FINAL REPORT

Industry Standard Practice: Thermal Oxidizers

MA23C02-B-ISPREPOS

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Executive Summary

This study summarizes the ISP research and results for thermal oxidizers. The ISP for thermal oxidizers was defined in 2012 based on the results of research conducted as part of the impact evaluation of the PY2010 Custom Gas program. Because the measure ISP is based on research conducted more than 10 years ago, stakeholders decided to conduct new primary research to update the measure ISP.

There are three main types of thermal oxidizers. The most basic type is a Direct-Fired Thermal Oxidizer. A more thermally efficient design is the Recuperative Thermal Oxidizer (TRO). Lastly, there is the Regenerative Thermal Oxidizer (RTO), which boasts the best thermal efficiency of all oxidizers and is best suited for large air volumes and is the only type incentivized by Massachusetts Program Administrators.

Methodology and Approach

Work plan → Interview implementers → Generate interview questionnaire → Interview vendors → ISP recommendation

Results/Key Findings

Flow capacity	Baseline
More than 2,000 cfm	90% efficient regenerative thermal oxidizer (RTO).

Conclusions and Recommendation

The key finding from this study is that the industry standard practice (ISP) performance changed since the last research was conducted in 2013. Regenerative thermal oxidizers (RTO) have become common, and the performance of ISP units increased. Based on information gathered from four TO vendors, DNV concluded that a 90% efficient RTO is ISP for new TOs with capacities greater than 2,000 cfm.

For applications that require a flow greater than 2,000 cfm, the study team recommends to update the ISP repository to reflect the performance presented above.

For all other applications, the team recommends conducting an ex-ante review to determine the project baseline.

1 INTRODUCTION

Industry standard practice (ISP) research is a method for identifying appropriate equipment baselines and is important for two reasons. First, for measures with an applicable code or equipment efficiency standard, it allows the program to identify whether above- or below-code practices are more appropriate than the code or standard. Second, for measures that do not have an applicable code, determining the industry standard practice is the only appropriate way to determine what common practices look like and how they may be translated into baselines and savings.

According to the C&I Baseline Framework, ISP research is limited by the following:

- It is only for measures that are not unique technology-customer specific applications. There must be a definable market about which common practice can be researched.
- A below-code ISP is only a relevant option for gross baseline evaluation if there is no PA program that seeks to increase code compliance for the relevant measure.
- An above-code ISP baseline is not relevant for gross impact evaluation if there are only two efficiency options for the measure: lower (baseline) and higher (incentivized). In such cases free ridership research is expected to capture the effects of a higher or blended baseline. ISP research could still be important for such measures for program planning and free ridership consideration even if not for gross baseline determination.

This report summarizes the ISP research study and results for thermal oxidizers.

1.1 Study purpose and objectives

DNV carried out the Thermal Oxidizers Low Rigor Industry Standard Practice (ISP) Study (MA23C02-B-ISPREPOS) for the Massachusetts Program Administrators (PAs) and Energy Efficiency Advisory Council (EEAC) Consultants from July to September 2023. The study's overall purpose was to research and understand what industry standard practice is for thermal oxidizers, and if it has changed since previous ISP research conducted in 2012.

The study team assessed thermal oxidizer standards to understand how specific applications may impact ISP. The study team primarily focused on the assumptions that drive savings and how they are influenced by the rated performance of the equipment. Primary data collection was conducted via vendor interviews, with the objective of determining what types of thermal oxidizers and auxiliary equipment, including VOC concentrators, are being purchased and installed throughout the state.

1.2 Measure background

Thermal oxidizers (TO), also known as incinerators or after-burners, are a type of industrial equipment used in manufacturing and other industrial processes to reduce emissions of harmful or volatile organic compounds (VOCs), air pollutants, and other industrial emissions. Using extreme high temperatures (1400°F to 1450°F) to trigger a combustion reaction, the emissions undergo thermal oxidation, transforming the complex organic solvents used in the manufacturing process into carbon dioxide and water, destroying the pollutants before releasing the exhaust into the atmosphere.

There are three main types of thermal oxidizers. The most basic type is a Direct-Fired Thermal Oxidizer, also known as an incinerator or afterburner. As the simplest type of oxidizer, it does not include any heat recovery, heat exchanger, scrubber, absorbent, or catalyst material. It offers the lowest upfront capital investment cost but requires the most energy to operate. As the other types of oxidizers, the direct-fired type burns up to 98% or 99% of VOCs.

A more thermally efficient design is the Recuperative Thermal Oxidizer (TRO). In a recuperative system, the hot exhaust gas is passed through a heat exchanger to pre-heat the incoming process air from approximately 200°F to 700°F. This way, the burner in the oxidizer only needs to provide a fraction of the heat load required for a successful combustion reaction. The heat exchanger and additional ductwork costs more money upfront, but the recuperative design requires less natural gas and offers lower operating costs. The fuel efficiency of a TRO can be increased by expanding the size of its heat exchanger at the expense of making the unit more expensive. The cost of a TRO with a heat recovery efficiency greater than 70% makes it more expensive than an RTO. The heat recovery efficiency of a TRO typically ranges between 50% and 70%.

Lastly, there is the Regenerative Thermal Oxidizer (RTO). The regenerative thermal oxidizer boasts the best heat recovery efficiency of all oxidizers, exceeding 90%. This system typically uses two or three beds of ceramic media to store waste heat to pre-heat incoming air to upward of 1300°F, very near oxidation temperature. At reaction temperatures of 1450°F, the regenerative thermal oxidizer burner may only need to heat incoming air 50°F to 100°F. The standard three-ceramic-bed regenerative design allows for one of the beds to be exothermic, giving off heat to the incoming air, while another tower is endothermic, absorbing the waste heat from the exiting air stream. The third bed would be purging air at any time. Purge air is sent through the combustion chamber to ensure all VOCs are destroyed before being released into the atmosphere.

Table 1-1 details the key characters of each type of thermal oxidizer.

Table 1-1. Thermal oxidizer characteristics

Type of System	Heat Recovery	Minimum Destruction Efficiency	Heat Recovery Efficiency Range	Temperature Rise across the Burner(°F)
Direct Fired	N	98%	0% (no heat recovery)	1400°F
Recuperative (TRO)	Y	98%	50% - 70%	200°F–700°F
Regenerative (RTO)	Y	98%	90% - 97%	50°F–100°F

Currently, the custom gas efficiency program offers incentives for installing thermal oxidizers that are more efficient than ISP units. The ISP for thermal oxidizers was defined in 2012 based on the results of research conducted as part of the impact evaluation of the PY2010 Custom Gas program. For the research conducted in 2012, evaluators interviewed three vendors and used their responses to define the ISP. One finding of the research conducted in 2012 was that, because of their initial cost, RTOs were selected less frequently for applications that processed VOC flows less than 30,000 CFM. The current ISP is presented in Table 1-2.

Table 1-2. Current thermal oxidizers ISP baseline

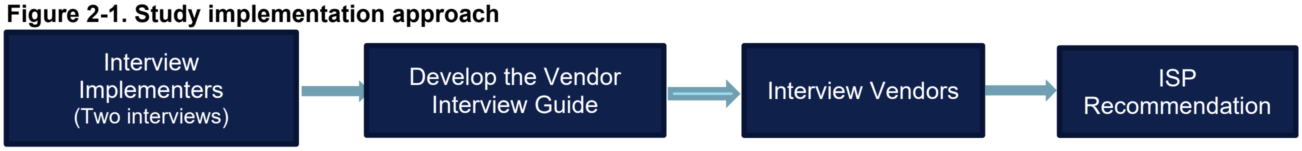
Flow capacity (cfm)	Baseline
Less than 10,000	Recuperative thermal oxidizer 70% efficiency
Between 10,000 and 30,000	Recuperative thermal oxidizer 70% heat recovery efficiency
More than 30,000	Recuperative or regenerative thermal oxidizer, whichever has a lower cost; 70% heat recovery efficiency

More recently (in 2022), as part of an ex-ante review for a coating facility, DNV recently interviewed three TO vendors and their responses indicated that, absent the program, they would specify an oxidizer with a better fuel efficiency than the current ISP. Given the information gathered indicated a potential change in the standard practice and because the measure ISP is based on research conducted more than 10 years ago, stakeholders decided to conduct additional research to gather current data that will be used to update the measure ISP.

2 STUDY METHODOLOGY

Because, on average, one thermal oxidizer project is installed through the Custom Gas program every year, stakeholders opted for conducting the ISP research using a low-rigor approach. The low-rigor ISP research consists of interviewing 3-5 vendors to gather information that is used to define an ISP. This study was designed to collect primary data through interviews of TO vendors that manufacture, sell, and install thermal oxidizers. The goal of the primary data collection was to determine what types of thermal oxidizers and auxiliary equipment, including VOC concentrators, are being purchased and installed throughout the state. Before developing the interview guide, DNV interviewed program implementers to gather details on key variables program administrators review when they process incentive applications for thermal oxidizers. Based on discussions with program implementers, DNV developed an interview guide that was reviewed and approved by stakeholders. The study targeted completing five interviews with vendors.Figure 2-1 presents the approach DNV used to conduct this research.

Figure 2-1. Study implementation approach



The following sections provide details on the methods used to complete each task presented in Figure 2-1.

2.1 Interview implementers

DNV interviewed staff from two firms that, in the past two years, assisted program administrators (PAs) with the implementation of thermal oxidizers projects. These firms review savings calculations that are submitted by program participants with the incentive applications for installing thermal oxidizers. During the calls the firms discussed the variables that play a role in the savings estimates participants provide to support incentive applications and indicated “dirty” volatile organic compound (VOC) may dictate the TOs’ technology and their capacity. In energy models, the efficiency of a given unit decreases as the flow passed through the unit increases. There are no standards to rate the performance of thermal oxidizers and performance data is provided by vendors. DNV used the information gathered during the calls with the implementers to develop the interview guide that was used to interview the TOs’ vendors.

2.2 Interview guide

DNV developed an interview survey guide that includes questions about installations in the most recent five years, what equipment was installed (technology, capacity, fuel efficiency performance, additional features, new or used), selection criteria, and energy efficiency programs support. The interview guide was reviewed and approved by stakeholders. The survey guide is presented in APPENDIX A.

2.3 Interviews with vendors

The interview protocol was initiated with a recruitment phone call with a voicemail and email message. Follow-up phone call followed without leaving a voicemail. After completing three interviews, DNV attempted to increase the response rate by offering an incentive ($100 gift card).

3 RESULTS AND ANALYSIS

This section presents the results of the study DNV used to recommend the ISP performance for thermal oxidizers (TOs).

3.1 Sample population and recruitment

TOs are a specialty product and a limited number of manufacturers offer them throughout US. Vendors do not specify TOs based on the project location. DNV conducted a web search and identified eighteen firms that manufacture, sell, and install thermal oxidizers. DNV reached out to all 18 firms (out of which three out of state vendors that manufactured TOs that have been installed through Custom Gas program prior to PY2021) and 4 agreed to be interviewed. Table 3-1 summarizes the recruiting disposition.

Table 3-1. Recruiting summary

Outcome	Count
Complete	4
Dropped – not responsive	11
Dropped - manufactures TOs for a 3rd party	1
Dropped – does not sell TOs (sells VOC concentrators)	1
Declined	1
Total	**18**

To complete four interviews, DNV made 56 attempts using the following approach: initial recruitment phone call and left a voicemail, emailed, and follow-up phone call without leaving a voicemail. After completing three interviews, DNV attempted to increase the response rate by offering an incentive ($100 gift card). The incentive helped DNV to recruit an additional interviewee.

The firms that agreed to an interview are headquartered in Wisconsin (two firms), Texas (one firm), and California (one firm). Based on information gathered as part of Massachusetts Custom Gas program, DNV confirmed one interviewee manufactured TOs for a MA Custom Gas program participant. Two other vendors that supplied thermal oxidizers for projects that participated in MA Custom Gas program did not agree to be interviewed.

The interviewees were high quality contacts that would have the necessary knowledge to respond to the survey. Their positions were: Business Vice President, Chief Operating Officer, Projects and Applications Manager, and Sales Manager. DNV analyzed the responses provided by the four contacts and determined the ISP performance of thermal oxidizers.

One interviewee, referred as Vendor #4, refused to provide sales data and, instead, provided the total of number units the firm generated proposals for (whether won or lost).

3.2 Results

During the interviews with the four TOs vendors, DNV gathered information regarding the units sold in the most recent five years. The responses provided by the vendors are summarized in this Section.

3.2.1 Qualitative responses

Manufacturers reported they specify thermal oxidizers equipped with a heat recovery component (RTOs or TROs) for applications that operate continuously, and indicated the concentration of VOCs does impact the selection of TO only if VOCs are “dirty”. Unlike the conclusion of the ISP established in 2012, where RTOs were competitive only for applications that required a flow larger than 30,000 cfm, one vendor noted that, currently, RTOs are competitive in low flow applications.

That information is confirmed by the data gathered through interviews and shown in Table 3-4 that is presented in Section 3.2.4 below. According to the interviewees, the TRO and RTO technologies are suitable for the same applications and facilities install one of the two technologies based on the installation and operation cost.

A VOC concentrator can be installed upstream of the oxidizer to reduce the capacity of the TO required to burn VOCs but is not a competing heat recovery technology. The entire concentrator-TO system is more fuel efficient because it reduces the volume of air that must be heated, while the efficiency of the reduced sized TO is not changed.

The financial case for installing a TO equipped with heat recovery rather than a DF alone is compelling. Vendors reported that their clients recover the upfront cost difference from installing RTOs/TROs units instead of a DF unit in 4-6 months. However, there are applications where a DF is required. Because DF thermal oxidizers are only equipped with a burner and do not have a heat recovery component, they are specified for applications that require flaring concentrated dirty VOCs that would foul a heat exchanger, or where any downtime is unacceptable, or where intermittent (low usage) operation renders it the least total cost option.

Given the same application, the least expensive TO is a DF unit, followed by the TRO, and the RTO. For the same application a DF unit is the most expensive to operate, followed by the TRO, and the RTO.

During the interview, DNV gathered additional anecdotal information that adds details to the TO market, as follows:

- Clients rarely ask vendors to specify used TOs
- Vendors are not always aware if their clients get support from energy efficiency programs.
- There are electric TOs but limited in application.
- For large units, continuous monitoring is performed to avoid extended downtime
- Facilities replace TOs after approximately 20 years.

3.2.2 Number of TOs sold by technology

The approximate number of units installed in the most recent five years is summarized in Table 3-2. Vendor #4 provided only the breakdown of the number of proposed projects (not actually installed projects). The other three vendors provided the breakdown of installed projects.

Table 3-2. Quantity of TOs proposed and installed in the past five years

Type	Vendor #1	Vendor #2	Vendor #3	% of Total (Vendors #1-#3)	Vendor #4	%of Total (All Vendors)
Direct-fired unit – quantity	25	15	3	20%	200	25%
Recuperative unit (TRO) – quantity	0	10	2	6%	25	4%
Regenerative unit (RTO) – quantity	25	75	60	74%	525	70%
Other type – quantity	0	0	0	0%	20	2%

Note that on average one TO has been installed every year with support from the Custom Gas program in MA and, since MA does not represent a sizeable market, interviewees did not specifically indicate how many TOs they sold and installed in Massachusetts.

The number of RTOs proposed and installed represents over two thirds of TOs reported by the interviewed vendors. The percentage of RTOs the vendors proposed and installed ranges from 50% (as reported by Vendor #1) to 92% (as reported by Vendor #3) of the total units each proposed or installed. The number of TROs represent less than 7% of the total units equipped with heat recovery (RTOs and TROs) that were sold by Vendors #1, #2, and #3.

3.2.3 TOs receiving energy efficiency program incentives

The approximate number of units sold in the most recent five years that received incentives from an energy efficiency program is summarized in Table 3-3. Vendor #4 was the only vendor reporting an estimate of the number of units that received energy efficiency incentives in the past five years. However, it is puzzling that DF units were reported as receiving incentives, since the efficiency of DFs is zero and it is unlikely that any PA offers incentives for this technology.

Table 3-3. Quantity of installed TOs with support from energy efficiency programs

Type	Vendor #1	Vendor #2	Vendor #3	Vendor #4
Direct fired (DF)	Not reported	Not reported	Not reported	100
Recuperative unit (TRO)	Not reported	Not reported	Not reported	15
Regenerative unit (RTO)	Not reported	Not reported	Not reported	200

Equipment manufactured by Vendor #3 was installed recently thorough the MA Custom Gas program.

3.2.4 Performance of most recent five TOs sold

The interviewees were asked to provide details about the last five TOs that they sold and whether energy efficiency incentives were received. The intention of the question was to provide a snapshot of the characteristics of recently sold TOs. Vendor #1 did not provide specific unit capacity and efficiency for actual units sold but rather the performance of units he would quote today. Vendor #4 claimed the most recent five units sold received utility incentives.

The performance of five most recent TROs and RTOs vendors sold is summarized in Table 3-4.

Table 3-4. TOs performance by type – five most recent units sold

Type	Vendor	Quantity	Capacity (cfm)	Efficiency Range (%) - Incentivized	Efficiency Range (%) – Non-incentivized
Recuperative unit (TRO)	#1*	1	1,000-20,000	None reported	60%-70%
	#2	0	-	None reported	-
	#3	0	-	None reported	-
	#4**	1	1,000-15,000	65%-80%	-
Regenerative unit (RTO)	#1*	44	5,000-80,000	None reported	95%
		1	3,000	None reported	90%,
		1	12,500	None reported	97%,
	#2	1	15,000	None reported	95%
		1	30,000	None reported	95%
		1	50,000	None reported	95%
	#3	4	2,000 - 80,000	None reported	95% (standard) and 97% (more expensive)
	#4**	3	1,000-85,000	85%-95%	N/A

(*) – Typical efficiency
(**) – Received incentives but not necessarily in MA

Vendor #1 reported that sold 25 RTOs in the past years. DNV assumed that the five most recent units sold by Vendor #1 were: four RTOs and one TRO. Thirteen of the fourteen recently installed non-incentivized units are RTOs with capacities ranging between 2,000 cfm and 80,000 cfm and heat recovery efficiencies ranging between 90% and 97%.

3.2.5 Analysis of survey results

Based on the information presented in Table 3-4 above, DNV determined the ISP is a regenerative thermal oxidizer (RTO).

Using the mid-point of the efficiency range presented in Table 1-1 above and the sales reported in Table 3-2 above yields a weighted efficiency of 92% regardless of whether the reported sales from Vendor #4 are included or not. When calculating the weighted efficiency by assuming the lower end of the efficiency range presented in Table 1-1 above, the weighted average efficiency value is 88%. Table 3-5 presents the summary of units sold and average efficiencies calculated when considering both mid-point and lowest efficiency values.

Table 3-5. Summary of calculations

Unit Type	Mid-point Efficiency			Lowest Efficiency		
	Efficiency	Units sold V#1-#4	Units Sold V#1-#3	Efficiency	Units sold V#1-#4	Units Sold V#1-#3
Recuperative unit (TRO)	65%	37	12	60%	37	12
Regenerative unit (RTO)	93.5%	685	160	90%	685	160
Total number of units	N/A	722	172	N/A	722	172
Weighted efficiency	N/A	**92%**	**92%**	N/A	**88%**	**88%**

N/A = Not applicable

DNV did not include DF units in the ISP calculations because they are not selected for applications where heat recovery is viable. If DF units (0% efficient) would be included in the calculation the weighted average efficiency would be 70%.

DNV calculated an **ISP efficiency value of 90%** by averaging the weighted efficiency values presented in Table 3-5 above.

4 CONCLUSION AND RECOMMENDATION

This section presents the conclusions and recommendations that resulted from conducting this low-rigor ISP research.

4.1 Conclusion

The ISP performance changed since the last research was conducted in 2012. Installations of regenerative thermal oxidizers (RTOs) represent more than 92% of the most recent five non-incentivized units that are equipped with heat recovery for applications that process VOC flowrates greater than 2,000 CFM and represent more than 66% of all TOs proposed or installed in the past five years.

DF units are installed in applications dictated by technical constraints where heat recovery is not an option due to the quality of the emissions or where reliability or downtime criteria require more reliable units. DFs may also apply in situations, like a lab setting, where VOCs are only occasionally incinerated.

DNV concludes that the ISP *technology* for incineration is a 90% efficient regenerative thermal oxidizer(RTO). DF is a solution when heat recovery cannot be installed, and because paybacks are less than a year for continuous flow applications, if a unit equipped with heat recovery **can** be installed then it **will** be installed. Thus, the ISP efficiency should be calculated using the reported sales data for TRO and RTOs, but not DFs.

Based on information gathered from four TO vendors, DNV calculated an updated ISP that is presented in Table 4-1.

Table 4-1. ISP performance requirements

Flow capacity	Baseline
More than 2,000 cfm	90% efficient regenerative thermal oxidizer (RTO)

4.2 Recommendation

This section presents the recommendations that are based on the results and conclusion of the study.

Recommendation 1: update the ISP repository to incorporate the results of this research by changing the performance of ISP TOs with the new performance presented in Table 4-1.

Recommendation 2: conduct project specific ex-ante review for applications that require thermal oxidizers with capacities of less than 2,000 cfm.

APPENDIX A. TO VENDOR SURVEY INSTRUMENT

This Appendix presents the questionnaire DNV used to interview the vendors that participated to this low-rigor ISP study.

Acronyms:
TO thermal oxidizer
TRO recuperative thermal oxidizer
RTO regenerative thermal oxidizer
cfm cubic feet per minute
VOC volatile organic compound
HX Heat exchanger

TO Vendor Questions:

1. How many TOs have you recommended to your clients) in the last 5 years?
    a. Can you provide a breakdown by type (e.g., direct-fired, recuperative TO, regenerative TO, or other type of TO)?
    b. Were they new or used?
    c. Were they anything other than natural gas fueled? If so, about how many?

Answers will be summarized in the Table below.

Type	Counts
Direct-fired unit	
Recuperative unit (TRO)	
Regenerative unit (RTO)	
Other type	

2. Does the process or type of VOC impact the selection of TOs? If yes, how?
3. Do the amount or concentration of VOCs impact the TOs selection?
4. Of the TOs you recommended to your clients, what number received an incentive from a gas or electric energy efficiency program?

Answers will be summarized in the Table below.

Type	Count(s)	Incentive
TRO		
RTO		
Other		

5. Think about the last five units you recommended, what was their performance?
    a. For specified TOs that did not receive incentives from energy efficiency programs.
    b. For specified TOs that received incentives for utilities.

I am asking about their type, capacity, and overall efficiency (i.e., fuel efficiency of nat. gas).
Answers will be summarized in the Table below.

Type	TRO	RTO	Other
Count(s)			
Typical incentive value or range, if applicable ($)			
Size range (cfm)			
HX Efficiency (%) range – incentivized units			
HX Efficiency (%) range – non-incentivized units			

6. Do you recommend additional features that would make the destruction of VOC more fuel-efficient (e.g., additional controls, concentrators)?

If so, could you provide more details?

7. How much more efficient does ___ feature make the system, In percentage terms?
8. Customers that are installing new TOs, are they typically doing so for production/capacity increases, existing system not working/end of life, or to install more efficient units?
9. What are the alternatives that customers have when selecting a TO?
10. How does maintenance impact decision-making?

About DNV

DNV is an independent assurance and risk management provider, operating in more than 100 countries, with the purpose of safeguarding life, property, and the environment. Whether assessing a new ship design, qualifying technology for a floating wind farm, analyzing sensor data from a gas pipeline or certifying a food company's supply chain, DNV enables its customers and their stakeholders to manage technological and regulatory complexity with confidence. As a trusted voice for many of the world's most successful organizations, we use our broad experience and deep expertise to advance safety and sustainable performance, set industry standards, and inspire and invent solutions.