STRATUS CONSULTING

Analysis of Equipment and Practices in the Reclamation Industry

Draft Report

Prepared for:

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Contents

Tables

1. Introduction

Section 608 of the Clean Air Act Amendments (CAAA) of 1990, the National Recycling and Emissions Reduction Program, requires the U.S. Environmental Protection Agency (EPA or the Agency) to establish regulations to reduce emissions of ozone-depleting substances (ODS). These regulations maximize the recycling of ODS, including chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), and their blends. Code of Federal Regulation (CFR) Title 40, Part 82, Subpart F, details the rules and regulations implementing Section 608 of the CAAA.

Under these regulations, no person may sell, distribute, or offer for sale or distribution for use as a refrigerant any Class I (i.e., CFCs) or Class II (i.e., HCFCs) substance consisting wholly or in part of used refrigerant, unless the refrigerant has been reclaimed.[1] Refrigerant reclamation refers to the reprocessing and upgrading of recovered refrigerant through such mechanisms as filtering, drying, distillation, and chemical treatment in order to restore the substance to specifications outlined in the Air-Conditioning, Heating, and Refrigeration Institute's (AHRI) Standard 700-1995 (CFR, 2010).

Companies that intend to reclaim refrigerants must be certified by EPA. As of October 2010, there were 54 EPA-certified reclaimers. To become EPA certified, the reclaimers must provide the following, among other items:

- Information on the equipment used to reprocess the refrigerant[2]
- Information on the equipment used to analyze the refrigerant
- Certification that the refrigerant will be reprocessed to the specifications set forth in AHRI Standard 700 and that the specifications will be verified using methods outlined in that standard
- Certification that no more than 1.5% of the refrigerant handled will be released during the reclamation process
- Acknowledgment that reclaimers must maintain and annually report records of the entities sending them refrigerant for reclamation, as well as the quantity of the refrigerant received, the quantity ultimately reclaimed, and the mass of waste products.

1. This does not apply to used refrigerant originating from and intended for use with motor vehicle air conditioners.

2. If the equipment is purchased off-the-shelf, reclaimers are required to provide information on the make, model, and serial number of the equipment. Otherwise, reclaimers must provide a description and photographs of the equipment and processes used.

In 2008, the most recent year for which data are available, approximately 12.6 million pounds of refrigerant were reclaimed, including 10.0 million pounds of HCFC-22 (R-22), the most common refrigerant used in the industry (U.S. EPA, 2009c). In 2010, the year of a significant phase-down step for HCFC production, EPA estimated that 20% of R-22 servicing demand in the United States can be met using recovered (including reclaimed and recycled)[3] refrigerant. The amount of R-22 reclaimed in 2008 would represent only 7.3% of demand for that refrigerant in 2010. Adding the amount of recycled refrigerant to the refrigerant that is reclaimed will increase this percentage, but it is believed that the total current amount of recovered refrigerant will still be less than 20% (U.S. EPA, 2009b).

1.1 Concern about Quality of Reclaimed Refrigerant

To be properly reclaimed, refrigerant must be restored to the specifications outlined in AHRI Standard 700. This standard includes specifications for the maximum allowable levels of certain contaminants. As an example, Table 1 presents the maximum allowable levels of contaminants for R-22, the most commonly reclaimed refrigerant, as specified in AHRI Standard 700.

Table 1. Maximum allowable contaminant levels for R-22

Contaminant	Reporting unit	AHRI Standard 700 section	Maximum allowable level
Vapor phase contaminants			
Air and other noncondensable	% by volume at 23.9°C	5.10	1.5
Liquid phase contaminants			
Water/moisture	ppm by weight	5.4	10
All other volatile impurities (including other refrigerants)	% by weight	5.11	0.5
High boiling residue	% by volume	5.8	0.01
Particulates/solids	Visually clean to pass	5.9	Pass
Acidity	ppm by weight (as HCl)	5.7	1.0
Chloride	No visible turbidity	5.6	Pass

Source: AHRI, 1995.

3. Recycled refrigerant may be reused in the same owner's equipment without having to be reclaimed, so long as the refrigerant does not change ownership (40 CFR 82 Subpart F).

At present, there are no federally mandated standards that specify reclamation equipment and operational criteria to ensure safe practice and minimal releases of refrigerant to the atmosphere. In addition, the large volume of refrigerant that is reclaimed each year makes it difficult to verify that all reclaimed refrigerant has been returned to the specifications outlined in AHRI Standard 700. This challenge will become increasingly important as the United States continues to phase out HCFC production, which is expected to increase demand for reclaimed refrigerant.

In the past, EPA proposed establishing a mandatory third-party certification program where an independent laboratory would verify that reclaimed refrigerant has been returned to AHRI Standard 700 specifications. However, despite the fact that many reclaimers seek independent testing on their own, there is no mandatory third-party certification program at this time.

1.2 Purpose and Outline of Study

This study is intended to improve understanding of the technical aspects of reclamation equipment and practices, how they relate to the quality of reclaimed refrigerant, and the potential for environmental impacts. This study includes analyses of the following:

- Current reclamation technologies and practices (Section 2)
- Potential environmental impacts of reclamation (Section 3)
- Best practices for reclamation (Section 4)
- Approaches to ensuring best practices for reclamation (Section 5).

Section 6 provides a summary of findings and conclusions.

1.3 Information Collection Methodology

To complete this study, information on reclamation technologies and practices was collected using three approaches.

1.3.1 Industry input solicitation

Much of the information provided in this study is based on conversations with individuals affiliated with the reclamation industry.[4]

4. Although respondents were asked to answer a wide range of questions on reclamation topics, no single question was asked to more than nine respondents.

- **Reclaimers.** Reclaimers were contacted to obtain information on current reclamation technologies and practices, best practices for reducing potential emissions, and potential options for reducing refrigerant emissions and to maximize the amount of refrigerant that reenters the market.

- **Industry trade association representatives.** A representative of a major refrigeration and air-conditioning trade association was contacted for information pertaining to the implementation of a potential mandatory third-party certification program for reclaimed refrigerant.

- **Laboratory representatives.** A representative from a major refrigerant testing laboratory was contacted for information pertaining to how frequently and through what processes reclaimers have their products independently tested.

- **Refrigeration and air-conditioning system experts.** Experts from multiple refrigeration and air-conditioning system manufacturing companies were contacted regarding the environmental implications of charging systems with refrigerant that has not been properly or completely reclaimed.

Individuals contacted for this study are identified in Table 2.

Table 2. Individuals contacted for present study

Name	Company/organization
Reclaimers	
David Andrew	Perfect Cycle
Ted Atwood	Polar Technologies
Ken Beringer	Airgas
Tim Dean	Environment First
Rich Dykstra	Consolidated Refrigerant Reclaim
Michael Gerhart	Chill-Tek
Carl Grolle	Golden Refrigerant
Steve Mandracchia	Hudson Technologies
Aubry McCarley	Turner and Schoel
Jim Sweetman	Consolidated Refrigerant Solutions
Steve Trevino	Summit Refrigerants
Jimmy Trout	AllCool
Jeff Zirkle	Total Reclaim
Industry organizations	
Karim Amrane	AHRI

Table 2. Individuals contacted for present study (cont.)

Name	Company/organization
Refrigerant testing laboratories	
John Senediak	InterTek
Air-conditioning and refrigeration equipment manufacturers	
Ken Hickman	Johnson Controls (formerly with York)
Fred Keller	Carrier Residential (formerly)
Jeff Staub	Danfoss
William Walter	Carrier Residential

1.3.2 Patent search

A thorough review of U.S. and international patents was conducted to identify existing reclamation technologies and equipment. The U.S. Patent and Trademark Office was consulted. This information contributes to a general understanding of current reclamation technology commercialization and research.

1.3.3 Literature review

In general, there is little published information available pertaining to the reclamation industry's technologies and practices. However, several resources were essential to this study. These included:

- Materials available in dockets from past EPA regulatory development
- AHRI standards (e.g., AHRI Standard 700) and program operational manuals (e.g., AHRI Reclaimed Refrigerants Certification Program Operational Manual)
- Industry news (e.g., *Air Conditioning, Heating, and Refrigeration News*).

1.4 Overview of Results

This study produced several key findings, including the following:

- The reclamation industry is very diverse – there is no "typical" reclaimer. There are considerable differences between the larger and smaller reclaimers, including differences in the technologies used and the sophistication of the operations. This is evidenced by the many differences present in the patents identified in this study. In addition, reclamation systems have a variety of advantages and disadvantages, and the type of system used will depend on the reclaimer's needs.

- Each reclaimer contacted for this study stated that they use the best practices known to them. However, reclaimers were generally unable to articulate specific best practices that EPA should support. The few reclaimers that did identify specific best practices focused more on operations and maintenance, and less on technologies.

- As noted by most reclaimers, the primary reason why releases might occur would be human error during refrigerant handling. However, releases from air-conditioning and refrigeration systems due to contaminated refrigerant are possible, but it is difficult to determine whether such releases occur as a result of poor reclamation practices.

- Nearly every reclaimer contacted for this study emphasized the importance of reaching out to technicians as the most expedient means of increasing the amount of refrigerant that is reclaimed and reducing emissions (e.g., from illegal venting). In general, reclaimers did not believe that outreach to the reclamation industry about best practices would lead to significant additional benefits.

- Reclaimers are supportive of increased reporting requirements but believe that the benefits of such requirements would be minimal unless complemented by additional reporting requirements for technicians. Reclaimers believe that there would be significant benefits to requiring reporting that establishes a complete information chain (i.e., from technician to wholesaler to reclaimer) that describes how much refrigerant is being recovered and what its fate is.

- Reclaimers are supportive of mandatory third-party testing but are concerned about the costs of participation. Nearly every reclaimer contacted for this study sends samples of their product to be tested by independent laboratories. The AHRI Third-Party Certification program could be a useful model for a mandatory program, but many reclaimers have concerns about how the voluntary program is managed and the costs, as evidenced by the current low participation rate.

- Requiring that off-the-shelf equipment meet specific technological standards will only lead to minimal emissions reductions, considering the very small market for such equipment and the assumed effectiveness of the typical custom-made equipment used by reclaimers today.

2. Evaluation of Current Reclamation Technologies and Practices

This section provides an overview of the technologies and practices used by reclaimers, beginning with their receipt of recovered refrigerant and ending with their packaging of the reclaimed product for resale.

2.1 Sources of Recovered Refrigerant for Reclamation

The containers of recovered refrigerant that reclaimers receive are of variable size and condition. The contents of the cylinders can cover a range of refrigerants that, despite the containers' labeling, are typically assumed to be unknown because of the potential for cross-contamination.

The refrigerant comes from numerous sources. Most often, it comes to reclaimers indirectly from wholesalers who accept cylinders as a service to technicians. Less frequently, the refrigerant comes directly from technicians who drop it off at the reclaimers' facilities. In some instances, reclaimers will travel to work sites to recover the refrigerant themselves as a service to technicians. One reclaimer said his company gets most of its refrigerant by traveling to technicians' sites and doing pick-ups (Rich Dykstra, Consolidated Refrigerant Reclaim, personal communication, June 17, 2010).

According to some reclaimers, the amount of refrigerant that comes directly from technicians is increasing as the value of R-22 increases because technicians can get a better price from the reclaimers than from the wholesalers, who typically charge the technicians a disposal fee (which usually ranges between $20 and $75 per 30-lb cylinder; David Andrew, Perfect Cycle, personal communication, June 9, 2010; Steve Trevino, Summit Refrigerants, personal communication, June 22, 2010). One reclaimer noted concern that many wholesalers are "double-charging"; reclaimers have to purchase recovered refrigerant from the wholesalers and the wholesalers do not pass the money through to the technicians, who pay the wholesaler a disposal fee (Steve Mandracchia, Hudson Technologies, personal communication, June 9, 2010). Another reclaimer noted that with future increases in the price of R-22, it is reasonable to believe that wholesalers will begin to offer financial incentives to the technicians (TAP, 2010; Steve Trevino, Summit Refrigerants, personal communication, June 22, 2010).

In general, technicians who recover the refrigerant from refrigeration and air-conditioning systems are servicing multiple systems each day. The refrigerant recovered from each system can be exposed to a range of contaminants. In addition, refrigerant recovered from different systems can be of differing types [e.g., HFC-410A (R-410A) versus R-22]. Although most technicians will recover different types of refrigerant using different recovery cylinders, there is the potential for cross-contamination (e.g., using the same cylinder to service systems using different refrigerants or using the same hoses to hook up different cylinders). As a result, the refrigerant that arrives at the reclaimers' facilities typically has some degree of contamination or mixed refrigerant.

Only a very small portion of the recovered refrigerant that reclaimers receive originally comes from landfills or scrap yards. According to one reclaimer, it is not cost effective for reclaimers or technicians to spend time recovering very small quantities of refrigerant from small appliances at these locations (Ken Beringer, Airgas, personal communication, June 8, 2010). However, for one reclaimer, demolition of discarded air-conditioning and refrigeration equipment accounts for as much as 90% of the refrigerant that his company ultimately reclaims (Jeff Zirkle, Total Reclaim, personal communication, June 15, 2010).

One reclaimer explained that his company gets its refrigerant solely from refrigerant manufacturers. This refrigerant is usually from quality-control samples and trial runs or from production line manufacturing malfunctions. The manufacturers cannot sell this refrigerant directly, so they sell it to reclaimers (Tim Dean, Environment First, personal communication, June 16, 2010).

Many reclaimers have established incentive programs to encourage technicians and wholesalers to turn in recovered R-22 [for descriptions of these programs, see Stratus Consulting (2008) and Powell (2008)].

2.2 Refrigerant Preparation Practices

This section describes several steps that reclaimers take to prepare refrigerant for reclamation.

2.2.1 Weighing and evaluating contents of cylinder

The reclaimers' first tasks are to weigh the cylinder (to determine the volume of refrigerant inside) and to determine the contents of each cylinder they receive. In general, all reclaimers use a hand-held gas analyzer (e.g., a Neutronics tester) to determine the contents of refrigerant containers. If the contents of a specific container (e.g., a 30-lb cylinder) appear to be well-mixed, the reclaimer might decide to use a more sophisticated gas chromatographer to establish a more detailed understanding of the container's contents. In general, reclaimers believe that gas analyzers are reliable, especially the newer models. In addition, although gas chromatography can produce more detailed analysis, it is more time intensive and most reclaimers prefer to use gas analyzers when possible. According to one reclaimer, running the gas chromatographer on a cylinder takes as long as 30 minutes (this can be as short as 10 to 20 minutes for new models; Jimmy Trout, AllCool, personal communication, June 24, 2010).[5]

2.2.2 Recording information on cylinders and contents

Once the contents of a cylinder have been determined and the cylinder has been weighed, the information is typically entered into a computer database along with various transactional information, including the date, the name of the technician or wholesaler (or other source) from which the refrigerant came, and the cylinder identification number. Some reclaimers also include notes about the condition of the cylinder or notes describing concerns about unclear gas analyzers or chromatography readings. According to one reclaimer, entering this data typically requires approximately 3 minutes per 30-lb cylinder (Jimmy Trout, AllCool, personal communication, June 24, 2010).

Reclaimers often maintain these records as a service to the technicians and wholesalers with whom they work, as many technicians maintain refrigerant recovery/servicing records for facility owners and managers who are obligated to keep records by regulation. One reclaimer commented that the wholesaler from whom he receives all of his recovered refrigerant requires the reclaimer to maintain detailed records of every cylinder, as a service to the wholesaler’s technicians. The result, in many reclaimers’ practices, is a trail of information that can link a reclaimer to a specific technician and often to a specific job site if the technician also maintains accurate records.

2.2.3 Sending refrigerant off-site

After reclaimers determine the contents of the containers received, they often have to send some of the containers to other facilities if the refrigerant is a type that their systems cannot handle. For example, most off-the-shelf reclamation systems are designed to handle high-pressure refrigerants, so reclaimers with these systems typically send quantities of low-pressure refrigerant off-site to be handled elsewhere (David Andrew, Perfect Cycle, personal communication, June 9, 2010).

5. One reclaimer noted that refrigerant identification is an area where technology research and development is needed to reduce the amount of time it takes to complete detailed analysis of container contents. Faster, more accurate refrigerant analyses could save reclaimers a lot of time and energy consumption (e.g., if the analyses better enable them to plan batches; TAP, 2010).

2.2.4 Combining quantities of refrigerant to reach batch purity thresholds

Reclaimers will use the information in their databases to conceptually mix-and-match quantities of refrigerant from different cylinders to produce bulk batches that meet or exceed a given overall purity level. The objective of this exercise is to create combinations that will utilize the maximum amount of the recovered refrigerant while minimizing the energy that will be required to bring each batch back to the required purity level of 99.5%. Below a certain level of purity, multiple or abnormally long runs through the reclamation equipment might be necessary. Reclaimers typically have a batch target purity level in mind when designing these combinations. This target level might be determined by the amount of time a reclaimer has to run a batch (more time is required for batches of lower initial purity levels) or by the efficiency of the reclamation equipment. For many reclaimers, the target is approximately 98%, meaning that any combination resulting in an initial batch purity level less than 98% is probably not economical.

After planning out refrigerant combinations, reclaimers combine refrigerant from multiple cylinders into one batch. The size of the batch varies depending on the capacity of the equipment the reclaimer is using. Most off-the-shelf reclamation systems hold less than 100 pounds of refrigerant at a given time (e.g., the Van Steenberg JV-90 holds 90 pounds; Van Steenberg, 2010). Reclaimers who have designed their own systems, often for the purpose of being able to reclaim a significantly larger quantity of refrigerant, are typically capable of running batches of 10,000 to 20,000 pounds (Rich Dykstra, Consolidated Refrigerant Reclaim, personal communication, June 17, 2010; Steve Trevino, Summit Refrigerants, personal communication, June 22, 2010).

One reclaimer explained how one barrier to getting more reclaimed refrigerant back onto the market is the protection of patents for certain refrigerant blends. Many chemical manufacturers have patents on the blends they produce, and reclaimers are prevented from combining quantities of refrigerant to restore the purity to the correct specifications of that blend. For example, the reclaimer noted that it is impossible for reclaimers to combine quantities of R-410A to increase the overall purity level back to specification because doing so would be a violation of patents for that refrigerant (Carl Grolle, Golden Refrigerant, personal communication, June 10, 2010).

2.3 Blending

Some larger reclaimers are able to purchase virgin refrigerant, which can be combined with mixed refrigerant to increase the purity. For these reclaimers, “blending” can be a more cost-effective option than the more energy-intensive process of passing recovered refrigerant through a fractional distillation column or destroying the refrigerant (U.S. EPA, 2009a). Blending also requires much less energy than separation or destruction. According to one estimate, separation requires as much as 300 times more energy per pound to process refrigerant than blending

(Mandracchia, 2009). One reclaimer noted that if his company were able to blend, they would not have to send mixed gas of purities between 96% and 98% to another company to be separated (Rich Dykstra, Consolidated Refrigerant Reclaim, personal communication, June 17, 2010).

There is concern that blending refrigerant back to the requisite purity levels could result in lower-quality refrigerant than is possible with the more rigorous reclamation process. However, according to at least one reclaimer whose company does blend, blending is never considered a substitute for the reclamation process. Blended refrigerant is always run through the reclamation system to remove other potential contaminants. For this reason, the reclaimed refrigerant that is a combination of recovered and virgin refrigerant cannot be distinguished on the resale end from reclaimed refrigerant that comes solely from recovered refrigerant (Ken Beringer, Airgas, personal communication, June 8, 2010). Other reclaimers corroborate the assertion that reclaimed refrigerant that has been blended cannot be distinguished from other reclaimed refrigerant (e.g., TAP, 2010; Steve Mandracchia, Hudson Technologies, personal communication, June 9, 2010; Jimmy Trout, AllCool, personal communication, June 24, 2010).

Most of the reclaimers contacted for this study do not blend pure refrigerant into recovered refrigerant to meet specifications. Most claim that the price of pure refrigerant is prohibitive and will become more cost prohibitive in the future as the price of virgin R-22 increases (Ken Beringer, Airgas, personal communication, June 8, 2010). Some are not aware that this is practiced in the field but suspect that only the half-dozen largest reclaimers blend with pure refrigerant (Rich Dykstra, Consolidated Refrigerant Reclaim, personal communication, June 17, 2010).

2.4 Reclamation Processes

To be restored to AHRI Standard 700 specifications, refrigerant must pass through a number of different processes. The processes that are used depend on several factors, including type of refrigerant, quality of refrigerant, potential contaminants, size of the batch, and other considerations. These factors are a function of the reclaimers’ business operations (e.g., reclaimers that only process small batches of almost pure R-22 might use different processes than a large reclaimer that processes large batches of refrigerant with a higher proportion of mixed gas). This section describes the types of processes used to reclaim refrigerant.

2.4.1 Typical reclamation processes

To better understand the universe of technologies available, a review of U.S. patents for reclamation systems was conducted through the U.S. Patent and Trademark Office Web Patent Databases. The review revealed that there are 49 patents for refrigerant reclamation systems (the specific patents are listed in the appendix). These systems typically fall under three types of classification, depending on the primary technologies used to separate the desired refrigerant.[6] These primary separation technologies are described below.

Distillation

Simple distillation, which is sufficient for separating component parts with boiling points that are different by a significant degree (roughly 25°C), can be used to remove nonrefrigerant contaminants (e.g., oil, moisture, noncondensables) by evaporating components and then condensing them in separation. Distillation is the most common primary separation method for reclamation systems; this is probably due to the fact that it is a well-established technology in the refrigeration industry. Of the 49 patents identified in this study, 28 were for distillation systems. Based on information provided by reclaimers, nearly all of the systems in use today rely on distillation as the primary separation method.

Based on the patent review, there are two types of distillation-based reclamation systems:

- *Distillation using a compressor*. The majority of reclamation system patents were for distillation systems that use a compressor between the evaporation and condensation stages, although there was a significant amount of variability between these systems (e.g., in terms of application, some systems are intended for use with motor vehicles only). The compressor is used to increase the pressure of the refrigerant in order to use ambient air as a heat-exchange medium to condensate the refrigerant.

  The presence of oil is a concern with these types of systems. Because current compressors still require oil, it is inevitable that these reclamation systems will discharge some amount of oil into the distilled refrigerant. It is typical for these systems to discharge 0.5% to 1% of oil by mass with the refrigerant (TAP, 2010). Because AHRI Standard 700 requires that less than 0.01% oil by volume be present in reclaimed refrigerant, oil has to be removed with a dedicated separation technology after the distillation process. In addition, these systems typically have a larger number of components, meaning additional joints, each of which could be a potential leak source. However, the prevalence of leaks from such systems could not be determined from the patent review or through industry expert elicitation (TAP, 2010).

6. It is important to note that most reclaimers do not purchase the types of complete systems described in this section; as noted above, it is believed that most reclaimers build or modify their own reclamation systems.

- *Distillation without using a compressor.* Some distillation-based separation systems do not use a compressor between the evaporation and condensation phases. Elimination of the compressor can reduce the amount of energy required in the separation process and also eliminate the concern of oil in discharged refrigerant. In terms of refrigerant purification, this setup can be used to achieve the same purities as a distillation system that uses a compressor. However, with this arrangement, the reclaiming process rate could be limited in terms of processing, since the driving force is the pressure gradient within the system.

Adsorption/desorption

Adsorption/desorption separation systems rely on adsorbent beds to separate a refrigerant from other components. These systems can be operated in semicontinuous mode or in batch mode (with chambers in series or parallel form). In a typical system, contaminated refrigerant enters an initial adsorption chamber where the refrigerant is adsorbed to an adsorbent bed; impurities are not adsorbed in this chamber and continue to a second chamber, from which they are discharged. After the impurities have been isolated, the refrigerant can be desorbed from the adsorption bed by activating it with heat, after which it can be collected from the system.

The main advantage of this technology is that the pure refrigerant can be extracted from the contaminated refrigerant mixture without using numerous devices. It is a simple system that requires only pumping and desorbing energy. However, one major drawback is that the adsorbent refrigerant is designed to work for one specific refrigerant and usually its adsorbing capacity diminishes over time. Therefore, these systems are typically not flexible in terms of reclaiming different refrigerants (TAP, 2010). The adsorption/desorption system can only perform in a quasi-continuous mode. Once the adsorption chamber reaches its capacity to adsorb refrigerant, controls need to initiate the necessary changes to desorb the chamber. If there are plenty of chambers and the controls are sophisticated, the system can work in quasi-continuous manner. However, in terms of scalability and throughput, it is entirely dependent on the adsorbent refrigerant's reaction time.

Based on information provided by reclaimers, it is unlikely that many (if any) reclaimers use systems that rely on this technology.

Cryogenic subcooling

In a cryogenic subcooling system, dirty refrigerant is cooled in three stages to a temperature of -100°F. The refrigerant is then sent through cryogenic filtration with coalescent filters. These filters remove 100% of particles larger than 0.1 micron and 93% of particles smaller than 0.1 micron. In the last step, a microprocessor-controlled purge device releases noncondensables (TAP, 2010).

There are three advantages of this technology. First, this purification system can be used with any refrigerant. Second, the purity of the recovered refrigerant is not significant, unlike most distillation processes for which it is necessary to have a minimum concentration of refrigerant before the refrigerant enters the reclamation process. The third advantage is the operating pressure. Due to the extreme cold temperature of the refrigerant after cooling, the pressure is much less than in a typical distillation separation system; this presents a much smaller risk of leakage through faulty joints during the separation process. However, the energy required to cool the liquid to -100°F can be significant; this is likely a key reason why this technology is not common in the industry (TAP, 2010).

It is possible to account for the energy penalty associated with cryogenic subcooling compared to simple distillation. The estimated energy needed to process two types of refrigerant using these types of separation is presented in Table 3. As the table indicates, the amount of energy [in British Thermal Units (BTUs) per pound] is roughly three times greater for both refrigerant types in cryogenic separation systems. It is important to note that this is a first-order analysis that only accounts for the energy directly used for the refrigerant without impurities and without consideration of heat loss and/or gain and other system components.

Table 3. Comparison of energy demand per pound to process refrigerant in cryogenic separation and simple distillation systems

Refrigerant	Latent heat at 25°C kJ/kg	Sensible heat at 0°C to -75°C kJ/kg	Coefficient of performance	Overall energy required in kJ/kg (BTU/lb)
Simple distillation (condenser independent)				
R-22	187.2	Not applicable	3	62.4 (26.9)
R-410A	181.7	Not applicable	3	60 (25.9)
Cryogenic subcooling				
R-22	Not applicable	83.1	0.5	166.2 (71.6)
R-410A	Not applicable	105.1	0.5	210.2 (90.6)
Source: TAP, 2010.				

Based on information provided by reclaimers, the energy demands and overall costs associated with this technology make it very unlikely that many reclaimers would use cryogenic separation. However, at least one reclaimer does use this technology.

Other separation processes

The distillation, cryogenic subcooling, and adsorption/desorption methods described above are used to remove impurities (including other refrigerants) from the batch, such as those that might be introduced through mixing or as a result of chemical breakdown of the refrigerant itself (e.g., if moisture causes morphing). To reclaim refrigerant to all AHRI Standard 700 specifications, a number of secondary technologies must also be used. These technologies include desiccant driers for moisture and acid, high-efficiency purge systems for noncondensables, and micron filters for other particulates (TAP, 2010). Table 4 provides a general breakdown of the types of processes used to address the different specifications prescribed in AHRI Standard 700.

Table 4. Typical processes used to address AHRI Standard 700 specifications

Specification	Process used
Vapor phase contaminants	
Air and other noncondensables	High-efficiency cascade (refrigerated) purge units
Liquid phase contaminants	
Water/moisture	Distillation followed by desiccant drier
All other volatile impurities (including other refrigerants)	Prereclamation blending and mixed-gas separation (described in Section 2.5)
High boiling residue	Distillation
Particulates/solids	Multiple 1-micrometer filters
Acidity	Base bath followed by desiccant drier
Chloride	Distillation

2.4.2 "Off-the-shelf" compared to custom-designed systems

Primary and secondary separation technologies are combined in comprehensive reclamation systems. For example, a reclamation system that involves distillation with a compressor will incorporate an oil separation process to remove the oil that is discharged from the distillation equipment. Several of the patents reviewed for this study were for comprehensive reclamation systems that combined the primary and secondary separation technologies.

Reclamation system characteristics

The types and combinations of technologies used have implications for the following reclamation system characteristics:

- Speed of system
- Capacity
- Energy and water efficiency
- Type of refrigerant that can be reclaimed (e.g., high-pressure or low-pressure refrigerants)
- Ability to operate in continuous mode
- Minimum initial impurity level.

At present, there are a number of small-sized reclamation equipment models that can be purchased off-the-shelf. Although these systems are limited in terms of capacity and speed (reclamation rates vary from 2 to 5 lb per minute for the smaller off-the-shelf models), they are favored by reclaimers who process smaller quantities of refrigerant and by reclaimers who are just recently entering the market (David Andrew, Perfect Cycle, personal communication, June 9, 2010). One reclaimer, for example, explained that his company only runs its reclamation system once a week. For this off-the-shelf system, which holds approximately 90 lb of refrigerant at a time, it takes approximately 20 minutes to process the refrigerant (Aubry McCarley, Turner and Schoel, personal communication, June 11, 2010). According to one reclaimer, a used commercial reclamation system can be purchased for as little as a few hundred dollars (TAP, 2010).

Reclaimers who handle larger quantities of refrigerant or who require faster reclamation speeds will typically design their own systems in-house or substantially modify commercially purchased systems to meet their needs (Rich Dykstra, Consolidated Refrigerant Reclaim, personal communication, June 17, 2010). These systems are much more expensive. According to one medium-sized reclaimer, the cost to the reclaimer of rebuilding a reclamation system (the distillation piece, to be precise) from scratch would be a few thousand dollars, but the cost to replace the company's entire reclamation operations would be at least $500,000 (TAP, 2010).

According to a manufacturer of off-the-shelf reclamation equipment, most reclaimers start off using off-the-shelf equipment because their operations are smaller. Usually after two years of business, the reclaimers graduate to a self-designed system that can handle larger quantities at higher rates (David Andrew, Perfect Cycle, personal communication, June 9, 2010). In addition, most reclaimers start off purchasing systems that can handle high-pressure refrigerants (e.g., R-22) and send any quantities of low-pressure refrigerants (several major CFCs) to larger reclaimers (David Andrew, Perfect Cycle, personal communication, June 9, 2010).

Estimates of the percentage breakdown of reclaimers using off-the-shelf and custom-designed reclamation systems vary (see Table 5). Based on input from several reclaimers, the percentage of systems that are custom designed typically ranges from 10% to 40% (TAP, 2010; Ken Beringer, Airgas, personal communication, June 8, 2010). However, one reclaimer estimated that nearly every system in use was either custom designed or substantially modified from an off-the-shelf model (TAP, 2010). Estimates of the percentage of systems that are purchased off-the-shelf and used without modification are typically very small, no more than 10% (TAP, 2010).

Table 5. Estimates of breakdown of types of reclamation systems

Type	Estimated percentage of all reclamation systems
Custom designed by reclaimer	10 to 40
Purchased off-the-shelf	Less than 10
Purchased off-the-shelf and modified	40 to 80

2.5 Mixed-gas Separation and Destruction

Simple distillation and separation technologies, such as those described in Section 2.4, are not sufficient (or not economical) to separate quantities of low-purity (below 98%) refrigerant. Such "mixed gas" is typically the result of technicians inadvertently using the same recovery cylinder to service equipment that contains different types of refrigerant (Steve Mandracchia, Hudson Technologies, personal communication, June 9, 2010; Carl Grolle, Golden Refrigerant, personal communication, June 10, 2010; Rich Dykstra, Consolidated Refrigerant Reclaim, personal communication, June 17, 2010). This section describes options for handling mixed gas.

2.5.1 Mixed-gas separation

Several processes can be used to separate mixed-gas; the most common is fractional distillation (Powell, 2009). However, few reclaimers have the resources to perform these complex processes, which can require as much as 50 times more energy per pound to process refrigerant than standard reclamation processes (Mandracchia, 2009). According to one reclaimer, there are only three or four facilities with separation capability at present (Steve Mandracchia, Hudson Technologies, personal communication, June 9, 2010). Most reclaimers will send mixed gas that is not easily blended up to 99.5% purity to these separation facilities.

One reclaimer explained that the cost of separation for a 75% purity R-22 is about $3 per pound (not including the shipping cost), which would be taken out of the price the separation facility paid for the refrigerant. At present, separation facilities will purchase R-22 even if the purity of the refrigerant is as low as 75% because of the current price of R-22 (Jimmy Trout, AllCool, personal communication, June 24, 2010).[7]

7. According to one reclaimer, the price for recovered R-22 is currently close to $2.00 per pound (Steve Trevino, Summit Refrigerants, personal communication, June 22, 2010).

One reclaimer estimated that 10% of the refrigerant his company receives is mixed gas that is sent away to be separated (Rich Dykstra, Consolidated Refrigerant Reclaim, personal communication, June 17, 2010). Another reclaimer estimated that the amount of mixed gas the company receives is between 10% and 15% (Carl Grolle, Golden Refrigerant, personal communication, June 10, 2010). The mixed-gas problem might become more common in the near future, according to some reclaimers (e.g., Ken Beringer, Airgas, personal communication, June 8, 2010; Jeff Zirkle, Total Reclaim, personal communication, June 15, 2010). This is because of the increasing phase out of R-22; as more R-22 is phased out, consumption of R-22 substitutes will continue to increase. As more substitutes are used in the field, there will be greater potential for cross-contamination.

2.5.2 Destruction

When reclaimers receive a quantity of mixed-gas refrigerant that contains a relatively high percentage of other refrigerants (typically refrigerant with purity levels of 70% or lower), separating the refrigerants through conventional methods can be cost prohibitive. In such instances, mixed-gas refrigerant is usually destroyed through incineration, which is an energy-intensive process. According to one reclaimer, less than 5% of all the refrigerant his company receives is sent away to be destroyed (Rich Dykstra, Consolidated Refrigerant Reclaim, personal communication, June 17, 2010). Another reclaimer stated that his company sends only minimal amounts of refrigerant to be destroyed each year (Jimmy Trout, AllCool, personal communication, June 24, 2010).

2.6 Post-reclamation Practices

Once the refrigerant has been reclaimed, samples are drawn and tested on-site (using the same equipment as is used to determine the contents of refrigerant containers when they are initially received) to verify that the process has returned the refrigerant to AHRI Standard 700 specifications. Each reclaimer contacted for this study stated that their company sends a sample of every bulk batch of reclaimed refrigerant to an independent laboratory (typically InterTek Laboratories) to verify its quality. This procedure helps to validate the reclaimers' own testing methods.

3. Potential Environmental Impacts of Reclamation

As described in Section 2, the processes involved in reclaiming refrigerants are complex and involve numerous technologies. At present, there are no required equipment specifications or operational criteria for these processes and technologies that would ensure they are safe and minimize releases of refrigerants to the atmosphere, both during the reclamation process and when the refrigerant re-enters the market.

This section identifies ways in which reclamation processes and use of reclaimed refrigerant could lead to adverse environmental impacts, particularly emissions of refrigerant to the atmosphere.

3.1 Potential Environmental Impacts During the Reclamation Process

Because existing reclamation systems are not currently required to meet equipment specifications or operational criteria, there is concern that these systems might be emitting refrigerant to the atmosphere during reclamation processes.

Reclaimers consistently stated that although it is possible that small amounts of refrigerant could be released to the atmosphere during reclamation, these releases would generally be minute. The reclaimers emphasized the fact that any possible large releases would only be caused by human accident and that these are rare. When asked whether the reclamation process results in releases nearing the 1.5% *de minimis* threshold allowable under EPA regulations, reclaimers consistently stated that losing that much refrigerant would be very unusual. For a reclaimer that reclaims 100,000 pounds of refrigerant for the year, a 1.5% loss would amount to 150 pounds of refrigerant that the reclaimer has purchased but will not be able to resell. For most reclaimers, such a loss would be significant in terms of its effect on profits.

The most likely source of refrigerant release during the reclamation process is when reclaimers hook up portable cylinders that contain the recovered refrigerant to the larger batch containers. Reclaimers noted that there is always the potential for unavoidable releases when hose fittings are attached to or removed from cylinder valves, but these releases are typically believed to be much less than 1.5%.

According to one reclaimer, releases during hose hookup typically amount to less than 0.25% of the refrigerant handled (Rich Dykstra, Consolidated Refrigerant Reclaim, personal communication, June 17, 2010). Based on this estimate and using EPA data on the amount of each refrigerant that is reclaimed each year (as reported by reclaimers), it is possible to approximate the maximum amount of refrigerant that is lost each year due to releases during hose hookup. According to EPA, approximately 12.6 million pounds of refrigerant were reclaimed in 2008, the most recent year for which data are available (U.S. EPA, 2008b). Assuming a 0.25% loss rate, 12.6 million pounds represents 99.75% of the refrigerant that entered the reclamation process, meaning approximately 31,470 pounds of refrigerant were lost due to releases during hose hookups.

Table 6 indicates how this quantity of lost refrigerant could be distributed by refrigerant type, based on EPA data. The table also indicates the potential impacts on the environment in terms of the combined ozone depletion potential (ODP) and global warming potential (GWP) associated with emissions of the different refrigerants. As shown, it is estimated that an aggregate loss of 31,470 pounds of refrigerant in 2008 would result in the emission of 3 ODP metric tons and 39,000 metric tons of carbon dioxide equivalent ($MTCO_2e$), which is approximately equal to the quantity of carbon dioxide emissions produced by 7,500 passenger vehicles over the course of a year (U.S. EPA, 2010).[8] For the purposes of comparison, if it were assumed that 1.5% of refrigerant was lost during reclamation (the maximum amount allowable under EPA regulations), the total emissions using the same calculation would be approximately 18 ODP metric tons and 237,000 $MTCO_2e$ for 2008.

One reclaimer noted that there is the potential for releases post-reclamation (but before the cylinder reenters the market) if reclaimers are not careful to avoid overfilling cylinders with reclaimed refrigerant. If a cylinder is overfilled and then exposed to higher temperatures (e.g., in a hot warehouse), the increased pressure could cause the cylinder valves to “pop,” resulting in a refrigerant release (Rich Dykstra, Consolidated Refrigerant Reclaim, personal communication, June 17, 2010).

In addition to the potential for refrigerant emissions during the reclamation process, reclaimers were asked to comment on other potential environmental impacts associated with their activities. Several reclaimers commented on the energy intensity of the reclamation process in general and of certain subprocesses such as destruction and fractional distillation. When asked whether there were specific industry standards or best practices that could help reduce the amount of refrigerant that must be destroyed or fractionally distilled, reclaimers generally responded that outreach to technicians is the best approach to reducing the need to use these methods. They noted that the reason for using these methods is often that the refrigerant is mixed and of a purity that is too low for simple distillation methods, which is typically assumed to be the result of technician negligence or accidents.

Multiple reclaimers also noted that the amount of refrigerant that needs to be destroyed or fractionally distilled could be reduced if reclaimers had more access to virgin refrigerant that could be blended with the mixed refrigerant.

8. It is important to note that this calculation does not account for losses during hose hookups on containers of refrigerant that is ultimately sent for destruction. The quantity of refrigerant that reclaimers send for destruction is not currently reported to EPA. A draft EPA report on the sources of destroyed ODS does not provide information on the amount of destroyed refrigerant that is obtained from reclaimers (see U.S. EPA, 2008a).

Table 6. Estimated environmental implications of refrigerant releases during hose hookups for reclamation in 2008 (assuming a 0.25% loss rate)

Refrigerant	Classification	ODP	GWP	Quantity reclaimed (lb)	Quantity received (lb)	Quantity lost (lb)	ODP lost (metric tons)	GHG lost (MTCO2e)
R-11	Class I	1.0	4,750	989,234	991,713	2,479	1	5,342
R-12	Class I	1.0	10,900	476,726	477,921	1,195	1	5,907
R-23	ODS substitute	0.0	14,800	2,497	2,503	6	0	42
R-113	Class I	0.8	6,130	175,568	176,008	440	0	1,223
R-114	Class I	1.0	10,000	310,321	311,099	778	0	3,528
R-500[a]	Mixture containing Class I ODS	0.7	8,077	195,724	196,215	491	0	1,797
R-502[b]	Mixture containing Class I ODS	0.1	4,657	88,040	88,261	221	0	466
R-503[c]	Mixture containing Class I ODS	0.6	14,560	60	60	0	0	1
R-123	Class II	0.0	77	272,583	273,266	683	0	24
R-22	Class II	0.1	1,810	10,045,071	10,070,247	25,176	1	20,669
Total				**12,555,824**	**12,587,292**	**31,468**	**3**	**39,000**

Notes:
Calculations have been rounded.
GHG = greenhouse gas.
Data on the amount of refrigerant reclaimed in 2008 are obtained from reclaimers via annual reports to EPA (U.S. EPA, 2008b).
ODP values for Class I ODS and Class II ODS are available from EPA at http://www.epa.gov/ozone/science/ods/classone.html and http://www.epa.gov/ozone/science/ods/classtwo.html, respectively.
GWPs for refrigerants are available from the Intergovernmental Panel on Climate Change at http://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch2s2-10-2.html#table-2-14.

a. R-500 is 73.8% R-12 and 26.2% R-152a (National Refrigerants, 2010a).
b. R-502 is 48.8% R-22 and 51.2% R-115 (National Refrigerants, 2010b).
c. R-503 is 60% R-13 and 40% R-23 (National Refrigerants, 2010c).

3.2 Potential Environmental Impacts of Reclaimed Refrigerant upon Market Reentry

If used refrigerant is improperly reclaimed such that it is not returned to AHRI Standard 700 specifications before being resold on the market, potential contaminants in the refrigerant could affect air-conditioning and refrigeration systems in ways that could lead to environmental impacts. Based on conversations with industry experts, including representatives of several air-conditioning and refrigeration system manufacturers, there are three ways in which use of “dirty” refrigerant can lead to emissions.

1. *In certain conditions, contaminants in refrigerant can cause refrigeration and air-conditioning systems to leak their charge.* According to one industry expert speaking from experience with centrifugal water-cooled chillers having shell and tube heat exchangers, in extreme cases, contaminated refrigerant may cause overpressurization in the condenser and cause relief valves to vent refrigerant (Ken Hickman, Johnson Controls consultant, personal communication, July and August 2010). These chillers can range in charge size from 200 to 1,400 tons of refrigerant (York, 2010).

   According to the 2006 Report of the United Nations Environment Programme (UNEP) Refrigeration, Air Conditioning, and Heat Pumps Technical Operations Committee, there are approximately 56,700 centrifugal chillers in use in the United States, and half of these chillers using HCFC-123 (R-123) and the other half uses HFC-134a (R-134a; UNEP, 2007). According to one industry expert, nearly all of these centrifugal chillers are water-cooled and thus vulnerable to the refrigerant release scenario described above (Ken Hickman, Johnson Controls consultant, personal communication, July and August 2010). The UNEP report estimates that the approximately 28,350 centrifugal chillers in the United States that use R-123 hold a total of 9,130 metric tons of refrigerant, while the 28,350 centrifugal chillers in the United States that use R-134a hold approximately 14,300 metric tons of refrigerant. In sum, there could be as much as 23,430 metric tons of refrigerant banked in chillers that are susceptible to releases if the refrigerant charge is contaminated.

   In addition, industry experts noted that it is possible that contaminated refrigerant could cause freeze-up in chiller evaporators, which could lead to refrigerant leaks from tubing, and erosion of O-rings and seals on refrigerant line service valves, potentially leading to emissions. Such events are considered to be very rare, as chillers and other refrigeration and air-conditioning equipment is generally well maintained by technicians (Ken Hickman, Johnson Controls consultant, personal communication, July and August 2010; Fred Keller, Carrier Residential consultant, personal communication, July and August 2010). One expert noted having witnessed a refrigerant release that occurred when impurities were caught in the bellows of a type of pressure switch that is commonly found on supermarket chillers, which typically have large charges (Jeffrey Staub, Danfoss, personal communication, August 3, 2010).

2. *Contaminants in refrigerant have deleterious effects on refrigeration and air-conditioning system efficiency*. Noncondensable contaminants can cause refrigeration and air-conditioning systems to operate at higher condensing pressure levels, resulting in reduced cooling performance and higher energy consumption (Ken Hickman, Johnson Controls consultant, personal communication, July and August 2010).

According to one study conducted by the American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE), a chiller with 5% to 6% oil content in its refrigerant will experience an energy efficiency loss of approximately 10% (see Table 7; ASHRAE, 2007). A chiller that operates between 6,000 hours to 7,000 hours per year can consume up to 1 MWh in that time (WSU, 2003). A 10% efficiency loss for such a piece of equipment would lead to an additional 100,000 kWh of electricity consumed per year. This excess energy consumption could result in the emission of more than 70 $MTCO_2e$ over the course of the year, or the amount of CO_2 produced by roughly 14 passenger cars over the course of a year (U.S. EPA, 2010).

Table 7. Relationship of presence of oil in chiller evaporators and energy efficiency loss

Percent oil in chiller evaporator	Energy efficiency loss (percent)
1 to 2	2 to 4
3 to 4	5.5 to 8
5 to 6	9.5 to 11
7 to 8	13.5 to 15

Source: ASHRAE, 2007.

3. *Poor system performance can necessitate opening the system for servicing, which can lead to emissions.* The efficiency losses caused by contaminants in refrigerant would likely motivate the system owner to have the system serviced by a technician. The technician would evacuate the system and recycle the refrigerant or send it to be reclaimed. In doing so, there are inevitable *de minimis* refrigerant losses. Although these losses are typically believed to be small, there is the potential for larger leaks as a result of human error (e.g., improperly fitting hoses to valves and overfilling recovery cylinders) (Ken Hickman, Johnson Controls consultant, personal communication, July and August 2010; Jeffrey Staub, Danfoss, personal communication, August 3, 2010).

Multiple reclaimers and industry experts have explained that the more times a quantity of refrigerant is handled (i.e., transferred between systems and/or containers), the greater the likelihood that some sizable portion of that refrigerant will be leaked, either by *de minimis* losses or larger losses caused by human error.

4. Best Practices for Reclamation

Considering the potential environmental impacts associated with the reclamation process and reclaimed refrigerant that reenters the market, reclaimers were asked whether it is possible to specify best practices for reclamation activities. In theory, it could be possible to require or encourage reclaimers to use certain technological or operational best practices during the reclamation process to minimize environmental impacts; these best practices could be formulated as industry standards. Reclaimers were asked to identify such best practices, based on their own experiences and knowledge of the field.

The reclaimers contacted for this study noted that they use best practice to the extent of their knowledge. However, they were generally unable to articulate specific reclamation technologies or practices that are particularly energy efficient, water efficient, or better at minimizing emissions of ODS. Reclaimers cited several reasons why it is difficult to identify industry best practices for technologies and practices:

- The technologies used will vary considerably depending on the size of the operation. For smaller reclaimers, equipment that can be purchased off-the-shelf can be adequate for processing the amount of recovered refrigerant received. However, larger reclaimers clearly stated that such small equipment would not be adequate to process large quantities of refrigerant and that large-scale off-the-shelf equipment does not exist.

- Most reclaimers do not know what others are doing in terms of operations. Reclaimers generally do not share information about their operations with each other. However, several smaller reclaimers noted that they have been in contact with other reclaimers to solicit information on off-the-shelf equipment.[9]

- Every reclaimer is already using the best practices available to them (which is limited by both knowledge and cost), simply out of concern for personal interest: it is in the interest of the reclaimer to minimize releases and ensure that the final product is of good quality.

9. One small reclaimer explained that when he was just beginning to reclaim refrigerant, he contacted another small reclaimer for advice on equipment, and the two continue to share thoughts. Both use a Van Steenberg model (Aubry McCarley, Turner and Schoel, personal communication, June 11, 2010; Jimmy Trout, AllCool, personal communication, June 24, 2010).

A few reclaimers did specify certain technological or operational best practices, but these were often shared with a caveat that the benefits that might be achieved by prescribing such practices would be small compared to the benefits that could be achieved through outreach to technicians.

Some reclaimers explained that emissions during the refrigerant reclamation process really only occur during hose hookup and that once the refrigerant is into the distillation tower, the system is closed (Steve Mandracchia, Hudson Technologies, personal communication, June 9, 2010; Carl Grolle, Golden Refrigerant, personal communication, June 10, 2010; Jim Sweetman, Consolidated Refrigerant Solutions, personal communication, June 15, 2010). For this reason, reclaimers should pay close attention to their hoses and valves. Best practices could therefore include:

- Draw cylinders down to as deep a vacuum as possible.[10]
- Regularly test reclamation systems for leaks.
- Completely evacuate all hoses connecting to the recovery cylinder once the refrigerant is transferred to bulk storage.
- Replace hoses regularly (one reclaimer suggested a frequency of once every two years) to avoid potential inadvertent leaks.
- Use shorter connector hoses when connecting to the cylinder in order to minimize the amount of refrigerant that is released when the cylinder is disconnected from the hose if the hose has not been completely evacuated.
- Use special ball valves on hoses to prevent small emissions. However, such “no-leak” valves can be expensive and cost prohibitive for some reclaimers and often require more time to hook up to a cylinder (Jimmy Trout, AllCool, personal communication, June 24, 2010).
- Allow cylinders to cool before evacuating the refrigerant.

One reclaimer noted that another potential point of refrigerant loss is after cylinders have been refilled with reclaimed refrigerant. Cylinders that are overfilled, due to human error or malfunctioning equipment, could leak, especially if they are exposed to extreme heat (e.g., on the

10. One reclaimer voiced concern that some smaller reclaimers might sometimes not draw the cylinder down to a deep vacuum because of the additional time required, only drawing as deep as 15 or 20 inHg (Steve Mandracchia, Hudson Technologies, personal communication, June 9, 2010).

back of a service truck; Rich Dykstra, Consolidated Refrigerant Reclaim, personal communication, June 17, 2010).

5. Approaches to Ensuring Best Practices for Reclamation

Conversations with reclaimers explored the viability and potential benefits and costs of different approaches to reducing the environmental impacts of refrigerant reclamation practices and to maximizing the amount of refrigerant that reenters the market. This section describes the feedback received from reclaimers when asked about these different approaches, which include:

- Communications and outreach
- Technology standards
- Reporting requirements
- Mandatory third-party certification.

These approaches are described in detail below.

5.1 Communications and Outreach

When asked what approaches could lead to increases in the amount of refrigerant reclaimed and to reductions in the environmental impacts associated with refrigerant reclamation, most reclaimers suggested increased outreach to technicians, reclaimers, or both.

5.1.1 Outreach to technicians

In addition to providing feedback on the approaches described above, reclaimers consistently emphasized the importance of reaching out to technicians in order to encourage them to recover more refrigerant. In general, reclaimers expressed considerable concern that technicians are rarely compliant with federal regulations regarding refrigerant recovery and the prohibition on venting. According to one reclaimer, fewer than 20% of technicians are in compliance with EPA's prohibition on venting. In addition, many reclaimers are concerned that technicians are not careful enough about not mixing refrigerants; this is likely to become more of a problem as the use of R-22 alternatives increases. As described above, mixed gas can be costly to handle. In addition, according to one reclaimer, off-the-shelf reclamation systems cannot separate R-410A, a common alternative that is sometimes found mixed with R-22 (David Andrew, Perfect Cycle, personal communication, June 9, 2010).

Reclaimers consistently noted that if EPA's goal is to maximize the amount of refrigerant that reenters the market, it could realize substantial benefits by engaging technicians.[11] Several reclaimers commented that EPA would see noticeable increases in the amount of refrigerant that is reclaimed if it were to require technicians to report more information on the amount of refrigerant they recover and where it goes after it leaves their hands. Such reporting requirements could complement additional requirements that might be directed at reclaimers (see Section 5.3). The issue of technician noncompliance was of considerable importance to each reclaimer contacted for this study.

In addition, one reclaimer noted that the amount of refrigerant that is recovered but is not required to be reclaimed (e.g., refrigerant that is recovered on-site and charged back into the same appliance) has doubled recently (Rich Dykstra, Consolidated Refrigerant Reclaim, personal communication, June 17, 2010). In addition to the implications this has for the amount of recovered refrigerant that reclaimers receive, there is also concern that there is no way to test and confirm that recovered refrigerant is not contaminated when it is recharged into the same system or another system owned by the same individual or company. However, the reclaimer also noted that because recovered refrigerant that is not reclaimed does not change possession (e.g., from technician to wholesaler to reclaimer), the potential for leakage could be diminished (Rich Dykstra, Consolidated Refrigerant Reclaim, personal communication, June 17, 2010).

5.1.2 Outreach to reclaimers

In addition to requesting better communication with technicians, several reclaimers noted that there could be benefits if EPA were to reach out to reclaimers in order to provide best practices information and guidance (although, as described in Section 4, reclaimers struggled to identify specific best practices). This would be especially helpful for reclaimers who recently entered the market. One reclaimer explained that when his company received EPA-certification, they found that there was no guidance or assistance available from EPA and the only available resource for information was the manufacturer of the off-the-shelf system the company purchased (Jim Sweetman, Consolidated Refrigerant Solutions, personal communication, June 15, 2010). Although several of the larger reclaimers seemed less concerned about what best practices might be available (presumably because they are confident in their own operations), smaller reclaimers generally appeared to be interested in any sort of information guidance or best practices (such as those identified in Section 4) that EPA could provide.

11. One reclaimer commented that EPA should be working with wholesalers to create economic incentives to encourage technicians to return refrigerant (Carl Grolle, Golden Refrigerant, personal communication, June 10, 2010).

5.2 Technology Standards

In order to mandate technology standards for the reclamation industry, there would need to be a clear advantage of one technology over others. This is not the case for the patented reclamation technologies identified in this study. There are clear differences among patented technologies, but each has some advantages as well as disadvantages, making it difficult to specify a superior technology. In addition, different types of technologies are used for different types of applications, which differ primarily in scale (TAP, 2010).

Reclaimers were asked whether and to what degree it would be possible to identify potential standards for equipment used during the refrigerant reclamation process, including distillation towers, hoses, valves and fittings, gas analyzers, and other equipment, and whether such standards would have benefits (e.g., fewer emissions in the reclamation process or more reclaimed refrigerant reentering the market).

Few of the reclaimers interviewed were able to specify what such a standard might entail. Two reclaimers noted that there could be a requirement that all reclaimers use hoses with “no-leak” ball valves, but that the emissions reduction gains might not offset the costs to reclaimers of having to upgrade their operations. In responding to questions about technology standards, reclaimers consistently noted that it is in their interest to prevent leakage during the reclamation process. Lost refrigerant translates into lost profit, so the marginal gains of requiring reclaimers to meet specific standards would be minimal.

5.2.1 Applicability of AHRI Standard 740

Considering the similarities between the refrigerant reclamation process and the recycling process, the following question arises: could AHRI Standard 740-1998 (AHRI Standard 740; which applies to recovery and recycling equipment) be applicable to reclamation equipment? AHRI Standard 740 includes requirements that recycling equipment be tested for the following certified ratings:

- Flow rate
- Moisture
- Acid
- Noncondensables
- Residual trapped refrigerant
- Quantity of refrigerant processed
- High boiling residue.

In addition to these certified ratings, the standard also includes requirements that equipment (1) pass chloride tests, (2) pass particulate tests, and (3) be measured for refrigerant loss. In order to be sold on the market, refrigerant recycling equipment must meet all certified ratings and requirements (these requirements are identified in Table 8).

Table 8. Comparison of AHRI Standard 740 and AHRI Standard 700 specifications

Parameter	AHRI Standard 740 (for recycling equipment)	AHRI Standard 700 (for reclaimed refrigerant)
Performance parameters		
Recycle/reclaim flow rate (kg/min)	X	
Refrigerant loss (kg)	X	
Residual trapped refrigerant (kg)	X	
Refrigerant processed at rated conditions (kg)	X	
Contaminant parameters		
Moisture content (ppm by weight)	X	X
Chloride ions (pass/fail)	X	X
Acidity (ppm by weight)	X	X
High boiling residue (% by volume)	X	X
Particulates (pass/fail)	X	X
Noncondensables (% by volume)	X	X

Note: "X" indicates that the standard includes requirements for the parameter.

Sources: AHRI, 1995, 1998.

As described in Section 1, reclamation equipment must be capable of ensuring that reclaimed refrigerant is returned to the AHRI Standard 700 specifications. A comparison of these specifications with the requirements of AHRI Standard 740 indicates that the only equipment parameters in AHRI Standard 740 not accounted for by the specifications in AHRI Standard 700 are flow rate, quantity of refrigerant loss, quantity of residual trapped refrigerant, and quantity of refrigerant processed (see Table 8).[12]

12. To be clear, AHRI Standard 740 includes parameters that enable one to compare refrigerant recovery and recycling equipment. Among other things, this equipment must be proven to be able to return refrigerant to AHRI Standard 700 specifications. Because reclaimers are required to return refrigerant to AHRI Standard 700 specifications, the only AHRI Standard 740 specifications that would be additional to what reclaimers are already required to meet would be the performance parameters in Table 8.

The requirement that off-the-shelf reclamation equipment meet AHRI Standard 740 specifications could lead to small reductions in the amount of refrigerant released during the reclamation process. This is due to the fact that it might increase reclaimers' awareness of better-performing systems on the market (customers would be better able to compare key characteristics of reclamation systems, such as the amount of residual trapped refrigerant).[13]

However, as noted in Section 2, most reclaimers do not use systems that are purchased off-the-shelf. In addition, the information on the performance parameters outlined in AHRI Standard 740 that are not addressed by the specifications in AHRI Standard 700 can be incorporated into EPA's reporting requirements without reference to a standard. For example, if EPA were to require reclaimers to report the amount of recovered refrigerant they receive, the amount that is entered into the reclamation process, and the amount that is ultimately packaged for resale, it would be possible to gather information on the amount of refrigerant lost (or that is left as residual)[14] during the reclamation process, one of the performance parameters identified in AHRI Standard 740.

5.3 Reporting Requirements

To improve understanding of the reclamation industry and its technologies and practices, EPA could require that reclaimers provide additional information during the application process and in their annual reports.

5.3.1 Reporting information on technologies used

Under current regulations, EPA-certified reclaimers must provide information to EPA on the equipment used to reclaim refrigerant. If the equipment is purchased off-the-shelf, reclaimers must provide the make, model, and serial number. Otherwise, reclaimers must provide EPA with descriptions and photographs of custom-made equipment and processes used. Certified reclaimers are also required to submit information on equipment used to analyze refrigerant.

EPA could specify the type of information that reclaimers must provide in this submission and require that this information be submitted annually to account for any changes or upgrades. Specific information to be provided in such submissions could include:

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13. For completeness, purchasers of reclamation systems would also want to know the energy used per pound of refrigerant reclaimed. However, the AHRI Standard 740 does not currently include ratings for this metric.

14. Residual refrigerant is typically assumed to be released, as reclamation systems are typically cleaned between batches.

- *Primary separation technology involved (e.g., distillation versus adsorption).* As described in Section 2.4, the type of primary separation used in a reclamation system can have a number of implications, including increased potential for leakage from joints (e.g., in systems that have a larger number of components, as is the case with distillation systems that have compressors) and increased energy consumption, in the case of cryogenic subcooling. EPA could require reclaimers to provide specific information about their systems' operating characteristics, including (as identified in Section 2.4) the following: system speed; capacity; energy use (e.g., per pound or ton of refrigerant reclaimed); type of refrigerant that can be reclaimed (e.g., high-pressure or low-pressure refrigerants); ability to operate in continuous mode; and minimum initial impurity level (this is probably more a matter of the reclaimers' preferred operations than the capabilities of the system).

- *Secondary separation technologies used and specific equipment for each.* As noted in Section 2.4, most primary separation technologies are not sufficient for returning refrigerant to AHRI Standard 700 specifications and, for this purpose, it is necessary for refrigerant to be passed through a number of other separation processes. For example, as noted above, in distillation systems with compressors, oil is typically discharged with refrigerant. EPA would want to know that a reclaimer who reports using such as system is using oil separation equipment after the primary separation process.

- *Hoses and fittings.* As described in Section 3, use of certain types of hoses and fittings and proper handling of these pieces can help minimize the potential for inadvertent releases. EPA would benefit from knowing the age of the hoses used, the length of the connector hoses, and the types of valves used (e.g., quick-release valves).

- *Refrigerant testing equipment.* Section 2 explained how reclaimers typically use hand-held gas analyzers to evaluate the contents of cylinders prior to reclamation and again afterward to test the quality of the product. Some reclaimers use gas chromatographers to obtain more precise information than can be obtained using the gas analyzer. As noted in Section 2, more recent analyzer models tend to be more accurate than older ones. EPA would benefit from knowing whether reclaimers are using the most up-to-date equipment. As such, EPA could require that reclaimers report any upgrades or changes to equipment used to test refrigerant.

5.3.2 Reporting information on refrigerant received and reclaimed

Under 40 CFR 82 Subpart F, certified reclaimers are required to keep records of how much recovered refrigerant is sent to them to be reclaimed and how much refrigerant is ultimately reclaimed. Reclaimers must report this information to EPA annually. However, reclaimers are not required to report whether the refrigerant they reclaim was drawn from stockpiles or was recently recovered in the field.[15] In addition, reclaimers are not currently required to report:

- The type of source from which the recovered refrigerant was received (e.g., distributors as opposed to wholesalers)
- The quality of the refrigerant received
- The amount of refrigerant that is blended back to AHRI Standard 700 specifications using pure refrigerant before being reclaimed
- The amount of mixed gas that is sent off-site to be separated or destroyed
- The amount of refrigerant that enters the reclamation system but is not ultimately reclaimed (i.e., refrigerant that is either released in the process or remains in the system as residual)
- The amount of refrigerant that was sold.

Having such information would provide EPA with a better understanding of the net yield achieved in the reclamation field, in terms of how much product is returned to the market relative to how much is received.

In general, reclaimers would not be opposed to increased reporting requirements. Most reclaimers already record information on every container of recovered refrigerant they receive. Reclaimers will typically keep a paper trail on the refrigerant as it passes through the reclamation process, from single recovery cylinder to aggregate holding tank, to batch of reclaimed refrigerant, to final packaged product. In general, reclaimers are able to determine the potential source containers that held the recovered refrigerant that eventually went into a refurbished cylinder for resale.

Several reclaimers have developed sophisticated databases for tracking refrigerant from the time it comes into their facilities to the time it leaves (e.g., Jim Sweetman, Consolidated Refrigerant Solutions, personal communication, June 15, 2010; Jimmy Trout, AllCool, personal communication, June 24, 2010; Jeff Zirkle, Total Reclaim, personal communication, June 15, 2010). Information that reclaimers typically record for each container of refrigerant (whether it be a 30-lb cylinder or a 1,000-lb container) includes source (name of business), size, weight,

15. In a previous study (Stratus Consulting, 2008), it was noted that a lot of reclaimers are stockpiling R-22, waiting for the price to increase. However, reclaimers interviewed for this study did not believe that stockpiling was common. This might be due to the fact that most of the reclaimers contacted for this study run smaller operations and cannot afford to keep much refrigerant in inventory.

condition of container, DOT-39 number (or comparable container identification), and contents (as determined by either a gas analyzer or gas chromatographer). Reclaimers will also record whether the refrigerant was delivered to them as part of a tolling agreement (i.e., the refrigerant will be returned to its owner after being reclaimed) or whether the reclaimer purchased the recovered refrigerant for resale.

Many reclaimers collect and maintain this information in the interests of their customers. Some larger technicians and wholesalers maintain records for their clients as proof of their compliance with the CAAA. In some instances, reclaimers commit to keeping rigorous records of the recovered refrigerant they receive as part of their agreements with wholesalers (Jimmy Trout, AllCool, personal communication, June 24, 2010). One reclaimer has developed a database system that customers can log into and see information on all the cylinders they have delivered to the reclaimers (Jim Sweetman, Consolidated Refrigerant Solutions, personal communication, June 15, 2010).

One reclaimer recommended additional reporting requirements as a way of ensuring that reclaimers are not deliberately venting mixed-gas refrigerant. The reclaimer noted that some reclaimers are not charging their clients when their clients give them cylinders with mixed gas. The reclaimer noted that if these reclaimers are taking the correct action and sending this mixed gas to be separated or destroyed, they would most likely charge their clients for the service. If they are not charging them, it might be an indication that the reclaimer is venting the mixed gas (Ken Beringer, Airgas, personal communication, June 8, 2010).

Although reclaimers were generally accepting of the idea of increased reporting requirements, they expressed considerable concern that the information that EPA would receive from reclaimers would not be sufficient to provide a clear, complete picture of how much refrigerant is in circulation, where it is, and whether it is being recovered and reclaimed. For this, EPA would need to collect more detailed information from technicians regarding the amount and type of refrigerant recovered at each job site and where the refrigerant went when they were done handling it. EPA would also need to require wholesalers to be a part of this reporting system, as they are currently not required to report any information on how much refrigerant they receive and what they do with it (Jim Sweetman, Consolidated Refrigerant Solutions, personal communication, June 15, 2010).

In addition, some of the smaller reclaimers were concerned about having to track additional information because of the amount of time it requires to record information on each 30-lb cylinder that comes in (approximately 3 minutes per cylinder, in one reclaimer’s estimation; Jimmy Trout, AllCool, personal communication, June 24, 2010).

5.4 Mandatory Third-Party Certification

To help ensure that refrigerant that reenters the market is properly reclaimed and, in turn, help reduce the potential for adverse economic and environmental impacts on air-conditioning and refrigeration systems, EPA could require all reclaimers to participate in a third-party certification program. Reclaimers were asked to comment on the viability and efficacy of such a program and to provide information on their own current participation in third-party testing or certification.

In general, the reclaimers interviewed for this study are supportive of mandatory third-party certification. Reclaimers consistently noted that requiring third-party certification, in addition to helping to ensure that refrigerant is properly reclaimed, would help level the playing field by forcing all reclaimers to internalize the costs of verifying the quality of their product.

All of the reclaimers interviewed noted that they already have reclaimed refrigerant independently tested and they are concerned that there are others in the industry who do not test their product or who do so but not through an independent laboratory. Most explained that they send a liquid sample of every batch to an AHRI-certified laboratory to be tested (in nearly every instance, this laboratory was InterTek).

According to a previous Stratus Consulting study (Stratus Consulting, 2008), approximately 50% of all samples sent to InterTek failed to meet specification. However, it was noted that some reclaimers send not-yet-reclaimed refrigerant to be tested in order to verify the measurements generated by their own equipment. Other times, reclaimers send samples of reclaimed refrigerant that do not meet specification as determined by their own equipment in order to verify their measurements. Reclaimers can voluntarily report whether the submitted sample will be sold; of those identified as for sale, only 20% of samples fail. In addition, the previous Stratus Consulting study revealed that samples from smaller reclaimers are more likely to not meet specification (Stratus Consulting, 2008).

5.4.1 AHRI third-party certification program

Under current regulations, reclaimers are required to certify to EPA that their reclaimed refrigerant has been returned to at least the AHRI Standard 700 specifications. However, there is concern that such self-certification is not entirely reliable and that allowing reclaimers to self-certify their reclaimed refrigerant could result in less diligent testing, which, in turn, could lead to “dirty” refrigerant (i.e., refrigerant that does not meet the AHRI Standard 700 specifications) reentering the market.

To help ensure that reclaimed refrigerant is returned to the AHRI Standard 700 specifications at a minimum, EPA could establish a mandatory third-party certification program that would involve required random and regular testing of reclaimed refrigerant before it is authorized to reenter the market. A voluntary program administered by AHRI could potentially serve as a model for such as mandatory program.

AHRI's program

AHRI's voluntary Certification Program for Reclaimed Refrigerants offers participating reclaimers the opportunity to have their reclaimed refrigerant certified by a third party as meeting the specifications of AHRI Standard 700.

To participate, reclaimers must commit to submitting a specific number of samples of their reclaimed refrigerant to an AHRI-certified laboratory for testing. As long as a reclaimer's refrigerant samples are found to meet the AHRI Standard 700 specifications, the reclaimer's refrigerant will be eligible for listing in the AHRI directory of certified products and reclaimers will be authorized to advertise their product as AHRI certified.

Steps in the process

As described in the AHRI Reclaimed Refrigerants Certification Program Operational Manual, AHRI, through an associated voluntary laboratory certification program, certifies laboratories that are qualified to test reclaimed refrigerant samples. AHRI works with participating reclaimers to have their reclaimed refrigerant sampled and tested by these independent laboratories.

In general, a minimum of four samples from a reclaimer's facility are tested by laboratories each year. At least one sample of each refrigerant that the reclaimer intends to have certified must be taken each year. If a reclaimer intends to have one refrigerant certified, all four samples taken will be of that refrigerant. If a reclaimer intends to have four refrigerants certified, a minimum of one sample could be taken for each in a given year. A reclaimer's ability to claim AHRI certification for any refrigerant expires three years after the date of the laboratory inspection.

Samples are drawn in AHRI-specified 500-cc stainless steel test cylinders by reclaimers. These samples must be drawn from container(s) (30-lb cylinders) chosen by the laboratory representative and as directed by AHRI. If an initial sample fails, a second sample is drawn; if the second sample fails, the reclamation process for the refrigerant shall cease and sales, shipments, and reuse of the entire batch of refrigerant from which the sample was drawn shall be suspended until certification is reinstated (AHRI, 2002).

Current status of the program

As of October 2010, only one reclaimer, National Refrigerants, was earning AHRI certification for reclaimed refrigerant (seven refrigerants that National Refrigerants reclaims are certified at this time; AHRI, 2010).

In the past, more reclaimers were participating in the program. However, over time, all but National Refrigerant dropped out of the voluntary program. Former program participants cited the high cost of participating in the program as the primary reason for ending participation. Multiple reclaimers explained that there was a lack of demand for AHRI-certified reclaimed refrigerant, which made it impossible for them to justify the additional operational costs of participating (Steve Mandracchia, Hudson Technologies, personal communication, June 9, 2010; Carl Grolle, Golden Refrigerant, personal communication, June 10, 2010).

5.4.2 Criticism of AHRI's voluntary program

Considering the general support for a mandatory third-party certification program, reclaimers and other industry experts were asked to comment on the advantages and disadvantages of employing the AHRI voluntary third-party certification program as a model for a mandatory program. According to AHRI staff, the AHRI program could function as a ready-to-implement model for a mandatory program. The program would have an advantage in that a number of reclaimers have participated in the program in the past and are familiar with how it is administered.

Despite the apparent advantages of using the AHRI program as a model, several reclaimers noted concerns with the program. First, considering the fact that most reclaimers have samples from every batch sampled, the AHRI program requirement that a minimum of only four samples of each refrigerant type from a reclaimer's facility be tested each year seems very low in comparison.

In addition, several aspects of the AHRI program present opportunities for "gaming the system," as one reclaimer describes it (Steve Mandracchia, Hudson Technologies, personal communication, June 9, 2010; Carl Grolle, Golden Refrigerant, personal communication, June 10, 2010). One of the primary concerns with the program, as identified by several reclaimers, is that reclaimers are notified of the laboratory representatives' visits beforehand, which provides an opportunity for reclaimers to remove any refrigerant of questionable quality from the facility prior to the inspection. Similarly, reclaimers are permitted to indicate to laboratory representatives which refrigerants will be available for testing before their visits. In addition, in the event of a first-sample failure, reclaimers are permitted to notify the laboratory whether a second sample should be drawn from the same container as the first, a second one chosen at random, or from one that may have already been set aside.

Several reclaimers interviewed for this study stated that the program should be revised so that the laboratory inspections are truly random and the reclaimer is not able to specify which cylinders to draw samples from.

Another recommendation relates to condemnation of failed refrigerant. Several reclaimers commented on the fact that if a sample drawn from a single cylinder fails, the entire batch from which that cylinder was filled is condemned. According to the reclaimer, a more appropriate approach would be to test the refrigerant at the batch level first and condemn the batch if the sample fails. Secondary testing could be done at the cylinder level. If the cylinder sample fails but the batch sample does not, the packaging procedures should be targeted for evaluation, but the entire batch should not be condemned (Carl Grolle, Golden Refrigerant, personal communication, June 10, 2010; Rich Dykstra, Consolidated Refrigerant Reclaim, personal communication, June 17, 2010). Other reclaimers noted concern that reclaimed refrigerant could become contaminated during the packaging process (e.g., if a cylinder has a certain amount of oil in it from the time of its manufacture; e.g., Jeff Zirkle, Total Reclaim, personal communication, June 15, 2010).

Despite the fact that a number of reclaimers have participated in the program in the past, reclaimers who have not participated in the program generally have very little understanding of how the program works. Multiple reclaimers indicated that they knew about the program's existence but knew nothing about it.

Sufficient testing capacity

Whether or not there is currently a sufficient number of laboratories to meet the needs of all reclaimers is debatable. At present, there are three AHRI-certified laboratories participating in the program. According to AHRI staff and some reclaimers, there would be a need for more certified labs. However, it is believed that over time, the market would take care of this as more entities would seek to become certified (TAP, 2010; Ken Beringer, Airgas, personal communication, June 8, 2010; Karim Amrane, AHRI, personal communication, July 20, 2010). However, one reclaimer noted that the number of laboratories that are currently certified or that have been certified by AHRI in the past would be sufficient to meet the needs of all reclaimers (Steve Mandracchia, Hudson Technologies, personal communication, June 9, 2010). In addition, based on the findings of this study, it appears that InterTek currently handles the testing for most reclaimers (nearly all of the reclaimers contacted for this study), which makes it difficult to see the immediate need for more laboratories. One reclaimer noted that it might be advantageous to have a smaller number of laboratories to help ensure consistency (Steve Mandracchia, Hudson Technologies, personal communication, June 9, 2010). However, as noted by several reclaimers (primarily in western states), the cost of shipping samples to InterTek in Ohio is not trivial and having more certified laboratories might help keep costs down for reclaimers (e.g., Jeff Zirkle, Total Reclaim, personal communication, June 15, 2010).

If third-party certification is mandatory, it would be necessary to establish criteria for the laboratories doing the testing. AHRI already has a program in place that establishes procedures for certifying laboratories. According to one reclaimer, these procedures present an appropriate model for certifying the laboratories that would be testing reclaimers' products (Steve Mandracchia, Hudson Technologies, personal communication, June 9, 2010). This position is supported by the fact that many reclaimers (despite not participating in the program) still seek independent testing of their products from a laboratory that is AHRI certified. AHRI staff commented that the stringency of the criteria for laboratories will affect the costs of the program (Karim Amrane, AHRI, personal communication, July 20, 2010).

5.4.3 Benefits of third-party certification in general

Reclaimers and other industry experts were asked to comment on environmental and other benefits associated with a mandatory third-party certification program.

The primary environmental benefit associated with third-party certification of reclaimed refrigerant is increased assurance that contaminants in reclaimed refrigerant will not cause or lead to additional ODS or GHG emissions when the refrigerant reenters the market. As described in Section 3.2, if refrigerant is not fully reclaimed to AHRI Standard 700 specifications, it can cause equipment to release its charge in certain extreme cases. In addition, using dirty refrigerant will always impair system performance, resulting in energy losses.

Unfortunately, it is difficult to quantify this benefit because it is unknown what proportion of reclaimed refrigerant that currently reenters the market fails to meet AHRI Standard 700 specifications. As noted above, an earlier Stratus Consulting study found that refrigerant samples sent to testing laboratories by reclaimers failed to meet AHRI Standard 700 specifications about 50% of the time (Stratus Consulting, 2008). However, some of the samples sent to the laboratories were from batches of refrigerant that had not yet been reclaimed; reclaimers often send dirty samples to laboratories in order to corroborate their own analyses. In addition, reclaimers occasionally send samples of reclaimed refrigerant to laboratories after in-house testing reveals that the sample does not meet AHRI Standard 700 specifications. In sum, although approximately half of all samples sent to laboratories for testing by reclaimers fail to meet AHRI Standard 700 specifications, not all of this refrigerant would be packaged for resale without being processed.

In addition to the potential environmental, energy, and system maintenance benefits associated with a mandatory third-party certification program for reclaimed refrigerant, a number of reclaimers commented that mandating certification would help “level the playing field” across the industry. Several reclaimers expressed concern that others in the industry were less diligent in their practices and might be taking shortcuts.

5.4.4 Costs of third-party certification in general

Any third-party certification program that EPA authorizes or establishes will have certain administrative expenses to cover the costs of working with both reclaimers and laboratories. It is expected that the certification program will pass these costs along to the reclaimers. When questioned about the potential advantages and disadvantages of a mandatory third-party certification program, several reclaimers cautioned against imposing additional costs on them. Many reclaimers, they noted, are small businesses that cannot afford additional operational expenses. However, it appears that most reclaimers already pay to have each batch of reclaimed refrigerant tested by InterTek; this cost is approximately $145 per sample (not including shipping costs) (Steve Trevino, Summit Refrigerants, personal communication, June 22, 2010; Jimmy Trout, AllCool, personal communication, June 24, 2010).

As noted above, participation in the AHRI program has become cost prohibitive for all but one reclaimer. AHRI staff explained that the costs of participating had increased over time as the number of reclaimers participating decreased. This was due to the fact that the costs to AHRI of implementing the program are fairly constant, meaning the total cost to all participating reclaimers combined would be approximately the same whether there were few or many participants. As a result, AHRI was forced to increase the costs for remaining program participants as the program’s participant base diminished (Karim Amrane, AHRI, personal communication, July 20, 2010).

However, as noted by AHRI staff, the costs to individual reclaimers of participating in AHRI’s voluntary program would decrease with a larger number of participants (Karim Amrane, AHRI, personal communication, July 20, 2010). Presumably, if all reclaimers were required to participate in a mandatory certification program, the administrative costs of the certification program could be distributed across a wider base of participants.

6. Conclusions

The purpose of this study was to evaluate reclamation technologies and best practices and identify options for reducing environmental impacts associated with reclamation and reclaimed refrigerant. Information for this study was collected from a variety of sources, primarily through conversations with reclaimers and other industry experts, as well as an assessment of patented technologies and a review of existing literature. This study produced several key findings, including the following:

Reclamation technologies and practices

- The reclamation industry is very diverse, that is, there is no "typical" reclaimer. There are considerable differences between the larger and smaller reclaimers, including differences in the technologies used and the sophistication of the operations.

- The technologies used by reclaimers vary considerably. This is evidenced by the many differences present in the patents identified in this study. In addition, reclamation systems have variable advantages and disadvantages, and the type of system used will depend on the reclaimer's needs.

Environmental impacts associated with reclamation

- Releases during the reclamation process are likely very small. Reclaimers state that they are doing everything possible to minimize releases, because lost refrigerant is lost revenue for them.

- The most likely source of releases during reclamation is the hose-hookup process used when transferring refrigerant from individual cylinders to large batch containers. These emissions rarely exceed the 1.5% maximum threshold established in EPA regulations and are believed to typically be less than 0.25%. Assuming 0.25% of all refrigerant that is run through the reclamation process is released, the estimated environmental impacts from reclamation in 2008 would be the emission of 3 ODP metric tons and 39,000 $MTCO_2e$ over the course of the year.

- Releases from air-conditioning and refrigeration systems due to contaminated refrigerant are possible, but it is difficult to determine whether such releases occur as a result of poor reclamation practices or simply due to the natural decrease in system performance over time. According to one industry expert, centrifugal water-cooled chillers having shell and tube heat exchangers can be susceptible to releases if contaminants are present in refrigerant. Based on a rough approximation, it is possible that these types of chillers hold more than 23,000 metric tons of refrigerant in the United States.

Best practices for reclamation

- Reclaimers believe very strongly that they use the best practices known to them to minimize releases and maximize the amount of refrigerant that returns to the market. As such, they were generally unable to articulate what specific best practices EPA should support.

- The few best practices that reclaimers could specify were focused on operations and maintenance and less on technologies. As noted by most reclaimers, the primary reason why releases occur is human error during refrigerant handling.

Options for ensuring best practices

- Nearly every reclaimer contacted for this study emphasized the importance of reaching out to technicians as the most expedient way to increase the amount of refrigerant that is reclaimed and reduce emissions. In general, reclaimers did not believe that outreach to the reclamation industry about best practices would lead to significant benefits.

- Reclaimers are supportive of increased reporting requirements but believe that the benefits of such requirements would be minimal unless complemented by requirements for technicians. Reclaimers believe that there would be significant benefits to requiring an information chain that tells EPA how much refrigerant is being recovered and where it is going.

- Reclaimers are supportive of mandatory third-party testing but are concerned about the costs of participation. However, nearly every reclaimer contacted for this study sends samples of their product to be tested by independent laboratories.

- The AHRI Third-Party Certification program could be a useful model for a mandatory program, but many reclaimers have concerns about how the voluntary program was managed and the costs, as evidenced by the lack of participation at present.

- Requiring that off-the-shelf equipment meet specific technological standards will only lead to minimal emissions reductions, considering the very small market for such equipment and the assumed effectiveness of the typical custom-made equipment used by reclaimers today.

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A. Reclamation System Patents

Table A.1 provides the identification numbers and titles for the reclamation technologies identified in the patent search described in Section 2.

Table A.1. Reclamation system patents registered with the U.S. patent office

Patent number	Patent title
7,174,742	Combined method and apparatus for recovering and reclaiming refrigerant, solvent flushing, and refrigerant recharging
6,425,263	Apparatus and process for the refrigeration, liquefaction, and separation of gases with varying levels of purity
6,303,022	Method of gas stream purification having independent vapor and liquid refrigeration using a single refrigerant
6,029,472	Refrigerant recycle and reclaim system
5,943,867	Refrigerant reclamation system
5,749,245	Refrigerant separation system
5,647,961	Refrigerant decontamination and separation system
5,620,502	Recovery and purification of refrigerants
5,605,054	Apparatus for reclaiming refrigerant
5,570,590	Refrigerant reclaiming method and system
5,544,494	Method and apparatus for refrigerant purification
5,535,596	Refrigerant reclamation and purification apparatus and method
5,471,848	Refrigerant recovery and purification method and apparatus
5,465,590	Refrigerant reclaim with air purge
5,442,930	One step refrigerant recover/recycle and reclaim unit
5,433,081	Refrigerant recovery and purification method and apparatus with oil adsorbent separator
5,426,950	Refrigerant separation apparatus and method
5,425,242	Process for recovery and purification of refrigerants with solid sorbents
5,377,499	Method and apparatus for refrigerant reclamation
5,361,594	Refrigeration recovery and purification
5,357,768	Refrigerant reclaim method and apparatus
5,355,685	Purification of refrigerant
5,327,741	Refrigerant recovery and purification machine
5,327,735	Refrigerant reclaiming and recycling system with evaporator chill bath

Table A.1. Reclamation system patents registered with the U.S. patent office (cont.)

Patent number	Patent title
5,291,743	Refrigerant reclaim with automatic air purge
5,289,693	Refrigerant recovery and purification apparatus with telecommunication monitoring facilitation device
5,247,812	Portable refrigerant purification module
5,245,840	Refrigerant reclaim method and apparatus
5,243,832	Refrigerant reclaim method and apparatus
5,243,831	Apparatus for purification and recovery of refrigerant
5,214,931	Apparatus for sampling the purity of refrigerant in the storage container of a refrigerant recovery and purification system
5,193,351	Refrigerant recovery and purification system
5,189,889	Refrigerant reclaiming device
5,187,940	Refrigerant recovery and purification system
5,172,562	Refrigerant recovery, purification, and recharging system and method
5,157,936	Method and apparatus for reclaiming refrigerant
5,101,641	Compact refrigerant reclaim apparatus
5,086,630	Refrigerant reclaim apparatus
5,078,756	Apparatus and method for purification and recovery of refrigerant
5,050,388	Reclaiming of refrigerant fluids to make same suitable for reuse
5,033,271	Refrigerant recovery and purification system
5,022,230	Method and apparatus for reclaiming a refrigerant
5,020,331	Refrigerant reclamation system
5,005,369	Refrigerant purification with automatic air purge
4,939,903	Refrigerant recovery and purification system and method
4,909,042	Air conditioner charging station with same refrigerant reclaiming and liquid refrigerant return and method
4,805,416	Refrigerant recovery, purification, and recharging system
4,766,733	Refrigerant reclamation and charging unit
4,285,206	Automatic refrigerant recovery, purification, and recharge apparatus

Note: The above patents were identified through a search of the U.S. Patent and Trademark Office Web Patent Databases. The following key words were used: reclaim, reclaiming, reclamation, separation, decontamination, clean, purification, refrigerant, and refrigeration. Irrelevant patents identified by the keyword searches were excluded from the analysis.

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