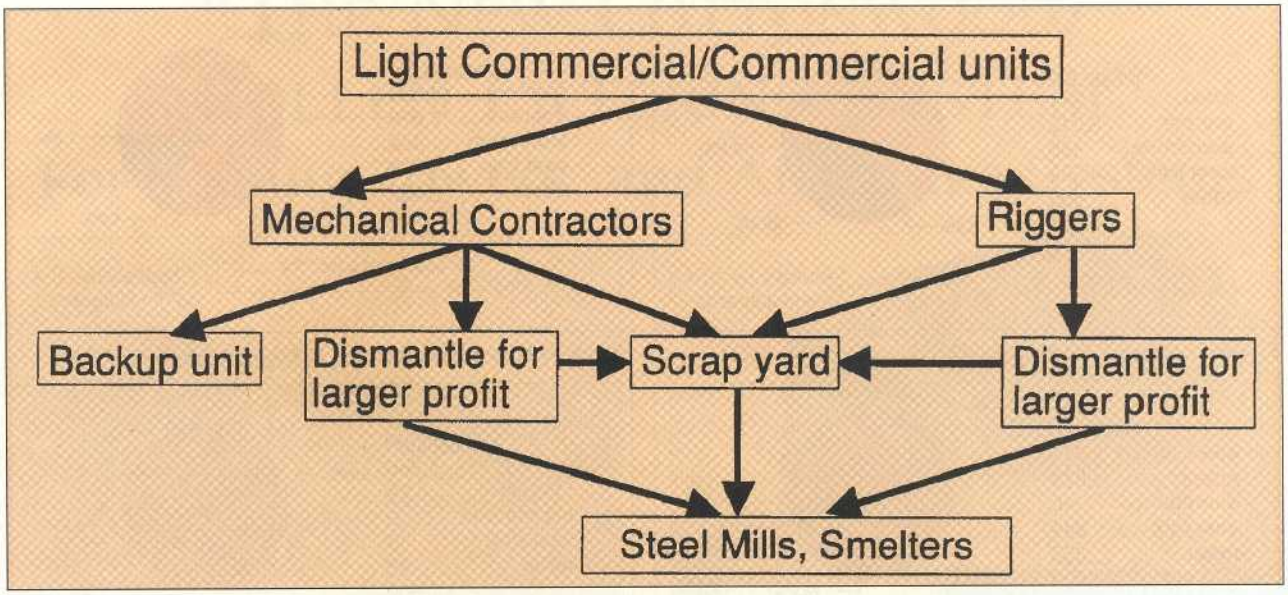

Figure 1A: *The flow of decommissioned light commercial/ commercial air-conditioning and refrigeration equipment.*

Recycling of Air-Conditioning and Refrigeration Equipment in the U.S.

By Glenn C. Hourahan, P.E.; and Karim Amrane, Ph.D.

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This is an overview on the disposal of construction materials from decommissioned air-conditioning and refrigeration equipment. The analysis relied upon surveys and interviews conducted with equipment manufacturers, mechanical contractors and companies involved in the solid waste handling/ recovery field. Equipment covered herein includes commercial chillers, unitary split and package-systems, refrigerated food cases, and ice makers. Information not previously available on the material composition of representative systems is presented. It is found that the high metallic content of these types of equipment result in a residual intrinsic value, thereby leading to a high level of material recovery.

Utilization of air-conditioning and refrigeration (AC&R) equipment has become ubiquitous in developed countries. Notable uses include comfort conditioning, industrial process cooling, and food preservation. Beyond satisfying specific application requirements, current drivers impacting equipment designs are cost effectiveness, legislated energy efficiency minimums, and environmental sensitivity to ozone depletion and global warming implications.

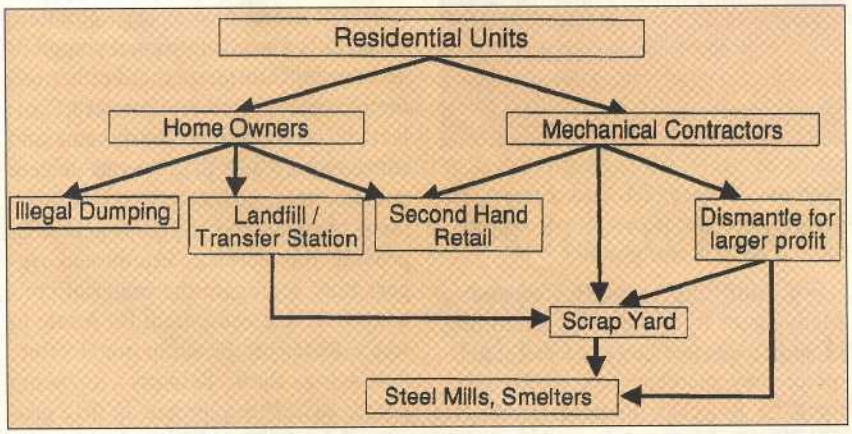

Figure 1B: *The flow of decommissioned AC&R residential units.*

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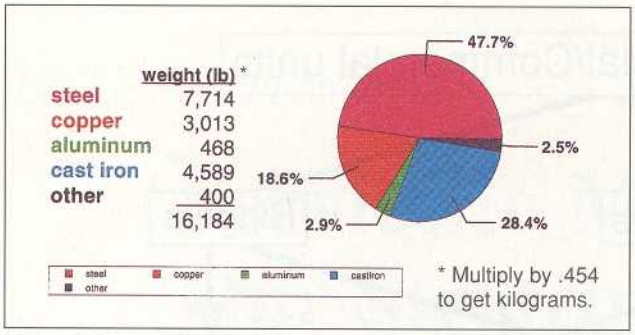

Figure 2: Material content of a 400-ton centrifugal chiller.

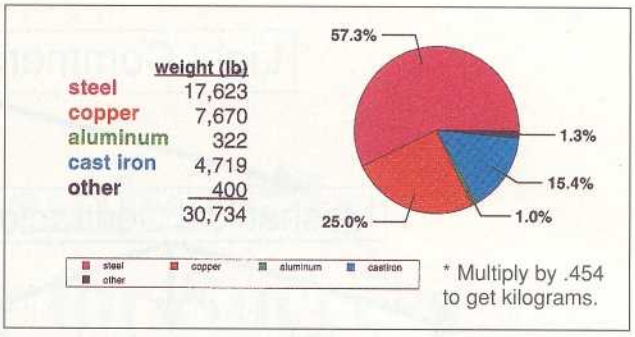

Figure 3: Material content of a 1,000-ton centrifugal chiller.

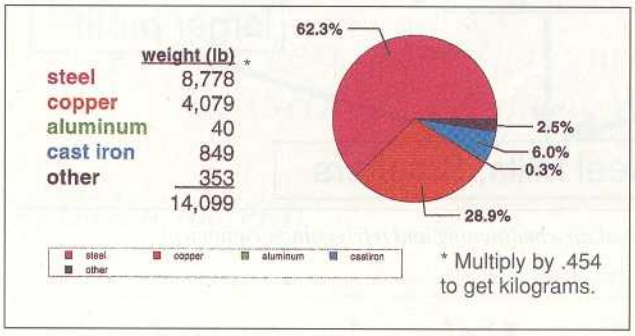

Figure 4: Material content of a 500-ton screw chiller.

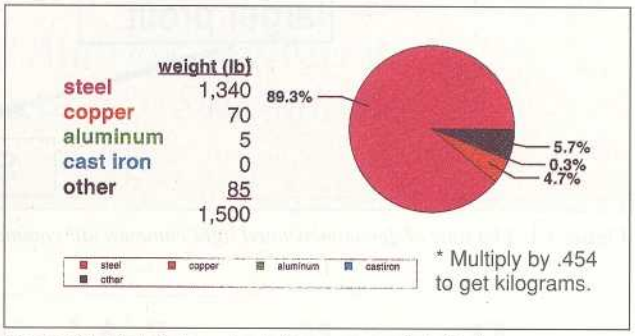

Figure 5: Material content of a supermarket display case.

However, limited attention has been given to the environmental consequence of what happens to decommissioned AC&R products at the end of their useful lives. In various equipment applications, a large percentage of each year's production is for replacement of obsolete or worn out systems. Where do the decommissioned units end up? Are landfills being burdened by this refuse? What percentage of the decommissioned unit can be diverted from landfills via recycling activities? Does a market exist for these recycled components? These are questions that this work sought to address.

This investigation was undertaken in two distinct steps. The first step was to contact people in the waste/recycling industry to ascertain how, and to what extent, AC&R systems are received from the field and are ultimately disposed of. Mechanical contractors, scrap yard dealers, landfill operators, and ancillary entities that coordinate material processing/transporting/repackaging were contacted.

The second step involved the identification of equipment classifications to obtain a broad profile representative of the U.S. AC&R market. For each of these categories, material content information was solicited from manufacturers on equipment most reflective of those sold in the marketplace (e.g., representative capacity and efficiency).

Decommissioning paths of AC&R equipment

When AC&R equipment is decommissioned, there are several potential options available (depending on size): the equipment can be sent to landfills, recycled for scrap metal, repaired for resale, or used as emergency backup systems. *Figure 1A* and *Figure 1B* summarize the flow of decommissioned AC&R equipment.

This investigation was undertaken in two distinct steps. The first step was to contact people in the waste/recycling industry to ascertain how, and to what extent, AC&R systems are received from the field and are ultimately disposed of . . . The second step involved the identification of equipment classifications to obtain a broad profile representative of the U.S. AC&R market.

• **Landfilling** is rarely seen today. Many states have outlawed landfilling of appliances and larger AC&R equipment; they mandate that such equipment be recycled. In most instances, AC&R equipment delivered to landfills is not disposed of there. Instead, equipment is stockpiled until a large enough quantity is reached to sell to a scrap dealer. In rural areas, however, AC&R units with low intrinsic value are sometimes illegally dumped in remote ravines, water ways, abandoned industrial areas, railroad right-of-ways, and roadsides. Typically, persons illegally dump AC&R equipment to avoid the inconvenience of properly disposing of them at scrap yards or waste management facilities.

• **Recycling** is the most prevalent method of disposing of AC&R units because there are many entities that make a living by salvaging discarded equipment. Mechanical contractors and large AC&R retailers often offer to remove old units with the purchase of a new one. This service is usually reflected in the new system purchase price, either as an additional charge or as a credit. Contractors will either use their own staff and equipment to collect decommissioned equipment and subsequently sell it to scrap dealers and smelters, or for very large equipment, specialized riggers generally provide this service. Equipment riggers may segregate the material content of AC&R equipment for resale to scrap dealers at the scrap metal value. Following their delivery to scrap yards, AC&R equipment is first processed, and then shredded either on

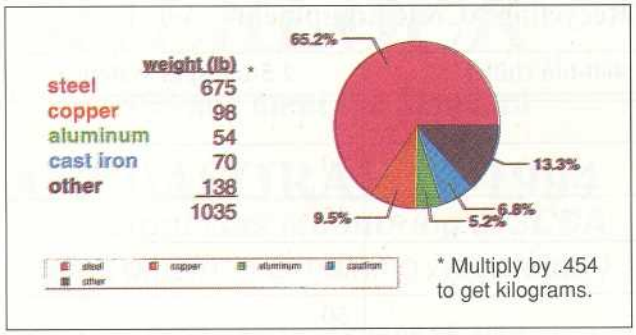

Figure 6: Material content of a 10-ton rooftop unit with gas heat section.

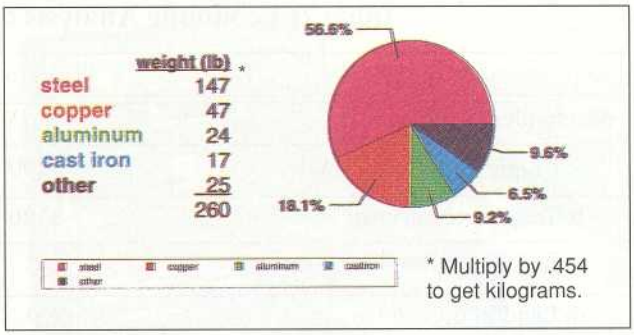

Figure 7: Material content of a 2.5-ton residential split system.

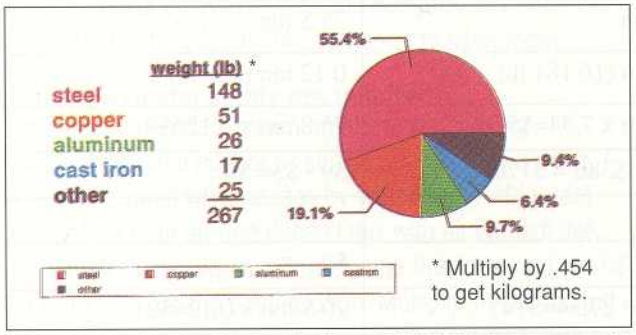

Figure 8: Material content of a 3-ton (10 SEER) heat pump with air handler.

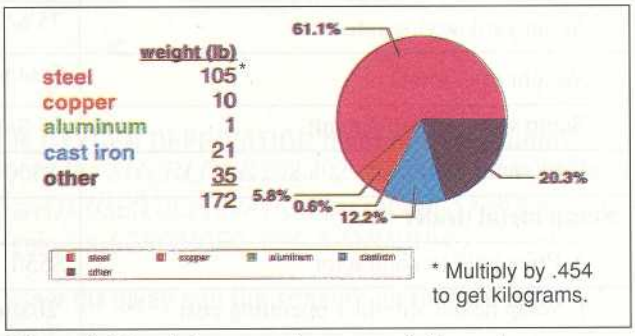

Figure 9: Material content of a commercial ice maker.

site or at a metal shredding facility. Finally, the shredded metal is sold to steel mills and various smelters.

• **Processing** usually involves removing several components of the decommissioned AC&R equipment such as motors, compressors, oil, copper tubing, and wiring. In addition, PCB (polychlorinated biphenyl) capacitors, as well as the refrigerant contained in the equipment, are recovered as required by law. These capacitors are used to assist motors during start ups. The processing of AC&R equipment is often performed at the scrap yard, but there are instances where outside contractors are hired to do the work.

• **Shredding** consists of fragmenting the scrap metal into small and more manageable pieces. The fragmentation process is usually done by feeding the scrap metal into a hammermill or shredder. After this process, the resulting material travels on a conveyor belt to a sorting operation where ferrous metals and nonferrous metals are separated from the nonmetallic waste. The steel materials are magnetically separated and discharged from the conveyor belt to form large piles of shredded steel scrap, and are then sold to steel mills. Nonferrous metals such as copper, aluminum and zinc are sorted and shipped to their appropriate smelters. The remaining materials or "fluff" (usually made of glass, plastic and rubber), which has no intrinsic value, is sent to landfills for disposal.

• **Secondhand retailers** are those who specialize in repairing used AC&R for resale. They purchase used equipment from mechanical contractors, homeowners and new AC&R retailers, at a price that depends on the condition of the equipment, the cost of repair, and the transportation distance. Secondhand retailers market small unitary equipment to low income residents. Equipment that is not repairable is stripped of its useful spare parts, and the remains are sold to scrap dealers. Secondhand retailing is not a significant sector of the market.

Commercial equipment in relatively sound operating condition may be stockpiled by a mechanical contractor for subsequent use as emergency backup for temporary applications. Although this equipment performs satisfactorily, it may be decommissioned prior to its useful life due to other considerations such as remodeling and expansion, markedly lower or higher capacities required from the system, or, as of late, managment decisions to phase out CFCs. Temporary cooling enables comfort conditioning during emergency loss of cooling, for remodeling activities, and for temporary events or short-term functions. Eventually, however, these units will require disposal.

Type of Scrap	Approximate Value
Steel (shredded auto scrap)	$142-$152 per ton (6.5 cents per pound)
Copper (heavy copper and wire)	98-105 cents per pound
Aluminum (low copper clips)	60-65 cents per pound
Cast iron (heavy breakable cast)	$90-$110 per ton (5 cents per pound)

Table 1: Value of segregated scrap delivered to steel mills and smelters.

Material content of AC&R equipment

AC&R equipment is fabricated from a large variety

Table 2: Economic Analysis of Recycling AC&R Equipment

	400-ton chiller	2.5-ton split system
Mechanical Contractor		
a. Contractor pick-up cost[1]:	$200	$0
b. Transportation cost:	$180	$3
c. Refrigerant handling cost:	$0[2]	$0
d. Landfill tipping fee:	$0[3]	$0
Disposal cost to contractor (a+b+c+d)	$380	$3
Scrap yard buying rate[4]:	75 $/ton	75 $/ton
Weight of equipment[5]:	7.34 ton (16,184 lb)	0.12 ton (260 lb)
Scrap value of equipment:	75 $/ton x 7.34=$550	75 $/ton x 0.12=$9
Contractor net profit:	$550 - $380 = $170	$9 - $3= $6
Scrap metal dealer		
e. Price paid to contractor	$550	$9
f. Scrap dealer shredder operating cost:	20$/ton x7.34=$147	20 $/ton x 0.12=$2
g. Cost of dismantling for max. profit: Time to dismantle the unit: Hourly wage of dismantlers:	$10 x 24=$240 24 hours $10	$0 n/a n/a
h. Capacitor disposal cost:	$50	$5
i. Fluff disposal cost: Fluff disposal rate: Weight of fluff:	40 $/ton x 0.18=$7 40 $/ton of fluff 0.18 ton (400 lb)	40 $/ton x0.011=$0.4 40 $/ton of fluff 0.011 ton (25 lb)
j. Transportation cost of fluff to landfill:	25 $/ton x 0.18=$4	25 $/ton x0.011=$0.3
k. Transportation cost of recovered metals to steel mills & smelters:	25 $/ton x 7.34=$183	25 $/ton x 0.12=$3
Scrap dealer cost (e+f+g+h+i+j+k)	$1,181	$20
Value of unit's metallic content:	$4,082	$73
Scrap dealer profit	$4,082 - $1,181 = $2,901	$73 - $20 = $53

1. Excludes disassembly/removal from the mechanical room since that transaction is usually included in the replacement costs of the unit.
2. There is approximately 800 lb of refrigerant in a 400-ton chiller, with a street value of approximately $4,500 if not contaminated. Since the refrigerant may be retained by the owner or the contractor, this positive offset is ignored.
3. The avoidance of a landfill tipping fee by recycling the equipment should result in a positive offset (for the 400 ton chiller, this fee is of the order of $25/ton x 7.34=$183). However, this analysis handles the tipping fee at no cost.
4. Higher rates may be paid to regular suppliers of scrap.
5. This weight excludes the weight of the refrigerant and all working fluids.

of materials. However, the greatest percentage of the overall weight is from the metals. Steel is used for structural support rails and. brackets, enclosure casings, motor bodies (e.g., stamped laminations), and compressor shafts and rotors. Copper and aluminum are used in heat exchangers (e.g., tube bundles and fins) and electric induction motors. Cast iron is utilized in component housing and compressor bodies. To a smaller extent, a whole suit of other materials is also used, including plastics (used in casing electronic and other small components), various insulation materials (for heat and electrical impedance), rubber (vibration isolators), and a small amount of glass. As indicated earlier, these "other" materials are considered "fluff" at time of disposal, and, having little residual value, are generally put into a landfill.

Following are various application that are reflective of systems most commonly marketed in the U.S. For the purposes of discussion, the weights of the refrigerants (generally 1.5-3.0 pounds of refrigerant per ton [one ton= 12,000 Btu/hr of cooling capacity] of system refrigeration capacity), the lubricants (generally a few ounces up to 50 gallons [189.5 L] depending on the type and capacity of the unit), and the initial packaging materials have been subtracted from the overall weights. Only the dry, free standing weight of the equipment was considered.

Commercial Chillers: Commercial chillers are used for industrial processes and air-conditioning of large applications. These units are typically sized from 200 tons (700 kW) to well in excess of 10,000 tons (35000 kW). The U.S. domestic usage, for the past several years, has been approximately 3800-4800 units per year[1]. For the last several years, approximately 60% of these are for the replacement of existing applications; the balance are for new applications.

Figures 2, 3, and *4* depict the material content for a 400-ton (1400 kW) centrifugal chiller, a 1000-ton (3500 kW) centrifugal chiller, and a 500-ton (1750 kW) screw chiller, with total weights of 16,184 pounds, 30,734 pounds, and 14,099 pounds, respectively. As can be seen, approximately half of the weight is steel. Other metals are copper (18-25%), cast iron (6-28%), and aluminum (.3-3%). Thus, only 2% of a chiller's overall weight ends up in landfills.

Hence, chiller equipment is 98% composed of metals that maintain an intrinsic value at the time the systems are decommissioned. By using the values of segregated scrap metals shown in *Table 1*, the chiller residual values were calculated and found to be quite high: $4,082 for a 400-ton (1400 kW) centrifugal chiller, $9,368 for a 1000-ton (3500 kW) centrifugal chiller, and $4,778 for a 500-ton (1750 kW) screw chillers.

Supermarket Display Cases: Food display cases (used in grocery and convenience stores for the preservation of frozen goods, dairy product and produce) come in many sizes and configurations. Today's supermarket cases are constructed with the evaporator coils inside the cases and the refrigeration rack system in the back of the store. The refrigeration racks have useful lives of approximately 25 years, while in general, display cases have effective lives of 5-8 years. Food display cases are replaced more frequently since marketing upgrades, done to continually attract customers, are the driving factor. Since the materials of construction for refrigeration racks are very similar to that of commercial equipment, the more interesting assessment is on the display cases. As can be seen in *Figure 5*, a typical dairy display case (including sides and shelving) is nearly 90% steel. The balance of the weight is nearly equally split between the copper and aluminum in the evaporator and the "other" category (e.g., insulation in the side panels, lighting, wiring, glass, etc.). Using *Table 1*, it can be seen that the residual value for a 12-ft long dairy case is approximately $161.

Unitary Rooftop Units: Roof top units are widely used in applications from small commercial buildings to sprawling strip malls. These units typically range in capacity from 5 tons (17.5 kW) to 25 tons (87.5 kW). The majority of units shipped are in the 7.5 (26.3 kW) to 12-ton (42 kW) size range. Approximately 55% of newly-manufactured roof top systems go to the replacement market.

The vast majority of decommissioned AC&R equipment is recycled by scrap yards. Very little equipment ends up in landfills as there is a great economic incentive to recycle it. The recycling infrastructure is well established, from collection, to processing, shredding and manufacturing. Various businesses, including mechanical contractors, riggers, retailers, refrigerant reclaimers, scrap yard dealers and smelters have a stake in this recycling infrastructure.

Figure 6 illustrates the material content of a typical 10-ton rooftop unit with a gas heat section. In this case, nearly 65% is steel, 10% copper, 7% cast iron, 5% aluminum, and 13% "fluff". Using *Table 1*, the residual value is evaluated at $181.

Residential Air-Conditioning: The vast majority of residential air-conditioning built into homes is made up of unitary ducted split systems in the 2 to 5-ton (7 to 17.5 kW) range. This definition excludes small window units (generally, consumer installed) and packaged terminal air-conditioners (PTACs; generally through-the-wall systems). These systems are composed of two distinct units: an indoor coil (a sheet metal boxed "A" coil or slant coil) and an outdoor condensing unit. These two components are connected via copper tubing. Approximately 5 million such units are produced each year[1], with about 50% for the replacement market.

Figures 7 and *8* illustrate the material content for a 2.5-ton (8.75 kW) split system air conditioner and a 3-ton (10.5 kW) split system heat pump (neglecting the inter-connecting copper tubing). It is seen that a high percentage of metals exists in decommissioned residential systems. The amount of "fluff" is approximately 10% of the overall weight. Again, using *Table 1*, the residual values are found to be $73 for a 2.5-ton (8.75 kW) residential split system, and $78 for a 3-ton (10.5 kW) heat pump system.

Ice Makers: Commercial ice machines are widely used in restaurants, hotels, sporting facilities, movie theaters, etc. Approximately 160,000 ice makers (cubers and flakers) are produced each year[3]. *Figure 9* illustrates the material content of a 500 lb/day commercial ice maker. In this case, 61% is steel, 6% is copper, and 12% is cast iron; 20% of the unit represents "fluff." The residual value of ice makers is $19.

An economic example of recycling

As indicated earlier, material recycling is the most prevalent method of disposing of AC&R equipment due to its high intrinsic values. Yes, there is a financial incentive for mechanical contractors and scrap yard dealers to recycle AC&R equipment. However, society as a whole also benefits from recycling due to the reduction in the solid waste stream, the life extension of landfills, and the preservation of natural resources.

In an attempt to ascertain the economics of recycling, a simple analysis was conducted on a 400-ton (1400 kW) centrifugal chiller and a typical 2.5-ton (8.75 kW) split system air conditioner. The analysis estimates the costs and profits to the mechanical contractors and scrap metal dealers resulting from the various operations involved in the recycling process of AC&R equipment. *Table 2* briefly illustrates the procedure followed to estimate these costs and profits. Some of the cost estimates used in the analysis were obtained from the Steel Recycling Institute.[4]

The estimated profits shown in *Table 2* are significant in the case of the chiller, particularly for the scrap yard

dealer because of the large residual value of the equipment, which in this case was evaluated at $4,082 based on the values shown in *Table 1*. This residual value is from the unit's metallic content after processing and when ready to be sold to steel mills and/or smelters. For the 2.5-Ton (8.75 kW) split system, the profits are considerably less. Equipment with even lower residual values, such as ice makers, may need additional incentives to be economically recycled.

Conclusion

The vast majority of decommissioned AC&R equipment is recycled by scrap yards. Very little equipment ends up in landfills as there is a great economic incentive to recycle it. The recycling infrastructure is well established, from collection, to processing, shredding and manufacturing. Various businesses, including mechanical contractors, riggers, retailers, refrigerant reclaimers, scrap yard dealers and smelters have a stake in this recycling infrastructure.

Information on the material content obtained from various AC&R equipment manufacturers indicates a high level of metal content. Fortunately, with today's technology, metals are easily recycled, which means that AC&R equipment is generally easy to recycle as well. In the future, it is expected that the recyclability rate of AC&R components will become higher as manufacturers keep improving designs for easier disassembly and as additional markets develop for recycled materials.

Acknowledgment

A variety of individuals provided data that assisted this investigation. To a large extent, that data was provided on a confidential basis. Information on the metallic content of specific air-conditioning and refrigeration systems is of a highly proprietary nature, especially in consumer applications. Knowing the approximate amount of materials used in various systems could enable third parties to make a rough estimate on the cost of manufacture, thereby establishing a profit profile. Additionally, the specific prices that various entities may pay for scrap material is also of a competitive nature. For these reasons, contributors were assured that they, their company affiliations, and trade names/model designation would not be identified. However, assistance from these individuals and their companies is greatly appreciated. ■

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