	Distillate Fuel Oil No. 2	0.01

The analysis provided here includes considerable uncertainty, including in the quantitative estimates of fuel use or emissions based on default or custom factors by fuel type, and inaccuracy of classification of unit types. As described above, the number of units for each type likely represents an extreme lower bound, because units classified as OCS in GHGRP reporting are likely also industrial units that fall into one of the other categories, and could potentially replace thermal needs with an electric equivalent. Industries such as pulp and paper, whose fuels include large proportions of biomass such as wood and wood residuals, may also not see as much of a greenhouse gas reduction benefit because much of their emissions may continue to be biogenic CO_2 from these fuels. Similarly, the use of fuel gas for heating in the petrochemical and refining sectors may be difficult to overcome in the near term, as it is a byproduct fuel, but its use may diminish in importance under future net zero planning scenarios.

Conclusions

There are many opportunities to decrease industrial fossil fuel use through the replacement of units that have high electrification potential. Electrifying these units would increase electricity consumption in Louisiana by an estimated 49,183 GWh and reduce industrial emissions by 5.24–14.22 $MtCO_2e$, depending on the state of grid decarbonization.

Some industries and unit types may have fewer opportunities but emissions reductions can still be experienced from electrification. High-temperature applications within the industrial sector may be resistant to electrification, but facilities could still introduce electric equipment to preheat incoming feeds to reduce fuel consumption. Preheating or providing additional heat through electric heaters in combustion units is already commonplace in some industries and is referred to as "boosting."[67] Additional advances in electric high-temperature electric heaters would also help to decarbonize these units. As a final option, low-carbon fuels (such as green hydrogen) or retrofit for carbon capture could be applied to the hardest-to-decarbonize units in the industrial sector.

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