A Tough Nut to Crack: What will it take to decarbonize industrial facilities?

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ABSTRACT

Energy use in the manufacturing sector accounted for 35% of primary energy use in the United States in 2023, mostly in the form of fossil fuels, making this sector a key target for clean energy efforts. However, decarbonizing manufacturing processes presents difficult technical and business challenges. Modifying production equipment or processes incurs costs and risks beyond installation, including lost production time and potential effects on product quality or workplace practices. The enormous diversity of manufacturing processes, inputs, and end products further complicates cost-effective decarbonization. Effective decarbonization programs must therefore rely on a granular understanding of sector composition and opportunities.

A recent study in New York provides such a granular understanding, compiling data from web and phone surveys with over 600 facilities and from onsite visits to more than 100 facilities, yielding a comprehensive dataset of energy use and related practices. Building on this foundation, a follow-on study estimated decarbonization potential under various economic and policy scenarios. It examined pathways including energy efficiency, electrification, low-carbon fuels, and carbon capture, using economic inputs consistent with other New York state analyses. The analysis evaluated a broad range of decarbonization measures, with particular focus on opportunities to decarbonize medium- and high-temperature processes via heat pumps, alternative fuels, and thermal storage. Results reveal that New York's industrial sector has the technical potential to reduce its energy usage by 21% and greenhouse gas emissions by 69% compared to their respective baselines in 2050, and the economic potential to reduce energy usage by 26% and emissions by 40% to 48%. The achievable potential under various scenarios ranges from 16% to 21% of energy, corresponding to emissions reductions of 21% to 30% compared to the baseline in 2050.

Introduction

Industrial facilities represent a significant source of energy consumption and greenhouse gas emissions (GHG), posing both a major challenge and an essential opportunity for achieving decarbonization goals.[2] With ambitious targets established by New York State's Climate Leadership and Community Protection Act (Climate Act), understanding the industrial landscape and identifying actionable opportunities for emission reductions is critical. Given this, the goal of NYSERDA's New York Statewide Industrial Facilities Stock Study (IFSS) was to provide a deep, data-driven understanding of New York's manufacturing (North American Industry Classification System [NAICS] 31-33) sectors, along with indoor agriculture facilities, regarding facility size; energy use characteristics; energy efficiency, electrification, and clean energy goals; and carbon reduction improvements already undertaken.[3] This was the first IFSS conducted for New York, and at the time of scoping, represented the first study of its kind at the state level. This study supported achieving the Climate Act 2050 goals with results that:

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[1] The views expressed in this paper are those of the authors and do not necessarily reflect the views of the New York State Energy Research and Development Authority.

[2] The Industrial Facilities Stock Study estimated manufacturing facilities in New York consume approximately 150 million MMBTUs of energy annually and produce approximately 13 million $MTCO_2e$.

[3] *New York Statewide Industrial Facilities Stock Study: Phase Two Final Report* (DNV for New York State Energy Research and Development Authority, December 21, 2023), https://www.nyserda.ny.gov/-/media/Project/Nyserda/Files/Publications/PPSER/Program-Evaluation/2023-Industrial-Facilities-Stock-Assessment-Phase-2.pdf

- Have informed clean energy and greenhouse gas (GHG) reduction potential studies
- Will provide an understanding for incentive programs and support program benchmarking, design, implementation, and evaluation
- Will provide a baseline for longitudinal market trending
- Will educate service providers and industrial customers to take actions that advance NYS clean energy goals

Using the results from this study, NYSERDA commissioned a follow-on potential study to identify and estimate the potential for energy savings and GHG emissions reductions in New York State's industrial manufacturing sector.

Methodology

Industrial Stock Study

The population characteristics for the New York manufacturing sector described in this paper are drawn from the second phase of NYSERDA's Statewide IFSS. The first phase of the study focused on synthesizing existing secondary data and defining manufacturing subsectors of interest for primary data collection. The second phase included the primary data collection, comprising web surveys, physical site visits, and virtual site visits. The data collection and analysis activities undertaken by the stock study are summarized in Figure 1.

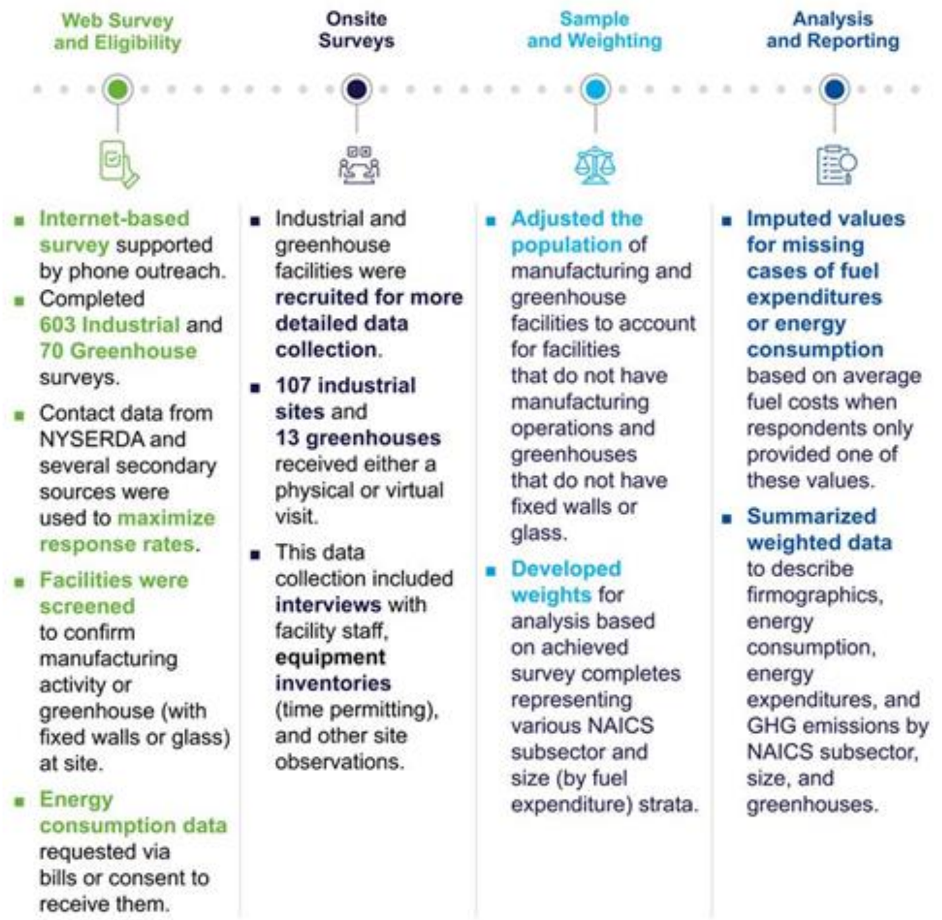

Figure 1. Data collection and analysis activities

While the NAICS manufacturing sector contains 16 subsectors, the scope of the stock study limited intensive data collection to 10 subsectors based on consideration of the study's schedule and available budget. To identify the most critical subsectors for research, the study team assigned scores to each subsector based on five characteristics:

- GHG emissions (weight of 0.25) is the primary target of Climate Act, important both for overall statewide climate change abatement and for environmental justice considerations.
- Value of Shipments (weight of 0.25) is another key indicator of economic value to the state.
- Energy Expenditures (weight of 0.25) is an indicator of business costs in the state related to energy.
- Energy Consumption (weight of 0.15) is the primary target of EE efforts.
- Employment (weight of 0.1) is a key metric of industry economic value to the state.

This scoring resulted in the following ranking of manufacturing subsectors for outreach, with paper manufacturing identified as the highest scoring and wood products identified as the lowest scoring. The top nine subsectors (other than miscellaneous) were assigned specific outreach targets, while the remaining subsectors were collected into a "non-key" group with an outreach target for the constituent subsectors in aggregate. These subsectors were further segmented into energy expenditure tiers for sampling: Tier 1 was defined as having greater than $1 million in annual energy expenditures, Tier 2 as

$500k to $1 million in annual energy expenditures, and Tier 3 as less than $500k in annual energy expenditures.

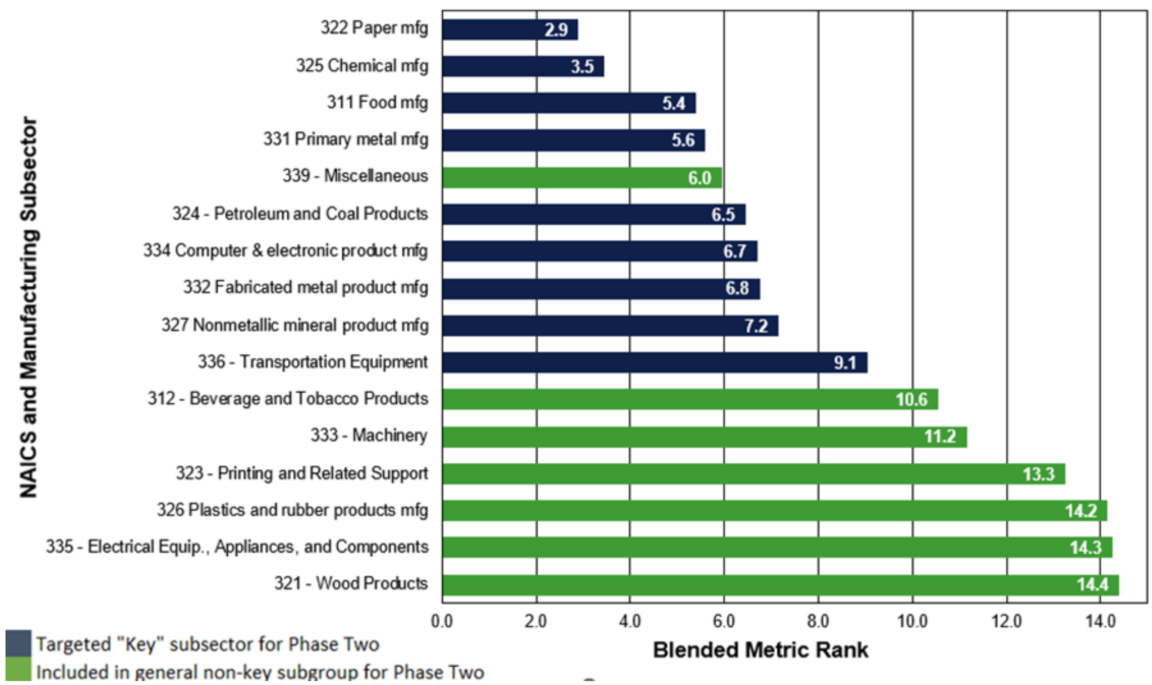

Figure 2. Key manufacturing subsectors for data collection

Through intensive e-mail and phone recruitment, the study was able to achieve survey response rates of 48% for Tier 1, 40% for Tier 2, and 20% for Tier 3, resulting in the number of completed surveys shown in **Table 1**.

Table 1. Final industrial web survey targets and completions

Subsector	Tier 1		Tier 2		Tier 3		Total	
	Target	Complete	Target	Complete	Target	Complete	Target	Complete
311 Food Manufacturing	9	9	8	3	46	29	63	41
322 Paper Manufacturing	28	24	13	12	8	6	49	42
324 Petroleum and Coal Products	9	8	2	1	1	0	12	9
325 Chemical Manufacturing	10	8	12	8	27	20	49	36
327 Nonmetallic Minerals	13	10	6	4	30	25	49	39
331 Primary Metal Manufacturing	13	17	8	6	9	11	30	34
332 Fabricated Metals	5	5	7	7	55	54	67	66
334 Computer & Electronic Products	6	9	7	6	38	40	51	55

Table 1. Final industrial web survey targets and completions

Subsector	Tier 1		Tier 2		Tier 3		Total	
	Target	Complete	Target	Complete	Target	Complete	Target	Complete
336 Transportation Equipment	5	7	6	8	12	13	23	28
Other (non-Key)	15	15	28	25	200	217	243	257
Total	**113**	**112**	**97**	**80**	**426**	**415**	**636**	**607**

Industrial potential study

Using the industrial stock study data, the potential study examined the GHG emissions and energy impacts of the energy efficiency, electrification, low-carbon fuels, and carbon capture and storage (CCUS) decarbonization categories and reported results for technical[4] and economic[5] potential, and achievable[6] potential under specific adoption scenarios (Table 2). For each scenario and level of potential, the emissions and energy savings are calculated annually as the sum of savings for new measures implemented that year and as rollover savings from measures adopted in prior years. A "measure" is a particular decarbonization activity or technology investment that creates savings over time relative to the baseline equipment/condition. Measure pairs (baseline activity paired with a decarbonizing measure) are then developed and characterized by energy and GHG emissions savings, implementation costs, expected useful life (EUL), proportion of the facility stock the measure could apply to (feasibility), and current stock penetration of the measure. When multiple measures can replace the same baseline equipment, they compete against each other based on expected emissions savings, costs, and other factors. This competition takes place in all scenarios.

Table 2. Achievable potential scenario descriptions and assumptions

Key assumptions	Base	Site Incentive	Carbon Price	Carbon Price +
Renewable natural gas (RNG) price	Base case RNG price forecast from the 2022 New York Climate Scoping Plan (NYS CAC)	Base	Base	Base
Green hydrogen price	Hydrogen price forecast (conservative case scenario provided by NYSERDA) that considers Inflation Reduction Act (IRA) production tax credit	Base	Base	Base

[4] Technical potential represents the upper limit of emissions reduction potential based on available technologies, matching applications for those technologies, stock turnover, and the market's capacity to deliver the measure.
[5] Economic potential refers to the portion of the technical potential that is cost-effective, as determined by the NYS Public Service Commission's Societal Cost Test (SCT) established in January 2016. Available at: https://documents.dps.ny.gov/public/Common/ViewDoc.aspx?DocRefId={F8C835E1-EDB5-47FF-BD78-73EB5B3B177A}
[6] Achievable potential is the impact of measures to be adopted under specific scenarios representing real-world factors that can affect customer adoption decisions. These factors include measure availability and awareness, costs, and savings; energy and carbon (if applicable) prices; market barriers; and program interventions.

Table 2. Achievable potential scenario descriptions and assumptions

Key assumptions	Base	Site Incentive	Carbon Price	Carbon Price +
Carbon price	No emissions cap or carbon price set	Base	Carbon price (Provided by NYSERDA)	Carbon price (Provided by NYSERDA)
Incentive levels (starting in model year 2023)	Set to zero. Internal Rate of Return % (IRR) used to set other incentives	Incentives bring IRR for each measure to 10%-16%, capped at 70% of incremental cost	Incentives bring IRR for each measure to 10-16%, capped at 70% of incremental cost	Incentives bring IRR for each measure to 10%-16%, capped at 70% of incremental cost
Program budgets [a]	Set to zero	Marketing budget: $155,000	Marketing budget: $2,770,000	From 2026 onwards $2,770,000 marketing budget increases with revenue generated from the carbon price
Market barriers	Assumptions vary by measure but do not change over time	Base	Base	Base assumptions for Year 1 lowered over time for electrification, low-carbon fuels, and CCUS
Emerging technology cost over time assumption	Cost declines over time for only emerging technologies - reference case trajectory [b]	Base	Base	Base
Emerging technology improved performance assumption	Two emerging tech performance time periods: 2025-2034 and 2035-2050 -reference case [b]	Base	Base	Base

a Marketing budget determines how many customers are aware of a measure and is one factor in determining measure uptake.

b Technology cost declines and improved technology performance assumption are based on EIA data that offers change(s) in cost and efficiency trajectory over time for emerging technologies. Reference case and high case refer to EIA cost scenarios.

Results

Industrial stock study

The following sections describe the results gathered through the web and onsite surveys with the recruited manufacturing facilities.

Manufacturing sector characteristics

Error! Reference source not found.3 shows select manufacturing sector characteristics by subsector in order of annual energy consumption. All manufacturing sector estimates are limited to facilities with confirmed manufacturing activity at the site. As a result, the total counts of facility and employment are smaller than in other data sources reporting counts of businesses by NAICS code without explicit screening for manufacturing activity. During survey recruitment, the study found that many facilities where the primary industry sector is manufacturing are offices or warehouses associated with a manufacturing business, but where the manufacturing activity occurs elsewhere. The table shows that Paper and Chemicals are the NAICS subsectors with the highest total energy consumption, energy expenditures, and energy-use emissions in the state, followed by Primary Metals, Food, Fabricated Metals, and Transportation Equipment.

Petroleum and Coal Products is comparatively small in terms of all the characteristics shown. While this subsector appeared to be large in New York based on employment reported for NAICS code 324, the screening conducted for this study determined that a large fraction of the facilities, particularly the large ones, were non-manufacturing.

Table 3. Manufacturing characteristics by subsector

NAICS and Subsector Manufacturing Type	Number of Facilities	Total Employees	Annual Energy Consumption (MMBtu)	Annual Energy Expenditures ($1,000s)	Annual Emissions from Energy Use (1,000s $MTCO_2e$)
322 - Paper	90	9,132	30,193,506	309,313	2,742
325 - Chemicals	142	~18,520	25,360,873	268,539	2,288
331 - Primary Metals	74	5,196	~15,542,029	~235,872	~1,258
311 - Food	357	16,075	14,382,126	152,192	1,304
332 - Fabricated Metal Products	1,570	85,473	14,205,015	213,438	1,183
336 - Transportation Equipment	89	16,445	~11,964,122	119,080	~1,084
327 - Nonmetallic Mineral Products	155	7,058	7,513,926	84,800	677
334 - Computer and Electronic Products	196	30,950	~7,186,419	~113,073	~560
324 - Petroleum and Coal Products	21	364	500,542	6,938	45
Non-key	5,083	138,408	21,884,521	285,390	1,849
Total	**7,777**	**327,622**	**148,733,079**	**1,788,634**	**12,990**

Note: The tilde ('~') indicates that one response made up 50% or more of a single result, or that the relative standard error (RSE) was between 50% and 100%.

Table 4 shows the same results provided in Table 3 by Tier. While Tier 1 and Tier 2 have similar numbers of manufacturing facilities, Tier 1 has a much greater number of employees than Tier 2, and accounts for roughly three-fourths of the consumption, expenditures, and emissions in New York State. Tier 3 contains most facilities and employees, but accounts for only about 20% of New York State manufacturing consumption, expenditures, and emissions.

[7] Includes Scope 1 (emissions from sources that facility owns or controls directly) and Scope 2 (direct GHG emissions associated with the purchase of electricity, steam, heat, or cooling) emissions. Scope 3, which encompasses emissions not produced by a facility itself but that the facility indirectly affects in its value chain are not included.

Table 4. Manufacturing characteristics by tier

NAICS and Subsector Manufacturing Type	Number of Facilities	Total Employees	Annual Energy Consumption (MMBtu)	Annual Energy Expenditures ($1,000s)	Annual Emissions from Energy Use (1,000s $MTCO_2e$)
Tier 1	172	72,517	111,697,147	1,302,872	9,788
Tier 2	142	23,358	8,384,380	99,287	739
Tier 3	7,643	231,747	28,651,551	386,475	2,462
Total	**7,777**	**327,622**	**148,733,079**	**1,788,634**	**12,990**

Manufacturing sector end uses

Table 5 shows manufacturing electric and non-electric[8] energy consumption by high-level use. Since a boiler may have joint use for both facility HVAC and industrial processes, boilers are listed as a separate use category. The table shows that three-quarters of electricity is used for production processes, while around half of non-electric fuels are used for boilers and 30% is used for production. In terms of non-electric fuels used for heating processes, 80% of boiler use and 60% of non-boiler heating are for low and medium temperature heating (under 570°F). For both electric and non-electric energy sources, basic facility operations account for about 15% of total energy use. Table 6 shows this information by tier.

Table 5. Manufacturing energy consumption by high-level use

Fuel	Basic Facility Operations	Boilers or Generators	Manufacturing or Industrial Production Process	Don't Know/ Unknown	Total
Electricity	15.6%	4.4%	74.8%	5.2%	100.0%
Non-Electric Fuels	17.6%	47.9%	29.6%	4.8%	100.0%

Table 6. Manufacturing energy consumption by tier

Fuel	Tier	Basic Facility Operations	Boilers or Generators	Manufacturing or Industrial Production Process	Don't Know/ Unknown	Total
Electricity	1	14.1%	4.8%	79.3%	1.8%	100.0%
	2	15.3%	5.9%	64.1%	14.7%	100.0%
	3	20.3%	3.0%	63.4%	13.3%	100.0%
	Total	15.6%	4.4%	74.8%	5.2%	100.0%
	1	12.2%	54.3%	30.8%	~2.7%	100.0%

8 Includes natural gas, propane, fuel oil, kerosene, distillate, diesel, motor gasoline, hydrogen, purchased hot water, or steam.

Table 6. Manufacturing energy consumption by tier

Fuel	Tier	Basic Facility Operations	Boilers or Generators	Manufacturing or Industrial Production Process	Don't Know/ Unknown	Total
Non-Electric Fuels	2	22.7%	32.3%	19.4%	25.6%	100.0%
	3	40.7%	23.0%	26.9%	9.5%	100.0%
	Total	**17.6%**	**47.9%**	**29.6%**	**4.8%**	**100.0%**

Note: '~' indicates that one response made up 50% or more of a single result, or that the RSE was between 50% and 100%.

Manufacturing sector energy and climate practices and policies

Some key findings concerning energy and climate practices from the surveys of industrial customers were:

Fewer than 9% of facilities report they have completed energy consumption baselines, and 16% are currently completing one or plan to within the next three years.

Twenty-three percent (23%) of facilities have completed process upgrades within the last three years, and 16% are currently completing them or plan to which the next three years.

Around 42% of facilities have used state and/or utility incentives to finance process upgrades and another 48% would consider using them.

75% of electricity is used for production processes

48% of non-electric fuels are used for boilers

30% of non-electric fuels are used for production

80% of non-electric fuels used for boilers provide heat at <570°F

Industrial potential study

The results from the follow-up potential study show technical potential to save 69% of its GHG emissions compared to the baseline emissions in 2050, and the economic potential to save 40% to 48% of emissions (Table 7). The mix of measures making up economic potential includes more energy efficiency, while technical potential includes a larger share of measures that are energy neutral (like hydrogen) or that actually increase energy use (like CCUS). This different mix of measures results in energy savings associated with economic decarbonization potential being higher, at 26% of baseline, than that associated with technical potential, at 21%. The achievable potential under various scenarios ranges from 21% to 30% of emissions, corresponding to energy savings of 16% to 21%, as compared to the baseline in 2050.

Electrification is the largest source and energy efficiency is the second largest source of achievable energy savings and decarbonization potential in the New York industrial sector throughout the forecast. In 2050, across all adoption scenarios electrification accounts for at least 55% of energy savings and 75% of decarbonization potential. In 2050, energy efficiency accounts for at least 41% of energy savings potential and 18% of decarbonization potential across all adoption scenarios. Low-carbon fuels (via green hydrogen) lead technical decarbonization potential in 2050 but have limited achievable potential. CCUS also has limited achievable potential.

By end use, process heating contributes the greatest energy savings and decarbonization potential. These savings come primarily from natural gas efficiency and electrification and make up more than 70% of potential in the adoption scenarios.

Table 7. Technical, economic, and achievable emissions and energy savings potential in 2050

	2027	2030	2040	2050
Baseline emissions (thousand $MTCO_2e$)	18,175	15,981	13,123	13,921
Cumulative savings (thousand $MTCO_2e$)				
Technical potential	2,361	3,531	7,193	9,659
Economic potential – HiCO2Value	1,545	2,144	3,859	6,730
Economic potential – LoCO2Value	1,509	2,075	3,466	5,536
Carbon Price+ Scenario	753	1,499	3,051	4,208
Carbon Price Scenario	706	1,332	2,588	3,381
Site Incentive Scenario	532	1,130	2,296	2,890
Savings as % of baseline				
Technical potential	13%	22%	55%	69%
Economic potential – HiCO2Value	9%	13%	29%	48%
Economic potential – LoCO2Value	8%	13%	26%	40%
Carbon Price+ Scenario	4%	9%	23%	30%
Carbon Price Scenario	4%	8%	20%	24%
Site Incentive Scenario	3%	7%	17%	21%

Conclusions

The NY Statewide Industrial Facilities Stock Study and the follow-up potential study identified opportunities within manufacturing facilities for GHG emission reductions through efficiency, electrification, and other interventions. The diverse nature of the subsectors examined, and the unique characteristics observed in them, require tailored offerings to achieve GHG emission reductions across this important customer base. Some key observations that could be used for targeting specific subsectors, or for GHG gas emissions reductions across the subsectors, include:

- *Only six manufacturing subsectors account for over half of NY's manufacturing energy consumption and emissions, and among those, the 5% highest consuming facilities represent 64% of manufacturing energy consumption, allowing for more efficient targeting by clean energy initiatives.* The top two manufacturing subsectors in terms of overall energy consumption and emissions in New York are Paper and Chemicals, together accounting for close to 40% of the manufacturing sector's consumption and emissions. Primary Metals, Food, Fabricated Metal Products, and Transportation Equipment each account for about 10% of consumption and of emissions. Thus, these six industries together account for most industrial energy use and emissions.
- *There remain substantial opportunities within the state for continued shaping of energy management practices, policies, and awareness of energy use within facilities.* Energy management practices, including tracking energy consumption or energy performance, maintaining a written energy policy, mapping key consumption drivers, and completing a greenhouse gas inventory, all had relatively low incidence across the industrial subsectors (ranging from under 2% to under 40% across practices and subsectors).
- *Electrification accounts for more than three-quarters of achievable emissions reduction potential across all achievable scenarios*. Energy efficiency makes up the next largest share.

- *Low-carbon fuels have the highest technical potential for GHG emissions savings*. However, these fuels have modest economic potential, and minimal adoption even under the Carbon Price+ scenario.
- *Several key subsectors were observed to have large portions of non-electric boiler and non-boiler fossil fuel use dedicated to low- and medium-temperature heating* (under 570°F). These low- and medium-temperature heating processes are potential candidates for electrification.
- *Substantial resources and time, including internet research, surveys, and phone or email contacts were needed to establish a true population of facilities that perform manufacturing.* The public and proprietary datasets used to establish a population of manufacturing facilities for study did not distinguish buildings or addresses that serve in administrative or other non-manufacturing capacities for a manufacturing company.

Overall, selective and systematic interventions with manufacturing facilities can create meaningful GHG reductions that will benefit both industrial customers and New York State residents.

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