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MEMO

DATE: 4/5/2018

TO: P73B TWG Members

FROM: Kevin Boyd and Jon Maxwell, ERS

RE: ISP STUDY FINDINGS – AIR COMPRESSORS AND COMPRESSED AIR DRYERS

EXECUTIVE SUMMARY

This memo details the findings of an industry standard practice (ISP) study undertaken as a part of the P73B research task. The intent of the P73B task is twofold: 1) To study ISP for a total of four different technologies that would benefit from a systematic examination, and 2) To pilot several different methods and rigor levels for this ISP research. The present ISP study of air compressors and compressed air dryers was intended to demonstrate a potential methodology for a high-rigor study.

The objective was to characterize the ISP technologies in Massachusetts for industrial plant air compressors that provide 75 to 150 psig air. The high-rigor study involved background research and two rounds of interviews. The first of these was a group discussion with PA representatives to establish a working understanding of the incentive programs as they currently exist. The second round of interviews involved individual discussions with 10 market actors including regional vendors, manufacturers, and industry experts.

The overall recommendations from this ISP study are summarized in Table 1.

Table 1. Compressed Air ISP Recommendations

System Type	Industry Standard Practice
General industrial air compressors larger than 15 hp and up to 350 hp	Oil-flooded, air-cooled single-stage rotary screw compressor Load/no load control For replace on failure: 1 gal/cfm storage For new construction: 4 gal/cfm storage
Air compressors for use in pharmacological, food, medical, and nano-production industries, as well as any application where oil-free air is required	Oil-free, air-cooled single-stage rotary screw compressor Load/no load control
General industrial compressed air dryers with dew point requirement >38°F	Non-cycling refrigerated dryer
Compressed air dryers with dew point requirement <38°F	Desiccant dryer

METHODOLOGY

ERS first reviewed four relevant program administrator (PA) documents regarding air compressor incentives:

1. The current prescriptive application
2. The current TRM measure
3. The 2015 DNV evaluation research report on prescriptive chillers and air compressors[1]
4. The 2017 Mass Save baseline guidance document

After review, the baseline research team held a group interview with four PA representatives via a conference call on 11/1/2017. The overall purpose of the PA interview process was to help the researchers develop an understanding about how the program currently handles projects involving air compressors and compressed air dryers and what information the program implementers felt could be clarified. The researchers provided the PA representatives with an overview of the evaluation ISP research process and solicited feedback.

The second interviewing task was to conduct a set of individual calls with market actors, including regional vendors, manufacturers, and national experts. Ten interviews were conducted, with 5 vendors, 3 manufacturers, and 2 experts selected by the researchers based on recommendations from the PAs.

BACKGROUND RESEARCH SUMMARY

As part of the PA interview process, the researchers identified the established program baselines for air compressors as provided in the 2017 Mass Save Baseline document. Its baselines, believed to be last updated in 2014, are provided in Table 2.

Table 2. 2017 Mass Save Baselines – Air Compressors

System Type	Baseline Efficiency and Standard Practice	Potential High-Performance Practices
Air compressors – oil-flooded	General manufacturing systems <130 psi or <200 hp oil-flooded single-stage compressors with modulating control via inlet valve and unloading point below 50% of rated CFM	• Load/no load compressors with storage > 4 gal/CFM of compressor capacity • Variable displacement compressors • VFD compressors • Two-stage oil-flooded compressors with load/no load control and storage

[1] *Impact Evaluation of Prescriptive Chiller and Compressed Air Installations*, prepared for the Massachusetts Program Administrators, Massachusetts Energy Efficiency Advisory Council by KEMA, Inc., October 26, 2015.

System Type	Baseline Efficiency and Standard Practice	Potential High-Performance Practices
	General manufacturing systems >130 psi or > 200 hp two-stage oil-flooded compressors	• Load/no load compressors with storage > 4 gal/CFM of compressor capacity • Variable displacement compressors • VFD compressors • Two-stage oil-flooded compressors with load/no load control and storage
Air compressors—oil-free	Medical, pharmaceutical, food processing and other specialty manufacturing facilities where oil free air is required. Oil-free air with single-stage compression and load/no load control.	• Multi-stage compression w/ VSD control, and storage >4 gal/CFM of compressor capacity • Centrifugal compressors for larger base load combined with rotary screw oil-free unit to meet changing load

The 2016–2018 MA TRM does not specify any parameters except that it applies for oil-flooded compressors and the baseline is load/no load (L/NL) control. The labeled market event types are retrofit and lost opportunity. The former is rarely applicable as few customers replace compressors before failure.

The basis of the TRM's prescriptive savings is a 2015 DNV evaluation report. The subject of that document's research is oil-flooded compressors eligible for prescriptive incentives: 15 to 75 hp, lost opportunity, and new construction. For this narrowly defined market, the report recommended a load-unload control baseline of 1 gallon per cfm of storage capacity.

Table 5, at the end of this report, compares the application criteria and baselines in these three documents with the recommendations.

The PA prescriptive incentive application does not declare a baseline but does specify eligibility criteria: the air compressors must include 15–75 hp oil-loaded screw air compressors that operate at 145 psig or below and for at least 2,000 hours per year.

The PA baseline information for compressed air dryers, also believed to be last updated in 2014, is shown in Table 3.

Table 3. 2017 Mass Save Baselines – Compressed Air Dryers

System Type	Baseline Efficiency and Standard Practice	Potential High-Performance Practices
Air dryers	• For facilities requiring pressure dew point of ≥ 35°F – refrigerated non-cycling dryers • For facilities requiring pressure dew point of < 35°F – desiccant dryers • Desiccant dryers for ≤ 35°F dew point requirements • Oil-free application – refrigerant or desiccant dryer	• Cycling thermal mass or variable speed dryers • Incorporate desiccant dryers with dew point sensing controls to reduce regeneration frequency • Incorporate piping changes to separate low dew point air demand from ≥35°F to achieve higher overall system efficiency with use of appropriately sized combination of desiccant & refrigerant cycling or VFD dryer • Heat of compression dryer when packaged w/new compressor

The 2016–2018 MA TRM only includes measure information for installing cycling or VFD-equipped refrigerated air dryers, for which the baseline is a non-cycling refrigerated air dryer, and the labeled market is Lost Opportunity.

The prescriptive energy savings for installing cycling refrigerated dryers is based on the same 2015 evaluation study by DNV GL that was used for air compressors.

PROGRAM ADMINISTRATOR INTERVIEW FINDINGS

Air Compressors

The researchers collected the following information about program practices for air compressors from the PAs:

- ❑ The current program baseline for prescriptive compressors (<75 hp) was L/NL control based on a 2015 program evaluation completed by DNV GL.
- ❑ The PAs indicated that a cutoff of 200 hp seemed appropriate for defining baseline technologies, as larger equipment would likely require custom-defined baselines.
- ❑ Single-stage oil-flooded rotary screw systems were described as the most common type of compressor encountered through the program.
- ❑ Medical, pharmaceutical, and food processing facilities were all mentioned as requiring oil-free air compressors.

The PAs felt that the most valuable information to be clarified in this ISP study was a clear baseline in terms of technology and control type for compressors in the 75–200 hp range. Additionally, the PAs requested that the researchers establish the approximate market share for

oil-free compressors, as there was a perception that they may be increasing in popularity. This was added to the script.

Compressed Air Dryers

The PAs provided the following information about compressed air dryers:

- Dryer demand controls have a growing share of the market, but they are not yet baseline.
- Dryer type is dependent on dew point requirements; desiccant dryers are often installed when piping is outside or when very dry air is needed.
- Non-cycling refrigerated dryers were considered the most common, and these were agreed upon as the baseline technology.

Based on this interview, the researchers determined that the most important points to clarify in the market actor interviews were specific values for which the dryer type changed and what types of controls were standard.

MARKET ACTOR INTERVIEW FINDINGS

This section summarizes the market actor responses to interviewer questions. Appendix A is the interview script and Appendix B contains abridged individual answers to each question by each respondent with summary observations. Table 3 summarizes the respondent market roles, service territories, and sales volumes.

Table 4. Market Actor Summary

ID	Market Role	Location of Work	Qty Compressors in MA in Previous Year	Qty Dryers in MA in Previous Year
1	Vendor	40% MA, rest throughout Northeast	10	10
2	Vendor	100% Northeast	35	No data
3	Vendor	100% Northeast	75	55
4	Vendor	75% work in MA, 25% work in NH	112	150
5	Consultant	Nationwide, mostly in NY	0	0
6	Vendor	60% MA, rest throughout Northeast and Midwest	18	18
7	Consultant	Nationwide; 20% in MA	10	9
8	Manufacturer	Nationwide; focus on Northeast region	200	100
9	Manufacturer	Nationwide; focus on Northeast region	20	17
10	Manufacturer	Nationwide; focus on Northeast region	100	80

All interviewees stated that they were familiar with the design, sale, and installation of air compressors in Massachusetts, and all interviewees also had experience in other states.

Program Influence

This section of the interview discussed the ways in which projects handled by the interviewee that took place in MA were impacted by incentive programs.

What percentage of the air compressor and compressed air dryer projects you worked on received financial incentives or technical assistance from the Massachusetts PAs (e.g., National Grid, Eversource, Cape Light, etc.)?

Most of the interviewees had a significant portion of their project work in MA entered in incentive programs: 77% of the overall MA compressor projects represented by these market actors were included in the incentive programs. Four of the respondents had 90% or more of their compressor projects participating in the program.

These values were somewhat lower for compressed air dryers, with 65% of the overall dryer projects participating in the incentive program and 3 respondents having 90% or more of their dryer projects participating in the program.

Are there any consistent differences in the air compressors and compressed air dryers that you sell/install for projects that do or do not receive incentives/assistance?

The interviewees largely indicated that air compressor design (aside from the efficiency measure) and surrounding compressed air system components were not significantly different at facilities where incentives were expected for the project. One vendor responded that 80% of their nonparticipants also purchased the VFD option, but three interviewees indicated that VFD projects are more frequently encountered on machines that were incentivized. Two other interviewees suggested that proposed projects that didn't receive incentives had a significantly lower completion rate than those that did; some facilities did not have sufficient capital to purchase a new system and instead relied on rental units.

Dryer design was much more consistent between the interviewees, with all but one interviewee stating that there were no design differences aside from the efficiency measure in projects that received incentives compared to those that did not.

Air Compressors

This section of the interview focused on establishing ISP for air compressors absent the influence of the program.

What is the standard practice for compressor type?

All interviewees indicated that rotary screw compressors were the most frequently installed type.

What is the standard practice for staging?

One interviewee who completed mostly larger systems listed two-stage units as their most commonly installed; all other interviewees indicated that single-stage units were the most common. The researchers have determined that single-stage is ISP.

What is the standard practice for lubrication type?

All interviewees said that oil-flooded systems were the most common by far, at 90% or more of the market.

What is the standard practice for control type?

The interviewees provided varying responses for control types.

- Two respondents indicated that modulating controls, a very low efficiency option for variable flow applications, are still encountered as a possible ISP alongside L/NL controls.
- All indicated that modulating and variable displacement controls were increasingly uncommon in most applications, with industry movement toward L/NL and VFD controls.
- Seven indicated that L/NL controls were one of the most common, with one interviewee suggesting that L/NL controls were most common below 100 hp and another indicating

that they were most often implemented in the 15–25 hp range. One interviewee suggested that L/NL systems represented about 50% of typical installations.

- Seven indicated that VFD controls were one of the most common(respondents could choose more than one type as being "one of the most common").
- Six interviewees with customers outside of program areas indicated that VFD control was less common.
- Three interviewees indicated that program participation is likely driving up VFD control usage in MA.

The respondents collectively indicate that both VFD and L/NL controls are commonly installed by nonparticipants. No other types of controls are common practice or candidates for ISP. A blended baseline for ISP was considered but L/NL is judged most appropriate due to the following conclusions:

- Vendors that were heavily engaged in the PA program were also more likely to describe VFDs as being common absent the program.
- L/NL is a realistic and commonly used practice that is less efficient than the VFD measure.
- The least efficient control option, modulating, is still considered acceptable for variable flow if not common by some
-
- Vendors described L/NL as being more common than VFDs outside Massachusetts, in areas where utility costs are low (e.g., in northern New York), and in areas with less history of program engagement.
- Within MA, vendors that were less engaged in the PA program were more likely to describe L/NL as common
- The interviewers suspect that some VFD installations described as being done absent program influence may actually have been installations by non-free rider participants[2]

Not all compressed air applications are best served by VFD compressors; base load machines and facilities with very flat load profiles may operate well with L/NL controls.

What is the standard practice for cooling type?

[2] The interviewers suspect that some VFD installations described as being done absent program influence may have been installations by non-free rider participants. Interviewers perceived that four of the air compressor respondents with a very high percentage of customers participating in the program struggled to identify non-participant behavior. This would bias the responses towards the more efficient technology.

All interviewees stated that air-cooled systems are by far the most common, at 90% of the market or more. One interviewee suggested that water-cooled systems were underutilized and perhaps should be considered at more facilities.

What design guidelines are used for compressed air storage?

- For L/NL systems, interviewee recommendations varied from 2 gal/cfm to 7.5 gal/cfm, with a median of 4 gal/cfm recommended.
- For VFD systems, interviewee recommendations varied from 2 gal/cfm to 5 gal/cfm, with a median of 3 gal/cfm recommended.
- Interviewees agreed across the board that approximately 1 gal/cfm is typically what they see installed at facilities, and that there is little appetite for additional storage installation due to perceived impacts on available space in a facility. This is clearly sub-optimal for most cases.
- Two interviewees suggested that system-specific values be used rather than rule-of-thumb calculations for storage design.

The researchers noted that actual installed storage seems were underperforming compared to the recommendations from vendors. This may warrant additional program action, as adequate storage is critical for optimizing compressed air efficiency values.

Are there any industries that systematically use or require a different configuration? What is different?

Each of the interviewees noted that one or more of pharmacological, food production, semiconductor, and medical production facilities use oil-free air compressors. The typical assessment was that approximately 10% of compressors installed were oil-free units.

Is there a horsepower or acfm size below or above which the typical type changes? How?

Most interviewees primarily install rotary screw units, with only very small and very large systems falling into different technology categories. While rotary screw units are available in sizes down to 5 hp, several interviewees indicated that approximately 50% of units below 15 hp were reciprocating systems.

Rotary screw units are also available in sizes up to approximately 500 hp, with most interviewees stating that centrifugal compressors become most common above approximately 350 hp.

Are there any particular applications in plants for which you typically sell different variants? Does the system design vary depending on whether it is replacing an existing unit (retrofit), replacing a failed unit (ROF), or adding capacity to a new or existing system (NC)? If so, how?

The interviewees indicated that both ROF and retrofit projects use the same baseline techniques, with one-for-one replacements of existing equipment being the most common. Retrofit projects appear to be rare; one interviewee expressed some doubt that retrofit (i.e., early replacement of

a properly functioning system) was a common practice, with most units instead falling into the ROF category.

New construction projects are much less common than ROF projects in Massachusetts, according to several interviewees. The main reason is that few new industrial facilities are being constructed in MA at this time. However, when they are warranted, new construction projects are typically significantly more efficient than equivalent ROF systems because they involve an up-to-date design of the air system to improve operating efficiency.

Compressed Air Dryers

This section describes the research findings about compressed air dryers absent the influence of the program.

What is the typical standard practice for dryer type?

All interviewees stated that refrigerated dryers were standard practice in MA.

What is the typical control type when you specify refrigerant dryers?

There was some variation in the control types specified when refrigerant dryers are a part of a project.

Four interviewees, including the two vendors believed to have the most MA sales, indicated that non-cycling dryers were most common. One of them provided a maximum cutoff value of 1,000 cfm for this control. The remaining six interviewees suggested that cycling dryers are the most common. However, three of the six stated that the reason that cycling dryers were most common was that dryer program incentives require the use of a cycling dryer to ensure eligibility and that the program is influencing the market for compressed air dryers.

Of the four interviewees who believed that non-cycling dryers were common two were vendors, one was an industry expert, and one was a manufacturer. Each of these interviewees had a significant portion of their dryer work (20%–60%) not receiving incentives. This indicates a relatively larger familiarity with non-program-influenced practices compared to those who specified cycling dryers as the most common (0%–10% of dryer projects not receiving incentives).

The researchers interpret this variation in the interviewee responses as indicative of an increasing market share for cycling refrigerated dryers, with evidence that incentive programs play a large role in shaping the market. Non-cycling dryers are still installed frequently, particularly when the project is not being incentivized. As a result, the researchers conclude that non-cycling dryers are the most appropriate baseline technology for compressed air dryers.

Are there any industries or applications that systematically use or require a different configuration? What is different?

The interviewees agreed that desiccant dryers were certainly required systematically in both industries that have low dewpoint requirements such as pharmacology and electronics, and for

facilities that have exterior plumbing. The suggested dewpoint cutoff for desiccant dryers was agreed upon at 38°F.

Does the system design vary depending on whether it is replacing an existing unit, replacing a failed unit (ROF), or adding capacity to a new or existing system (NC)? If so, how?

Replacing an existing, working compressed air dryer for efficiency reasons is uncommon. Similar to air compressors, the interviewees indicated that typical retrofit and ROF practices are to complete a simple one-for-one replacement with the existing equipment. Only one interviewee mentioned fully reworking a facility's compressed air dryer system sufficiently to justify going through the NC baseline.

Future Air Compressor and Dryer Markets

This section of the interview process involved a discussion about future developments in the compressed air industry.

Do you expect any market changes over the next 5 years? If so, in what way will it change?

None of the interviewees believed that any major technological disruptions were likely in the compressed air industry over the next 5 years. Instead, it was considered likely by several interviewees that the major changes would be in the continued centralization of vendors and distributors into fewer and larger companies. Two interviewees did think that oil-free compressors will begin to increase their market share as some food manufacturers move to oil-free units. No interviewees expressed an opinion regarding the continued growth of VFDs in the market.

Do the practices for air compressors and dryers in MA vary by location within the state? If so, how?

The interviewees did not note any major differences across MA in terms of air compressors and dryers, aside from inherent differences in compressor and dryer type and control based on industries in each area of the state.

Do the practices for air compressors and dryers differ between MA and other states where you have worked?

Most interviewees indicated that practices do not differ between MA and other states. Two interviewees pointed out that fixed-speed compressors are more likely in areas with lower utility rates, as customers in those areas are attempting to control cost as much as possible.

Are you able to provide historic sales data?

None of the ten interviewees were willing to share their direct sales numbers, and even estimates were difficult to come by. Several interviewees recommended that the researchers reference quarterly CAGI reports that are made available to CAGI member organizations to

determine overall market size and typical operation and installed equipment characteristics, but these reports were unfortunately not available to the researchers.

One interviewee was able to provide some estimates of the size of the air compressor market in New England based on his own professional experience:

- In MA, market size for compressed air is likely $40–$50 million.
- There are an estimated six major compressor sales companies in MA, with four salespersons per company. There are approximately 30 projects for each salesperson per year.
- The above assumptions yield 1,000–1,500 projects per year in MA total.
- An estimated 70% of those projects are going through programs. (Note that this aligns well with the research findings across all 10 interviews.)

DOE Efficiency Standards

The US Department of Energy has proposed new efficiency standards for rotary air compressors that is likely to be implemented between 2018 and 2023, though a final implementation date is not yet set. A pre-publication version of this rule was issued in December 2016, but it has not yet been published in the Federal Register. The rule will be effective 60 days after this publication.

This upcoming rule does not use the commonly cited kW/cfm measurement to establish compressor efficiency, but instead relies on the isentropic efficiency value for compressors. The new rule is technology-blind, allowing both rotary and reciprocating style machines as long as they meet the efficiency standard. Additionally, the standard does not establish a preference for control configuration of air compressors, meaning that VFD, L/NL, modulating, and other controls are all allowed.

The researchers asked the following questions to gauge familiarity with these upcoming rules.

Are you aware of the new DOE rotary air compressor efficiency standards proposed to go into effect between 2018 and 2023?

Only five of the interviewees were aware of these new rules, including all of the manufacturers.

Is your company making any changes that you are aware of to address the new standards?

The manufacturers were all making changes to accommodate the new rules.

How much of your line-up is already compliant?

The manufacturers believed that most of their line-ups were already compliant.

Do you think it will affect the mix of rotary versus non-rotary sales, or fixed versus variable speed sales?

The manufacturers assumed that no major changes to the mix of sales would occur due to these new standards.

Would you support a program design that incented high-efficiency air compressors relative to this new DOE baseline?

Several respondents requested incentives on systematic compressed air improvements, like for compressed air audits and for increased storage. This was noted in the context of a perception that compressors are not getting much more efficient.

CONCLUSIONS AND RECOMMENDATIONS

All of the market actors interviewed for this research project were credible and able to provide good insights into the compressed air market in Massachusetts. They had extensive industry experience both in and outside the state, and the approximately 500 projects that they completed in the last year across the state represents a wide variety of different facility and application types. Additionally, for many of the different parameters that were being studied, a high degree of consistency was present across the interviewee responses. The researchers did find that the interviewees seemed to have difficulty separating their design decisions between program participants and nonparticipants, likely due to the high program participation rate among the interviewees' projects.

We recommend the following ISP assumptions:

- General purpose industrial compressed air systems between 15 and 350 hp should be assumed to be single-stage oil-flooded rotary screw units with L/NL controls.
- The same assumptions should hold for systems that require oil-free air; the only difference is that an oil-free rotary screw compressor should be used as the baseline. Insufficient data is available to draw a conclusion about typical storage capacities for oil-free systems.
- New construction oil-flooded compressor projects should assume 4 gal/cfm storage in the baseline case, and replace on failure projects should assume 1 gal/cfm storage.
- For general compressed air systems with dewpoint needs of >38°F, the baseline should be a non-cycling refrigerated dryer.
- For compressed air systems with dewpoint needs of <38°F, the baseline should be a desiccant dryer.
- Sunset date: Revisit ISP for this measure no later than 2023, as VFD compressors and cycling refrigerated dryers are nearing ISP in MA, though much of this may be due to strong participation in incentive programs in the state. By 2023, the new federal efficiency standard will also likely be fully in effect.

While program design is not the study's primary objective, there were findings that could help with program evolution:

- Update the baseline document to reflect L/NL assumption for baseline equipment.
- Rewrite program rules such that a dedicated base-load machine is not eligible for a VFD, as unnecessary VFD installation uses more energy than L/NL in this case.
- Consider updating efficiency requirements with isentropic efficiency values to exceed DOE efficiency rules once those rules come into effect between 2018 and 2023.
- The interviewees indicated that the majority (50%–70%) of compressor projects receive program incentives. While the vendors are not predicting near-term disruptions and this study concludes that VFDs are not yet standard practice, the compressor market is likely to continue to gradually change and may soon be permanently transformed. If so, research to assess whether or not the program caused the long-term transformation would be

valuable. If the change is permanent and program-induced, the PAs could potentially phase out the VFD incentive and continue to claim associated savings for a period of time until it would have naturally transformed. Regardless of cause, if it is permanent the programs could redirect investment towards incentivizing other compressed air system-wide improvements mentioned by vendors in interviews:

- Compressed air system-wide audits and leak repairs
- Increased compressed air storage
- Water-cooled compressors

Smart sequencing, intermediate flow controllers, leak reduction, and low flow nozzles are additional options not mentioned by the interviewees.

- . Based on this information and the results of the ongoing study of free ridership in compressed air projects, PAs should determine whether compressed air incentive programs are adequately achieving savings goals.

COMPARISON OF STUDY RECOMMENDATIONS WITH OTHER DOCUMENTS

The recommendations reflect changes compared to the prescriptive application, the TRM, the 2015 study that focused on 15 to 75 hp prescriptive applications and the Mass Save Baseline document. Table 5 summarizes the differences regarding when the guidance applies for the five documents, that is, what compressor sizes and operating conditions are in the scope of the studies' findings. Table 6 follows with differences in baseline characterization for all but the application, which does not address baseline.

Table 5. Application Scope

Parameter	Prescriptive Application	TRM	DNV 2015 Study Referenced in TRM	PA Baseline Document	This Study
Size	15 to 75 hp	Not specified	15 to 75 hp	All	15 to 350 hp
Pressure	Up to 145 psig	Not specified	Not specified	Less than 130 psig	75 to 150 psig
Industries	Not specified	Not specified	Not specified	Two categories: (1) General (2) Medical, pharmaceutical, food processing, or specialty manufacturing facilities where oil free air is required.	Two categories: (1) General (2) Medical, pharmaceutical, food processing, or specialty manufacturing facilities where oil free air is required.
Market event type	Not specified	Lost opportunity, retrofit	Lost opp.& new constr. together	Lost opportunity & new construction together	Lost opportunity & new construction together

Table 6. Baseline Rotary Screw Technology Configuration for Applications

System Size	TRM	DNV 2015 Study Referenced in TRM	Baseline Document	This Study
<15 hp	Gen'l oil flooded: Load-unload + + "Properly sized" tank Oil free: Not in scope	Not in scope		
15 to 75 hp		Gen'l oil flooded: Load-unload + 1 gall/cfm tank + single stage implied Oil free: Not in scope	Gen'l oil flooded: Modulating & low-unload + single stage + unspecified gall/cfm, <<4 gall/cfm implied Oil free: Load-unload + single stage	Gen'l oil flooded: Load-unload + single stage + 1 gall/cfm ROF or 4 gall/cfm NC + air-cooled Oil free: *Same as above**
>75 to 200 hp		Not in scope		
>200 to 350 hp			Gen'l oil flooded:	

System Size	TRM	DNV 2015 Study Referenced in TRM	Baseline Document	This Study
>350 hp			unspecified control + two stage Oil free: Load-unload + single stage	Not in scope

**Gallons per cfm is not a significant variable for oil-free, as cycling losses are much lower.*

APPENDIX A. MARKET ACTOR PHONE INTERVIEW QUESTIONNAIRE

Introduction

Thank you for taking the time to talk with me today. As a reminder, we're currently working on a study of industry standard practices in air compressor and dryer design. We are not looking at whole system design, and we're also talking only about general industrial compressed air systems.

1. **Familiarity with ISP Technologies**
   - 1.1. Are you familiar with the sale and installation of air compressors and compressed air dryers in Massachusetts? (If no, thank and end survey; if yes, circle all that apply and ask about each of these technologies in the sections that follow – may need to call another person in the firm who is more familiar to answer Qs)
   - 1.2. How many air compressors and compressed air dryers have you sold/installed in Massachusetts in the last 1-2 years? How about throughout the Northeast?
     - 1.2.1. Air compressors:
     - 1.2.2. Air dryers:
2. **Program influence: air compressors**
   - 2.1. What percent of the air compressor projects you worked on received financial incentives or technical assistance from the Massachusetts PAs (e.g. National Grid, Eversource, Cape Light, etc.)?
   - 2.2. Are there any consistent differences in the air compressors you sell/install for projects that do or do not receive incentives/assistance?
   - 2.3. *(if needed)* How do you think your system designs would differ if incentive programs were not available for compressed air systems?
3. **Program influence: air dryers**
   - 3.1. What percent of compressed air dryer projects you worked on received financial incentives or technical assistance from the Massachusetts PAs (e.g. National Grid, Eversource, Cape Light, etc.)?
   - 3.2. Are there any consistent differences in the compressed air dryers you sell/install for projects that do or do not receive incentives/assistance?
   - 3.3. *(If needed)* How do you think your system designs would differ if incentive programs were not available for compressed air systems?

4. Technology #1: Air Compressors

4.1. **Standard practice.** In this section, we will be discussing a few characteristics of general industrial air compressor installations. We'll talk about typical installations first, and then we'll talk about exceptions. Absent any program incentives, what is the typical or standard practice for…

4.1.1. Compressor type (screw, recip, centrifugal, scroll, etc.) and staging (single vs. two-stage compression)

4.1.2. Lubrication type (oil vs. oil-free)

4.1.3. Control type (modulating, load/unload, VFD, variable displacement)

4.1.4. Cooling type (air vs. water-cooled).

4.1.5. Storage guidance or design (X gal/acfm, any differences depending on control type, new construction or retrofit

4.2. **Variations.**

4.2.1. Are there any **industries** that systematically use or require a different configuration? What is different?

4.2.2. Is there a **horsepower or acfm size** below or above which the typical type changes? How?

4.2.3. Are there any **particular applications** in plants for which you typically sell different variants? If prompt needed: For example, do customers buy modulating systems as base load machines, or do they rotate compressors enough that they buy more efficient control options?

4.3. **Baseline type** – Does the system design vary depending on whether it is replacing an existing unit, replacing a failed unit (ROF), or adding capacity to a new or existing system (NC)? If so, how? If yes, probe for whether there is a particular baseline type (retrofit, ROF, NC) that is more common for a given system design and fill in the table below

5. Technology #2: Compressed Air Dryers

5.1. Standard practice

5.1.1. What is the typical standard practice for dryer type? (e.g. refrigerated, desiccant, membrane, etc)

5.1.2. What is the typical control type when you specify refrigerant dryers? (cycling, non-cycling, VFD)

5.1.3. *(if needed)* If desiccant dryers are most common: What is the typical drying mechanism when you specify desiccant dryers? (compressed air purge, heated regen, heat of compression regen, chemical deliquescent)

5.2. Variations

5.2.1. Are there any **industries or applications** that systematically use or require a different configuration? What is different?

5.2.2. Baseline type – Does the system design vary depending on whether it is replacing an existing unit, replacing a failed unit (ROF), or adding capacity to a new or existing system (NC)? If so, how? If yes, probe for whether there is a particular baseline type (retrofit, ROF, NC) that is more common for a given system design and fill in the table below.

5.2.3. **What are some other factors that influence dryer selection?** How does typical dryer type change with these factors?

6. General Questions

6.1. Market changes

6.1.1. Do you expect any market changes over the next five years?

6.1.2. If so, in what way will it change?

6.1.3. When/why do you anticipate these changes taking place?

6.2. Do the practices for air compressors and dryers in MA vary by location **within the state**? If so, how?

6.3. Do the practices for air compressors and dryers differ **between MA and other states** where you have worked?

6.4. **DOE Standards (to be asked to manufacturers)**

6.4.1. Are you aware of the new DOE rotary air compressor efficiency standards proposed to go into effect between 2018 and 2023?

6.4.2. Is your company making any changes you are aware of to address the new standards?

6.4.3. How much of your line-up already is compliant?

6.4.4. Do you think it will affect the mix of rotary versus non-rotary sales?

6.4.5.

6.4.6. Or fixed versus variable speed sales?

6.4.7. Would you support a program design that incented high efficiency air compressors relative to this new DOE baseline?

7. <u>Data Request</u>

7.1. Can you share historic sales data with us? We are particularly interested in how many of each compressor type and dryer type you have sold in the last year. Details by (in order or preference) compressor/dryer type, compressor hp, compressor control type (particularly for screw units), dryer control type, facility type, receipt of utility incentives, and manufacturer, make, and model would be particularly helpful.

7.2. Who else do you suggest we contact who is knowledgeable about the sales/installation practices for air compressors and compressed air dryers in Massachusetts? Can you provide me with their contact information?
Bill Scales (retired)- worked out of long island, very knowledgeable.

8. <u>Surveyor Impressions</u>

8.1. Did you find this responder credible? Why or why not?

8.2. Was there anything in similar questions that are in disagreement with other comments made by the responder?

8.3. Was the information provided by the respondent consistent? Is there a clear baseline recommendation resulting from this interview?

APPENDIX B. SURVEY RESULTS SUMMARY

This tabulation summarizes each respondent answer. It is not a transcription. Additional contextual information was collected.

Question Number	1	2	3	4	5	6	7	8	9	10
0	**Vendor**	**Vendor**	**Vendor**	**Vendor**	**Consultant**	**Vendor**	**Consultant**	**Manufacturer**	**Manufacturer**	**Manufacturer**
1.2	40%	Work throughout Northeast	n.d.	75% work in MA, 25% work in NH	0% MA, mostly in NY	60%	20%	n.d.	n.d.	n.d.
	All interviewees worked on projects both in and out of MA									
1.2.1	10	35	75	112	0	18	10	200	20	100
	Total: 348									
1.2.2	10	n.d.	55	150	0	18	9	100	17	80
	Total: 224									
2.1	90%	57%	90%	80%	n.d.	100%	100%	n.d.	85%	60%
	High percentage of compressor projects receiving incentives.									
2.2	No differences	Larger units (>25hp) are typically submitted to programs.	No design differences, except the few small recips the do (<25hp) don't get incentives	80% of the time, same as incentive equip	Air receiver size increases, VFDs somewhat more common	Delayed payback period means the project may not happen	Projects without incentives don't actually go through as frequently	Depends on site requirements	Often no VSD on projects w/o incentives	More VFDs on machines with incentives
	VFDs more frequent on projects with incentives.									
3.1	n.d.	n.d.	n.d.	70%	N/A	100%	100%	n.d.	90%	40%
	High percentage of dryer projects receiving incentives.									
3.2	n.d.	n.d.	No design differences	80% of the time, go for cycling	No design differences	No differences	No differences	No differences	Fixed purge in non-incentivized projects	No difference
	No design differences in projects with incentives.									
4.1.1.1	Screw	Screw	Screw	Screw	screw	screw	Screw	Screw	Screw	Screw
	Screw compressors most frequent.									
4.1.1.2	Single stage	80% two stage	n.d.	n.d.	single stage	n.d.	n.d.	Single stage	Single stage	Single stage
	Single stage equipment is most frequent.									
4.1.2	Oil flooded	oil-flooded	oil-flooded	n.d.	oil-flooded	oil-flooded	oil-flooded	oil-flooded	Oil-flooded	Oil-flooded
	Oil-flooded dominates the market (most said 90-95%)									
4.1.3	Almost all VFD if >100hp, mostly L/NL for <100hp. Efficiency difference below 100hp is	VFD, L/NL, or a combination of both is most common, particularly >20hp.	VFD most common (75% of units installed last year), some L/NL in 15-25hp size.	L/NL or modulating with variable capacity control	Most machines are L/NL or modulating; depends on what control type manufacturer defaults to	98% VFDs, but might be different without incentives	if load drops below 80%, VFDs. Otherwise, load/no load. Incentivizing VFDs is	Each compessor has a control with up to 5 different types. Most common is dual control	L/NL 50%, and VFD 50%. A good sales person should be able to convince a site to go	In MA, predominant control is VFD >25hp, but without program, thinks that a higher % of

Question Number	1	2	3	4	5	6	7	8	9	10
	small between control types.	Modulation is not typical.	Modulating not typical.				encouraging their use even in 100% load systems.	(stop/idle/full load) (*note: we interpret this as L/NL)* and variable control also offered.	VFD. Modulation and Variable Displacement are both available options but nobody is buying them.	fixed speed machines would be there. Modulation is on the way out.
	VFD and L/NL were listed as the most common by all vendors. Vendors with a high % (90%+) of incentive participation were more likely to have VFDs as the most common. ISP determination was L/NL.									
4.1.4	Air-cooled	Air-cooled	Air-cooled	n.d.	Air-cooled	95% air cooled	Air cooled	Air cooled	Air cooled	Air cooled
	Air-cooled dominates the market (most said 95%+)									
4.1.5.1	4-5 gal/cfm	2 gal/cfm	5 gal/cfm	2 gal/cfm	5 gal/cfm	n.d.	3-5 gal/cfm	5 gal/cfm	4 gal/cfm	7.5 gal/cfm
	L/NL projects typically requre 4-5 gal/cfm of storage.									
4.1.5.2	4-5 gal/cfm	2 gal/cfm	2 gal/cfm	2 gal/cfm	3-5 gal/cfm	n.d.	n.d.	5 gal/cfm	2 gal/cfm	3 gal/cfm
	VFD projects typically require 2-3 gal/cfm of storage.									
4.1.5.3	0.5-1 gal/cfm	0.5-1 gal.cfm	0.5-1 gal/cfm	1 gal/cfm	75% less than optimal	n.d.	n.d.	n.d.	n.d.	1 gal/cfm
	Most common storage actually implemented on site is 1 gal/cfm. Several interviewees suggested that this was inadequate for appropriate operation.									
4.2.1	Pharma, food, semiconductor, painting go oil-free	n.d.	Food, pharma, high tech	n.d.	Medical, nanoproduction	Pharma	10% of projects oil free	Food, pharma, electronics	10% water cooled, 20% 2 stage, 10% oil-free (food, pharma, electronics)	25% oil free, 5% water cooled
	Oil-free compressor equipment is required in the food, pharma, and electronics industries.									
4.2.2.1	<100hp is VFD	<20hp mix of recips and screw units with on-board controls	<25hp is recip or screw	VCC >50hp	<10hp recip	n.d.	n.d.	screws 5 to 500hp	recip <15hp	<5hp is 50% recip
	Most interviewees install primarily screw units, with a larger share (about 50%) of reciprocating units for small systems (<15hp).									
4.2.2.2	n.d.	>350hp centrifugal	>200hp centrifugal	n.d.	>250hp centrifugal	n.d.	>350 centrifugal	>800hp centrifugal	>400hp centrifugal	>400hp centrifugal
	Interviewees varied on cutoff (median was 350hp) but centrifugal units are specified for large systems.									
4.2.3	For larger systems, multiple staging with several trim units	n.d.	90% of systems are single compressor systems	n.d.	n.d.	n.d.	n.d.	Food, pharma, electronics	n.d.	n.d.

Question Number	1	2	3	4	5	6	7	8	9	10
	Suggestion that single-compressor systems are most common, with larger systems having multiple staging and potentially multiple trim units to ensure optimal efficiency.									
4.3	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	Mostly unit replacement	NC systems are more efficient; retrofit or ROF usually asks for a 1:1 replacement	Retrofit and ROF generally use the same. NC tries to have more efficient controls and staging	No difference
	ROF and Retrofit projects are considered the same, with 1:1 replacements being most common. NC projects are typically much more efficient and involve a complete redesign of the air system to improve operating efficiency.									
5.1.1	Refrigerated	Refrigerated	Refrigerated	Refrigerated	Refrigerated	Refrigerated	Refrigeraed	Refrigerated	Refrigerated	Refrigerated
	Refrigerated dryers dominate the market.									
5.1.2	<1000 cfm non-cycling, >1000cfm cycling	Cycling most common, non-cycling only on lowest-bid jobs.	Cycling is 90% of the projects	non-cycling	non-cycling	Cycling	Cycling; generally specify an oversized dryer and use cycling.	Cycling makes the most sense for most; incentives sometimes awarded even when running at 100% load	Cycling is most common; a few VFDs are out there but rare	More non-cycling sold than cycling, but definitely dictated by the incentive program.
	3 interviewees suggested that non-cycling dryers were most common. 6 suggested that cycling dryers were most common. 1 provided a cutoff of 1000cfm between non-cycling and cycling units being most common. Suggestion that ISP is non-cycling.									
5.2.1	n.d.	n.d.	n.d.	dewpoint<38F goes to desiccant	pharma, microprocessor, power production	None	Dewpoint below 40F	Outdoor units use desiccant	Non-cycling is 50% of market in non-incentivized areas; exterior air lines, med, pharma use desiccant	Many are cycling, and outdoor piping or high purity industries go desiccant
	Low dewpoint industries like pharma and those with exterior plumbing default to desiccant units.									
5.2.2	Very little NC air compressors in MA. Existing plants use same as previous footprint	Usually 1:1 replacement with previous equipment type	n.d.	Pharma and semiconductors use desiccant	Perceived requirements for dewpoint	Use existing equipment as much as possible	n.d.	n.d.	Replace dryer system completely	Typically just replacement of existing unit 1:1
	For dryers, typical Retrofit and ROF practice is a 1:1 replacement with pre-existing equipment.									

Question Number	1	2	3	4	5	6	7	8	9	10
6.1.1	Yes	Yes	n.d.	n.d.	No	No	Yes	No	Yes	Yes
	Half of interviewees expected some market changes in the next 5 years.									
6.1.2	Fewer distributors, more uniformity in equipment efficiencies	Expect more oil-free compressors from IR in 2019	n.d.	n.d.	n.d.	n.d.	Maybe magnetic bearings on centrifugal units, plastic rotors on screw units	n.d.	Fewer distributors	Expect more oil free in food and beverage companies
	No major technology changes are expected, but some increase in oil-free compressors may arise.									
6.2	No differences	n.d.	No differences	n.d.	Cost sensitivity	Application dependency	Industry dependent	No differences	No differences	No differences
	No variations exist across MA, other than those associated with concentrations of different industries.									
6.3	More L/NL and VD compressors in cheaper areas	More fixed speed compressors in areas with lower utility rates	n.d.	n.d.	Cold weather states have higher % desiccant dryers	No differences	No differences	No differences	No differences	Slightly more efficient practices in new england
	No consistent differences were noted between MA and other markets, though areas with lower utility rates were considered slightly less likely to have VFD installations.									
6.4.1	Not aware	Not aware	Aware	Not aware	Aware	Not aware	Not aware	Aware	Aware	Aware
	Half of interviewees were aware of the DOE efficiency standards, with manufacturers being the most likely to be aware.									
6.4.2	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	Yes	Yes	Yes
	Manufactuers are making changes to meet the new standards.									
6.4.3	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	Most	n.d.	Most
	Most manufacturers believed that their lineup is already mostly compliant									
6.4.4	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	No	No	No
	No difference in rotary vs. non-rotary sales is expected.									
6.4.5	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	No	No	Maybe
	No difference in fixed vs. variable speed sales is expected.									
6.4.6	n.d.	n.d.	n.d.	No, but would like other incentive types	n.d.	n.d.	n.d.	Yes, but would prefer audit incentives	n.d.	Yes
	Several respondents requested incentives on systematic compressed air improvements, like for compressed air audits and for increased storage. This was noted in the context of a perception that compressors are not getting much more efficient and VFDs are standard enough practice that they are even being installed in some places where they are not appropriate.									
7.1	No	Yes	n.d.	No	No	No	No	No	in MA, market is $40-50 million. Estimate 1000 projects/year in MA, 70%	Estimating 50-60% variable drive

Question Number	1	2	3	4	5	6	7	8	9	10
									going through programs	
	None were willing to provide specific sales data, though several referred us to a CAGI dataset that is not available to non-members.									
7.2	Provided	n.d.	Provided	n.d.	n.d.	Provided	n.d.	n.d.	n.d.	n.d.