

Part C: Copper Recycling in the State of Connecticut

ABSTRACT

The recovery rate, recycling efficiency, and recycling rate for copper from in-use stock discards were quantified for the State of Connecticut for the year 2000. With a recovery rate of 84%, and recycling efficiency of 75%, the overall recycling rate was found to be 63%. The overall recycling rate of both old and new scrap is therefore estimated to be approximately 70%. Neglecting sewage sludge, the lowest recycling rate occurred in end-of-life vehicles and waste from electronic and electrical equipment (45%). The highest recycling rate occurs for copper derived from infrastructural discards (95%).

1. OVERVIEW

Copper, as a valuable material, commands a relatively strong price for its scrap form. Not as rare as some metals (e.g., gold and platinum) or as abundant as others (e.g., aluminum and iron), it nonetheless exhibits the same characteristic of other metals in that it takes less energy to produce copper from scrap than from ore. Therefore, as a raw material resource, it can be quite useful to understand the state of copper recycling.

Having quantified discard flows in Connecticut (see Part B), they can then be disaggregated between loss and recovery. Many definitions of various “recycling rates” exist, and although certain definitions are becoming more widely accepted, debate continues as to the details. In general, the first stage in recycling is the actual recovery of the scrap, while the second stage is the technological extraction of the metal from the scrap. Sometimes this second stage is a non-event (e.g., plumbing tube), while at other times it entails a major loss (e.g., copper extraction from vehicle shredding). The first stage is called the recovery rate. The second stage is the recycling efficiency. Multiplying these together gives the total recycling rate. Details of the ratios are given below (as adapted from Quinkertz *et al.* 2001 and Norgate 2004).

$$\text{Recovery Rate} = \text{Amount of scrap recovered} / \text{total amount of available scrap}$$

$$\text{Recycling Efficiency} = \text{Amount of scrap melted} / \text{amount of scrap recovered}$$

$$\text{Recycling Rate} = \text{Amount of scrap melted} / \text{total amount of available scrap}$$

$$\text{Recycling Rate} = \text{Recovery Rate} * \text{Recycling Efficiency}$$

2. METHODS

2.1 RENOVATION AND DEMOLITION DEBRIS (R&DD)

2.1.1 Recovery Rate

The recovery rate of R&DD was determined by finding the recovery rate of each individual category of R&DD. For HVAC, other built-in appliances, and mechanical mobility transport (elevators, escalators, etc.), the recovery rate was assumed to be the same as the steel recovery rate from construction and demolition debris and the recovery rate of large appliances (both about 85%) (ARIC 2000; U.S.EPA 1998). The recovery rate from Chromated Copper Arsenate (CCA) lumber was assumed to be zero, as it cannot be burned and must be disposed of by landfilling in most cases (a special incinerator can be used to reclaim heavy metals). Architectural scrap recovery was assumed to be 85%, based upon interviews with demolition contractors, in which they claimed that 80-90% of the “visible” copper is recovered. Wiring, plumbing, and other hardware was assumed to have an overall recovery rate of 50% in demolitions and renovations. This value of 50% is derived from the interviews with demolition

contractors. A discrepancy arose between the generally claimed recovery rate of copper (80-90%) and the actual amount of copper recovered from a typical structure. Demolition contractors claimed to recover 40-100 lbs of Cu from a typical single family home, though the CDA claims that a typical single-family house is comprised of ~440 lbs of copper, giving a recovery rate more like 10-20%. A middle ground of 50% was selected for this analysis. Further study would be worthwhile to resolve this discrepancy.

R&DD is somewhat special in that there are two clear actors in recovery: those first on the scene (predominantly demolition contractors), and the volume reduction facilities which receive R&DD, process it, and then ship most of it off to a landfill. Other actors may also add a third or fourth step in recovery, but it is unlikely this is how the majority of R&DD is handled. Based upon the STAF estimate of 500 ppm (mg/kg) copper concentration in Construction & Demolition Debris (C&DD) applied to the total C&D/Oversized MSW (managed together in Connecticut and called bulky waste, but is essentially C&D), a total amount of copper in the R&DD headed to the landfill can be assessed. This calculation assumes that this concentration applies to R&DD at the stage of the waste management stream in which the total bulky waste is shipped to the landfill (after volume reduction and material recovery). Total bulky waste in Connecticut is available in the Connecticut Solid Waste Management Plan of 2006 (CT DEP 2006). Assuming this concentration accounts for the total copper lost, than the volume reduction facilities would be recovering approximately 75% of the copper they receive. This value has yet to be verified. If it is not accurate, than it is likely true that more copper is being lost (and less being recovered) than the present numbers indicate.

2.1.2 Recycling Efficiency

The recycling efficiency of plumbing tube, wire, and architectural copper is assumed to be essentially 100%, as they are not intricately attached to other materials (e.g., alloyed). Other hardware, which contains a fair amount of brass hardware, is assumed to have a 75% recycling efficiency. This would mean that for brass hardware, the copper contained within brass has a 75% recycling efficiency when the object is processed for metal recovery. Of course, the metal recycled would be brass, not copper, but copper would nonetheless be recycled, so it is counted. The recycling efficiency for copper of HVAC, other built-in appliances, and mechanical mobility equipment is assumed to be the same as cooling appliances, at 65% (Malmgreen-Hansen and Nilsson 2005).

2.2 WASTE FROM ELECTRONIC AND ELECTRIC EQUIPMENT (WEEE)

2.2.1 Recovery Rate

The recovery rate of electronics and electrics varies somewhat between residential and commercial equipment. For electronics, the recovery rate of all electronics was assumed to be the same as that for computers (as recovery rates for other electronics

were not found or produced). So while 11% of computers are recovered (as of 1998), fully 80% of these computers are recovered from commercial sources (NSC 1999). A second calculation, based upon actual data on electronics recovery in the municipal solid waste stream, was also performed to find the copper recovered in residential electronic waste (CT DEP 2006b). For electrical equipment, 84% of major appliances were recovered from all sources (ARIC 2000). This recovery rate was applied to all electrical equipment, both residential and commercial. A refined calculation could separate small from large appliances, and electrics in municipal solid waste versus other direct routes of recovery (retail take-back and utility recovery incentive programs). In doing so, one would be able to utilize the facts that 67% of major appliances are recovered that enter the municipal solid waste stream, and that only 2.2% of small appliances are recovered (US EPA 2003). No recovery rate of industrial electrics was found or produced, so an assumption of 75% recovery was assumed.

2.2.2 Recycling Efficiency

The ability to extract copper from a computer is estimated at 90% (MCC 1996). This recycling efficiency was assumed to be the same for all electronics. The recycling efficiency of copper from cooling appliances has been estimated at 65% (Malmgreen-Hansen and Nilsson 2005). This recycling efficiency was applied to all electric equipment.

2.3 SEWAGE SLUDGE (SS)

2.3.1 Recovery Rate

Ten percent of the sewage sludge in Connecticut is composted, while the remaining 90% is predominately either incinerated (74%) or exported (14%) (CT DEP 2006). We were not able to determine the fate of exported sewage sludge (is it incinerated, composted, landfilled?), so it is assumed that all exported sewage sludge is not recovered. Connecticut law does not permit beneficial reuse of the ash residue produced from incinerated sewage sludge, so it is landfilled. Therefore, 10% of sewage sludge is recovered, as composting is considered a form of recovery (i.e., reuse).

2.3.2 Recycling Efficiency

No significant loss of copper is thought to occur during the composting process, providing a 100% recycling efficiency for composted sewage sludge.

2.4 END-OF-LIFE VEHICLES (ELV)

2.4.1 Recovery Rate

The recovery rate of automobiles is widely regarded to be about 95% (U.S. EPA 1996; Ward's 2005). Due to the low number of aircraft and the value of scrap aluminum contained in their frames, it is assumed that the recovery rate for aircraft is as high as for automobiles, or 95%. Marine vessel recovery varies depending upon the type of

ship. All submarines are recovered, as a submarine has not been lost by the U.S. Naval fleet since the late 1960s, and the U.S. Navy has a special program called the Ship and Submarine Recycling Program in which all decommissioned navy ships are carefully dismantled. Recreational boats, with hulls constructed mostly of fiberglass or wood, are often landfilled as bulky waste or scuttled in the sea (e.g., Rosynsky 2006).

It is actually quite unclear what happens to old boats, though the accumulation of scuttled boats in some parts of the U.S. has reached large enough magnitudes to become a problem. In contrast, many boat dismantling facilities exist for recreational boats, and municipal solid waste facilities in high boating areas often offer information on how to dispose of an old boat. Based upon all this anecdotal information, it was assumed that recreational boats are recovered at a 50% rate. For larger marine vessels such as fishing vessels, barges, and tugs, a recovery rate of 75% was assumed, as these boats are more worthwhile for recovery (called boat or ship breaking) for their metal contents, though it is known that a number of these are scuttled to produce artificial reefs or sink in accidents.

2.4.2 Recycling Efficiency

Automobiles are predominantly recycled in Connecticut by mechanical shredding, which has a recycling efficiency for copper of between 40-60% (van Schaick 2004; ICSG 2004; Zeltner et al. 1999). We use the recycling fraction of 0.47 for the actual calculation (von Schaick 2004). Aircraft are dismantled by hand, so the recycling efficiency of copper is likely to be higher than for automobiles. The demonstrated total potential fraction of material recovery from aircraft is 0.85-0.95, so for copper it is assumed to be a similar fraction, set at 90% for the calculation in this study. All copper from submarines is assumed to be recycled, given the thorough nature of the Navy's Submarine Recycling Program, while 85% recycling efficiency is assumed for copper recovered from recreational boats. No information was found or produced regarding the recycling efficiency of copper from other large marine vessels, so the recycling efficiency was arbitrarily set at 75%.

2.5 INFRASTRUCTURAL DISCARDS (SS)

2.5.1 Recovery Rate

The recovery of copper from infrastructural waste is assumed to be 95%. This informed estimate is based on interviews with SBC, United Illuminating, and Connecticut Light & Power, all of whom indicate that copper wire/cable scrap is entirely recovered, given the nature of heavy management of the wire that forms the very basis of their business. Ninety-five percent is selected to allow for miscellaneous losses. This recovery rate is extrapolated to apply to all infrastructural waste, including copper tubing used in water distribution.

2.5.2 Recycling Efficiency

Essentially all of the infrastructural waste is either copper wiring or copper tube, both of which have very high recycling efficiencies. As with R&DD, the recycling efficiency is set at 100%.

2.6 MUNICIPAL SOLID WASTE

Vin Langone of Wheelabrator reports that 0.05% of the municipal waste received at the Lisbon, CT waste-to-energy facility is composed of non-ferrous metals (Langone 2005). This value is assumed to apply to all waste-to-energy facilities in Connecticut. A calculation applied to data obtained for the Bridgeport, CT Waste to Energy RESCO facility indicated that copper comprised only .0001% of waste, which appears to be unrealistically low. As such, assuming that 40% of the non-ferrous fraction of municipal solid waste is comprised of copper (with much of the rest of the non-ferrous fraction as aluminum, with lower quantities of other metals), 02% Cu content of municipal solid waste was assumed for the municipal solid waste that is lost into incineration (incinerator ash is landfilled). The remaining municipal solid waste is recovered between discard and incineration, likely at transfer facilities.

Due to the overlap of electronic and electrical waste with municipal solid waste, this final recovery rate number is not used, as essentially all copper in municipal solid waste is either R&DD or WEEE, the recovery rates of which are already assessed, having factored in the waste regardless of whether it ends up in the bulky waste, municipal solid waste, electronic waste, or other waste stream in Connecticut. As for the other metal not accounted for that enters municipal solid waste, it is presently assumed all of this copper is lost, with no recovery.

2.7 HAZARDOUS WASTE

This category is not analyzed, as copper cyanide discards are not quantified.

2.8 INDUSTRIAL WASTE

This category of waste does not arise from in-use discards, but rather manufacturing/fabrication discards, so the recycling rate is not explicitly quantified here. Obsolete machinery does arise from in-use discards, and is incorporated into the WEEE number. A rough calculation is performed, combining Toxic Release Inventory (TRI) data (which disaggregates copper discards from large producers) with the old scrap recycling rate, to produce a rough approximation of the overall recycling rate (old and new scrap) in Connecticut.

3. RESULTS

The disaggregated copper flows for each independent waste stream are given in Table 1. The recycling efficiency of sewage sludge is 100% since once the sludge is recovered for composting, no other extraction step is required. Waste from

infrastructure is essentially either wire or tube, both of which have technological recycling efficiencies near 100% due to their non-alloyed nature. Though most of the copper in vehicles is recovered, much is lost during technological extraction. The present recovery rate for renovation and demolition debris is optimistic, as it assumes that the copper concentration used in the literature refers to post-recovery steps (e.g., what would be observed from sampling R&DD at the transfer station ready to head to the landfill).

Table 1 Summary of recovery rate, recycling efficiency, and recycling rate for each independent waste stream. The top half of the chart reports total copper mass flow, while the bottom half reports copper mass flow on a per capita basis.

Connecticut	Recovery Rate		Recycling Efficiency		Recycling Rate	
	<i>Lost</i> Cu kg/yr	<i>Recovery</i> Stream Cu kg/yr	<i>Lost from</i> Recovery Stream Cu kg/yr	<i>Recycled</i> from Recovery Stream Cu kg/yr	<i>Total</i> Lost Cu kg/yr	<i>Total</i> Recovered Cu kg/yr
End of Life Vehicles	239,968	3,664,256	1,903,746	1,760,510	2,143,714	1,760,510
Sewage Sludge	95,476	10,608	0	10,608	95,476	10,608
Waste from Electronics and Electrics	1,423,739	3,115,202	1,069,918	2,045,284	2,493,657	2,045,284
Renovation & Demolition Debris (w/o new clippings)	819,387	5,408,999	635,756	4,773,243	1,455,143	4,773,243
Infrastructural Discards	117,707	2,236,439	0	2,236,439	117,707	2,236,439
TOTAL	2,696,277	14,435,504	3,609,420	10,826,084	6,305,697	10,826,084

Connecticut per capita	Cu (kg/yr)/ person	Cu (kg/yr)/ person	Cu (kg/yr)/ person	Cu (kg/yr)/ person	Cu (kg/yr)/ person	Cu (kg/yr)/ person
End of Life Vehicles	0.07	1.08	0.56	0.52	0.63	0.52
Sewage Sludge	0.03	0.00	0.00	0.00	0.03	0.00
Waste from Electronics and Electrics	0.42	0.91	0.31	0.60	0.73	0.60
Renovation & Demolition Debris (w/o new clippings)	0.24	1.59	0.19	1.40	0.43	1.40
Infrastructural Discards	0.03	0.66	0.00	0.66	0.03	0.66
TOTAL	0.79	4.24	1.06	3.18	1.85	3.18

Table 2 The recovery rate, recycling efficiency, and recycling rates for Connecticut’s copper in-use stock discards. The recycling rate is found by multiplying the recovery rate by the recycling efficiency.

	Recovery Rate	Recycling Efficiency	Recycling Rate
End of Life Vehicles	94%	48%	45%
Sewage Sludge	10%	100%	10%
Waste from Electronics and Electrics	69%	66%	45%
Renovation & Demolition			
Debris (w/o new clippings)	87%	88%	77%
Infrastructural Discards	95%	100%	95%
TOTAL	84%	75%	63%

Taking into account new scrap produced from manufacturing (as reported in TRI data for large producers) and the new scrap clippings produced during construction, an overall recycling rate of copper for Connecticut is approximated at ~70%.

The largest error associated with these estimates is likely due to the recovery rate of the largest discard flow, R&DD, the complications of which have been discussed. A sensitivity analysis, wherein the volume reduction facilities were assumed to recover *no* copper, reduces the overall old scrap recycling rate to 54% (74% overall recovery and 72% recycling efficiency), with an overall recycling rate of copper (new and old scrap) for Connecticut approximated at ~65%. As such, it appears that the true old scrap recycling rate in Connecticut falls within the range 60% +/- 10%, with the true overall (new and old scrap) copper recycling rate falling within 65% +/- 10%.

4. DISCUSSION

The recovery rate of copper in Connecticut would appear to be quite good at 84%, matching the recovery rate found for New Haven (84%), and far exceeding the recovery rate of 42% for the entire U.S.A. (Gordon *et al.* 2004). However, this rate lags the 97% recovery rate observed in Sofia, Bulgaria (Dimitrova *et al.* 2007). Technological extraction of Connecticut’s copper once recovered lags behind the efficiency of recovery. The resulting overall (old and new scrap) recycling rate, ~70%, has no other comparable reference. No other recycling rate is known for the USA, though the USGS estimates 30% (USGS 2002). However, this rate is more accurately called a return rate, as it is influenced by the lifespan of products. Return rates tend to underestimate the true recycling rate of products that have longer lifetimes (Norgate 2004).

5. CONCLUSION

The value of the “recycling rate” of any metal, not just copper, appears to depend heavily upon how one defines the rate. Methodology and error play a secondary role

in defining the accuracy of the results. We try to use a modern definition of recycling rate, and report both recovery rate and recycling efficiency numbers. More room certainly exists not only to refine our reported recycling rate, which may vary by up to +/- 15%, but to conduct other case studies in order to better understand and quantify the metal material waste stream.

ACRONYMS

AHAM	Association of Home Appliance Manufacturers
ARIC	Appliance Recycling Information Center
ASTM	American Society for Testing and Materials
AWWA	American Water Works Association
BTS	Bureau of Transportation Statistics
CBECS	Commercial Buildings Energy Consumption Survey
CCEA	Connecticut Center for Economic Analysis
CDA	Copper Development Association
CTA	Center for Transportation Analysis
CT DEP	Connecticut Department of Environmental Protection
CT DOL	Connecticut Department of Labor
CT DOT	Connecticut Department of Transportation
CT DPH	Connecticut Department of Public Health
CT DPS	Connecticut Department of Public Safety
CT DPUC	Connecticut Department of Public Utility Control
EIA	Energy Information Administration
FHWA	Federal Highway Administration
HVAC	Heating, Ventilation, and Air Conditioning
ICSG	International Copper Study Group
JRCP	Jointed Reinforced Concrete Pavement
JEMAI	Japan Environmental Management Association for Industry
MCC	Microelectronics and Computer Technology Corporation
MECS	Manufacturing Energy Consumption Survey
NAICS	North American Industrial Classification System
NASS	National Agricultural Statistics Service
NSC	National Safety Council
OPS	Office of Pipeline Safety
RWGCP	Regional Water Quality Control Plant
TRI	Toxic Release Inventory
US EPA	United States Environmental Protection Agency
USGS	United States Geological Survey
WEEE	Waste Electrical and Electronic Equipment

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