

# **The Recycling of Computer Circuit Boards**

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## **ABSTRACT**

Through continual technological advances, computers are becoming obsolete at an increasing rate. With this increase comes a large supply of valuable assets that can be recovered for reuse and/or resale. From an environmental standpoint, it is necessary to find the most efficient processes for the disassembly and removal of these assets. Asset recovery not only reduces the amount of electronic scrap heading for landfills, but it also can provide the revenue needed to maintain recycling programs. It is important that an understanding of the factors affecting this asset recovery is obtained. This paper reveals some of the characteristics of the scrap product and the processes involved in their recovery. Also, a projection of future issues that will affect recycling is provided including legislation, economics and new technologies entering the mainstream.

## **I. INTRODUCTION**

In the information age, it is important that we support the recycling of electronics. In particular, the large amount of personal computers entering the mainstream is providing a supply of scrap at an ever-increasing rate. Technology is not only driving the performance of these machines to a higher level, but is also making them obsolete at a faster pace. A supply of relatively high value “scrap” is being sent to landfills. Manufacturers are now realizing the benefit from reclaiming their assets in the components that populate the circuit boards. Also, markets are now open for the resale of used electronic components.

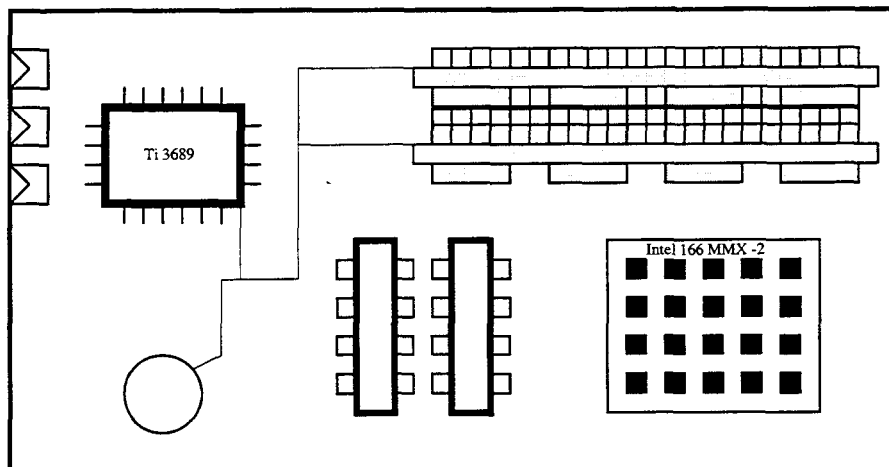
The focus of this paper is to characterize the processes presently employed to reclaim these components. Information is provided on the factors affecting these efforts such as cost, market health, labor, quality of the removed component, and underlying barriers to this processes. This characterization is important to provide some basis to judge the scope of the problems associated with circuit board recycling. As a primarily new science, there are few standard operating procedures to support the process. Unlike the manufacturing of electronics, there has been little attempt to provide general guidelines for efficient asset recovery in the form of component removal.

Finally, the issue arises as to why the recycling of electronics needs to have such research completed. Foremost, it must be understood that electronics contain hazardous materials and their landfilling should be avoided. Electronics require vast amounts of soldering during assembly. Solder's composition is of Tin and Lead, the latter being well recognized as a hazardous material. Although the reclaiming of components does not directly remedy this problem, it does have indirect benefit. Recyclers can offset their costs of environmentally conscious disposal of scrap through profits from component resale.

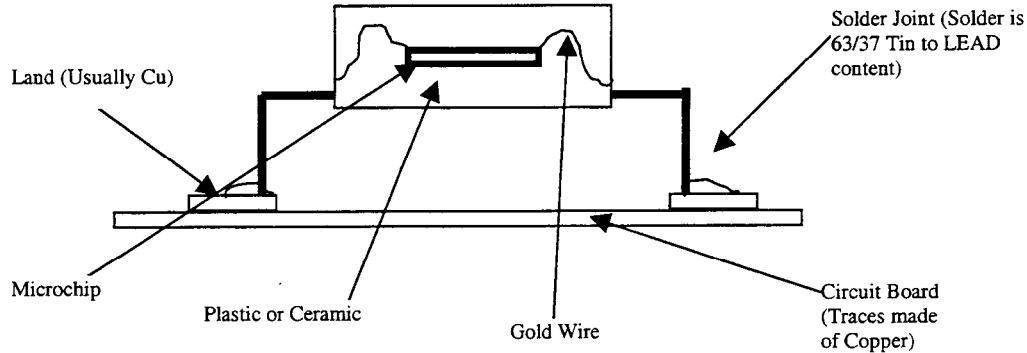
Furthermore, studying the processes of component removal and recycling can provide information, which can be shared with the designers of electronics. This form of concurrent engineering can provide waste remediation in its most effective form, Design for the Environment (DfE).

In 1994, Carnegie Mellon University estimated that by the year 2005 used computers in landfills will number 150 million. [1] It is imperative that we understand the processes being used today which can be further developed to combat the increasing problem faced by electronic scrap.

Figure 1 is a representation of a typical, basic circuit board while figure 2 gives a perspective of the typical structure for an electronic component.



**Figure 1 - Typical circuit board**



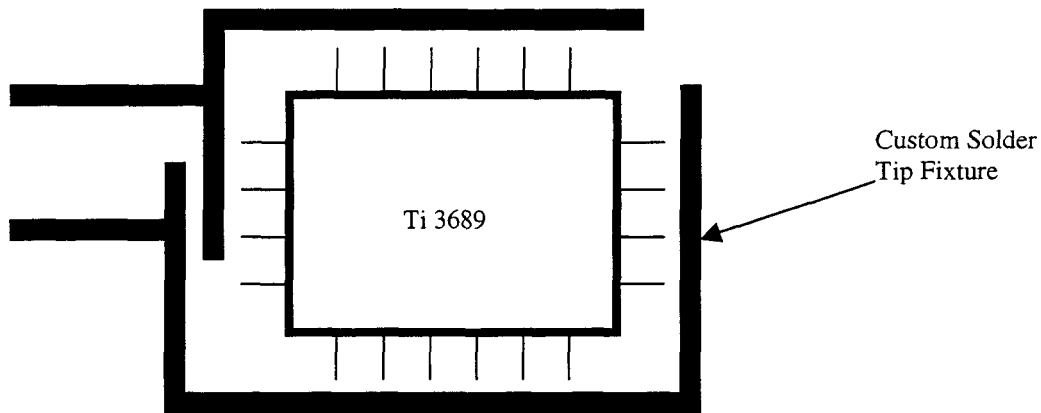
**Figure 2 - Typical Component**

## II. MANUAL PROCESSES

With the need to safely remove components and recycle circuit boards, many different processes have been developed. The wide range of component types that may populate a board dictates the need for various approaches. Each technique can be characterized by its range of use, cost, safety to the component, labor demands, and form of heating.

### A. Hot bar/Soldering Guns

Hand soldering tools have been used since the advent of electronics. Today, much of the hand soldering is used for reworking of damaged or faulty boards. It also is implemented as a component recycling process. A Hot Bar is essentially a custom tip for a soldering gun used for specified component type and size. Using direct contact heat to the leads of a component, it provides very localized heating. It can safely remove high price components with some degree of user experience. Due to this fact, the Hot Bar does require good user control for safety and therefore can be labor intensive. Another drawback is the maintenance of the tip. Contamination and general tip maintenance also can cost the operation time. [6] Consequently, hand desoldering finds limited use in the field and is reserved for special cases involving very high value components such as new components from a bad run in the manufacturing process.

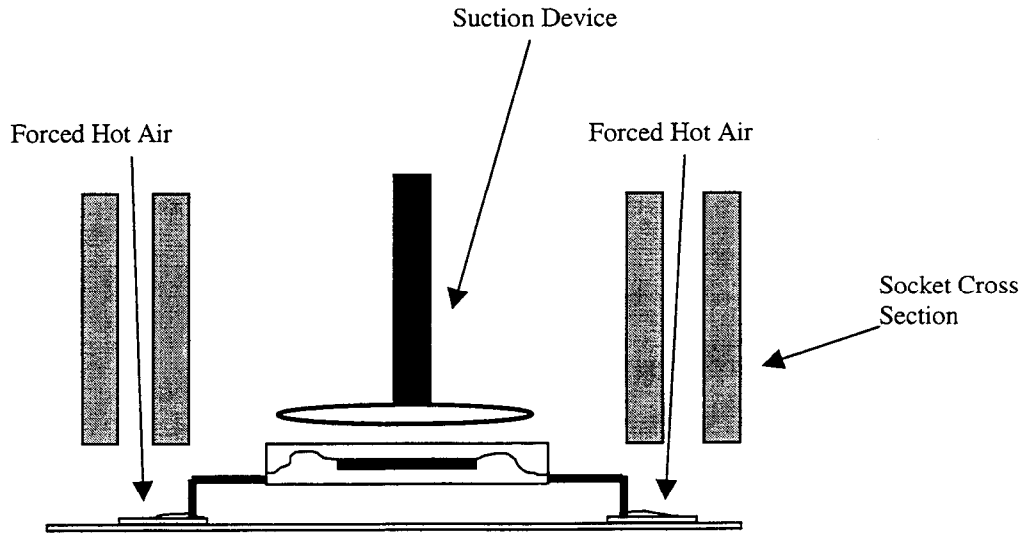


**Figure 3 - Hot Bar Desoldering Fixture**

*B. Specialized Convection- Vacuum Tools*

As an advance towards specialized approaches, tools that can automatically heat capture and remove specific components are used. The convection-vacuum tool uses custom “sockets” that surrounds the component. Through the socket walls, the application of forced hot air around the lead frame melts the solder. These benchtop setups have a suction device that attaches to the component face during the heating process. Once the solder is melted, the component is captured in the socket and removed from the board. This application is focused mainly on gullwing leaded components.

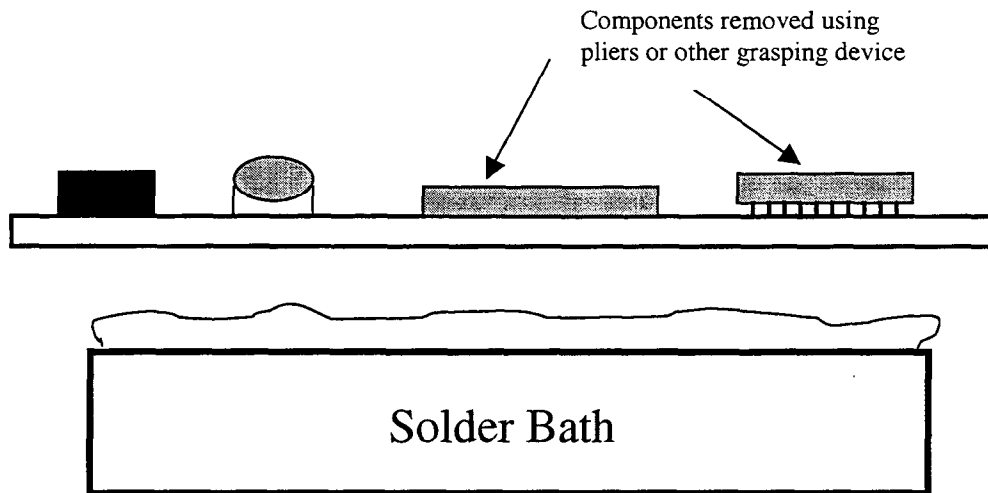
This lead arrangement is very fragile; being susceptible to bending which could render the component valueless. The process does not require much user training and has little error in overheating. It is a more costly approach with respect to heating time. Another drawback, similar to hand desoldering is that the user must change sockets for every new size package. Once again, usage is dictated by the value of the removed component. [2]



**Figure 4 - Convection Vacuum Tool**

### *C. Solder Baths*

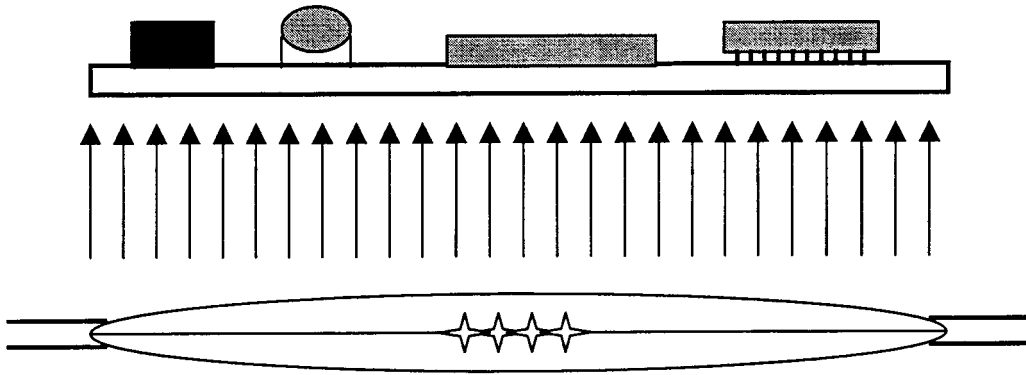
A very common form of soldering is the direct contact of melted solder to the circuit board. In manufacturing, wave soldering is performed in which actual waves are produced in the solder bath, causing contact with the board suspended over the pool. As a derivative, recyclers use small pools of solder to provide focused contact directly under the component to be removed. The process is more cumbersome than others due to the user dealing with a liquid bath. Care must be taken not to overexpose component packages to the molten solder, which causes overheating. As an environmental consideration, the use of molten solder containing lead also presents a compromise in the philosophy of reducing lead waste. As a case in point, a particular recycler revealed how their use of an aluminum foil layer over the pool to prevent splashing actually produced new hazardous waste. Once wrinkled or penetrated too much, the aluminum foil “skin” on top of the pool would now have to be treated as hazardous waste due to its contact with solder. [2]



**Figure 5. - Typical solder bath setup**

#### *D. Infrared Heating*

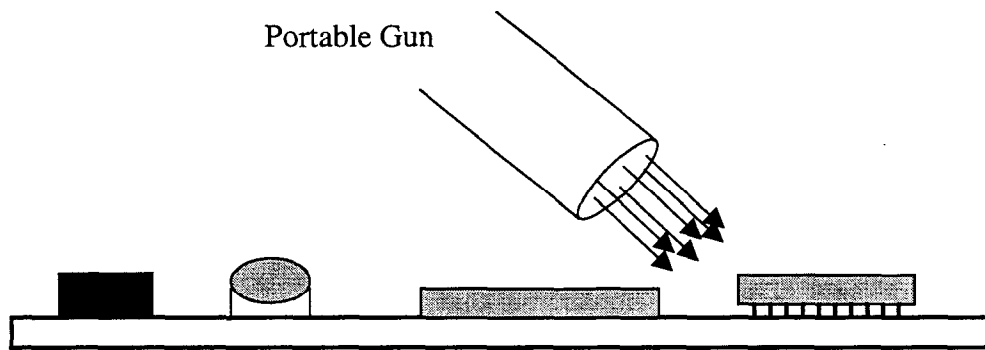
Infrared heat (IR) is used as another form of non-contact heating. Quartz halogen lamps can easily be the sources. Exposing the board to the light can rapidly bring the solder up to its melting point around  $183^{\circ}\text{C}$  [4]. However, heating is not specific to the lead frame. All items in the general neighborhood of the chip are heated, with some variance due to absorptivity differences. This brings in a component safety issue with respect to how much and how quickly a component can be heated. Unfortunately judgement is primarily qualitative with respect to what is too hot, or too fast. In many cases, the operator will continue to heat faster and hotter so long as they do not see charring of the resin board or physical damage to the chip package. From this, it follows that a degree of operator experience is required. With each application of heat, the user must be able to judge how to operate the lamp. On the other hand, the value of this process lies in its speed. With high labor costs in this field, it is important to be able to heat as fast as possible. IR does not use hazardous materials in its process and is not component-specific. Another benefit of this process is that very little maintenance is required. For improved accuracy and thereby safety, more focused light beams are sometimes used to limit the exposure to the thermally fragile chip packages which are made of plastics or ceramics. [7]



**Figure 6. - Illustration of I.R. heating**

*E. Forced Hot Air*

Forced hot air can be used in a similar fashion to IR heating. Usually heat guns similar to paint stripping guns are used for this process. The benefit of mobility is gained using these portable guns. The operator can easily redirect the flow of heat to optimize safe heating of the leads. Once again operator experience is needed, but not to the extent needed with IR heating. Convection heating is usually less rapid than IR heating and therefore reduces the chance of overheating. Forced hot air heating has a large range of applications and is widely used in recycling [5,13,14]]. It provides a low capital cost, generally simple process, which needs little or no maintenance. The process is basically waste-free and has found fairly widespread use in recycling.



**Figure 7. - Illustration of Forced Hot Air Application**

### **III. AUTOMATION**

Inherent with most large-scale manufacturing is the drive to automate as much of the system as possible. This philosophy is attempted in the disassembly and recycling of circuit boards. The barriers to automation are highlighted by the non-homogeneity of the products. [9] When a recycler receives a shipment of boards to recycle they are rarely categorized. Boards can differ in size, shape, resin type, resin thickness, circuit structure, and the population of the board. Sizes of boards can range from a few square inches to about a square foot. With automation, all boards would need to be captured by some gripping device to allow removal of components. This most likely will require an operator to hand feed the boards to the system, since the board geometries vary greatly.

The different geometries can also affect the heating process for each board. If in fact it is important to focus the heating, it will be difficult to have the system locate the areas of choice when each board is a different size and/or shape. Next is the resin type, which usually is standard FR-4, an epoxy-glass fiber. But, if the resin type does differ, heat transfer through the board is drastically changed which affects the heating process. Boards can also vary in thickness. Presently boards can come in a wide range of layer numbers. Each layer itself is basically a circuit board containing copper traces, which comprise the actual electrical circuit. With each added layer, heat transfer is greatly altered.[8]

To develop an automated heating system requires some compromises to be made. These compromises can affect the system's ability to safely handle the

components. A prototype system by NEC has been developed for circuit board recycling. The system receives populated boards, heats with IR, and paddles all the components and solder off the surface of the board. There is a greater chance of bending leads when striking components, rather than removing components individually. This process would be ideal for boards that have had the valuable chips previously removed. [3]

#### **IV. FACTORS AFFECTING RECYCLING**

There are many factors affecting the recycling of circuit boards. These factors can affect the recyclability of an individual board and/or the success of the entire process within a recycling facility. These factors can dictate the profit margin for a facility. For example, a board that is considered to have low recyclability will most likely be ground up for precious metal extraction. A more valuable board would warrant pulling components from the board for resale. Their reuse may be in a primary or secondary product; primary meaning use in another computer while the latter refers to use in products like electronic games and household appliances. [2]

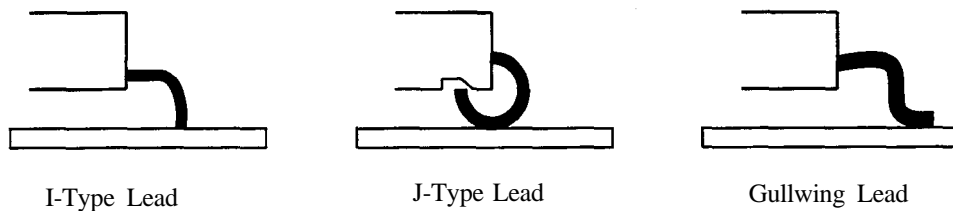
##### *A. Non-Homogeneity*

Homogeneity in a product line can be an asset in automation, reducing labor, tooling changes, inventory, etc. At the end of product life, non-homogeneity can have detrimental affects on the success of recycling.

The population of components can vary between each board. One board can contain a processor and memory chips that could provide profits in range of 2-600 dollars [2], while the next may have no value past grinding and smelting for precious metals. Also, with each different component type the worker must execute varied techniques for safe removal, which increase the time for disassembly.

The variation in board size and shape not only makes automation difficult, but also affects the heat transfer, varying the safe time needed for heating. In a similar fashion, differences in board thickness and layer number can drastically change the time for heating. Circuit board construction can contain single-sided, double-sided, or multilayers of circuit traces. With each added layer and consequently added mass of copper, the heat capacitance changes. To compound the problem, each board can have a different layout of through-hole vias (drilled and copper plated holes which interconnect the layers of circuitry). These vias are places of rapid heat transfer, which can cause concentrations of heat on the surface of the board. One spot on the underside of a component may exceed safe heating temperatures (preferably  $< 258^{\circ}\text{C}$ ) while other sections of the component lead frame may not attain the melt temperature of  $= 183^{\circ}\text{C}$ . Finally, differences in resin type used in board manufacturing can also change the heat transfer through the board. [2,4]

With respect to the individual component, different lead types and package structure can greatly alter the time and success of the removal process. General lead types come in three basic formats; I, J, and Gullwing (See Figure 8).



**Figure 8 - Illustration of Three Standard Lead Types**

I and J types are fairly strong and require less care when heating and removing. Generally these leads can allow the component to be scraped, vibrated, or dropped off by gravity after being desoldered. After removal, less care is also needed in packaging and shipping to their new destination.

Gullwings, which have gained popularity, need more care in removal. These lead frames usually have higher lead counts with finer leads. Often specialized tools are needed to safeguard from lead bending. Gaining use in

packages is the ball grid array (BGA). This connection is considered “leadless” using small balls of solder in place of the typical lead frame. With BGAs heating must usually be applied from underneath since the balls are not openly accessible. Once removed, the components are not ready for resoldering since the lost balls need to be replaced. The recyclability value is decreased due to the requirement of this post processing. Ever changing technology in lead types and packages will only add to the non-homogeneity of component types, which will be discussed later in this paper.

### *B. Market*

The resale and reuse of circuit board components can drastically affect the success of or even the decision to recycle circuit boards. Asset recovery within a company is one form of this “market”. Presently, the other major market is overseas. Through brokers, companies overseas buy used components from computers to be placed in secondary products like washing machines and electronic games. [2,14] With both asset recovery and secondary manufacturers, the purchase of used parts must be validated. A commonly accepted fact is that in 1995 demand and supply for computer chips reached equality. At that point the cost of chips, especially memory chips, dropped drastically. [5] With this drop, it became more difficult to validate spending the energy and resources needed for disassembly, especially when new chip prices reached such an all-time low.

### *C. Legislation*

Legislation concerning the treatment of electronic scrap can have a major affect on recycling. Although not in place in the U.S., some European “cradle-to-grave” legislation can validate the recycling of electronics merely as a source of waste remediation. When legislation makes it impossible or costly to dispose scrap, the manufacturer is somewhat forced to generate programs to recycle as much as possible. With cradle-to-grave philosophy, the manufacturer must

account for the products it releases into the mainstream, since it will be responsible to take back all of its products at end-of-life.

In the U.S. electronic scrap is considered hazardous waste in commercial settings only. There are regulations concerning the transportation and handling of electronic scrap. However, any private consumer can take a used computer and drop it in the trash. If legislation would mandate that all electronic scrap be classified as hazardous, manufacturers would have more incentive to subscribe to DfE. [5] With cradle-to-grave legislation, manufacturers would not be pressured to design environmentally, but would spend more research funding to develop better recycling practices. This type of legislation could have a major affect on the recycling practices for circuit boards, being the hazardous waste containing part of a computer.

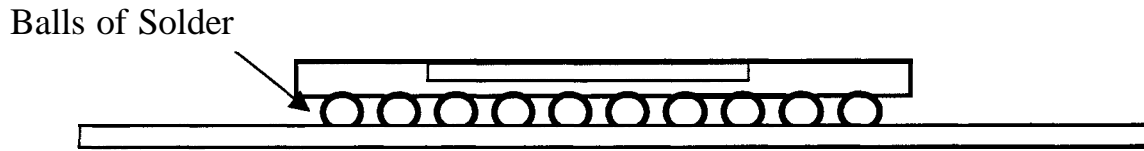
This type of legislative change, in a form, was recently suggested at a recycling conference in Washington, D.C. [5] It was noted that one form of lead containing scrap, the monitors, are not banned from landfills. They are in fact treated as hazardous waste and cost industry and recyclers a lot of money to store, handle, and transport. It was suggested that landfills should no longer accept them from the waste stream. At the same time, it was suggested to stop regulating them so tightly to allow cheaper handling and processing. In its present form, legislation for this waste is impeding the recycling push. Manufacturers know that their product can be simply landfilled. The problem is that the groups trying to deal with the scrap are hurt by the legislation. A comprehensive electronic scrap policy must be adopted, one that not only supports DfE, but that also aids the scrap handlers.

## **v. FUTURE ISSUES**

In the computer industry, technological advances seem to occur on a daily basis. Consequently, the time a computer becomes outdated is shortening with the introduction of each new product. These advancements can be helping the cause for recycling by providing a newer supply of “scrap” heading to the disassembly facilities. Especially for the overseas market in less industrialized nations, this provides a more advanced product line to sell to the secondary users. Unfortunately, each advance in component type, size, and lead type presents new challenges to recycling. Basically, future advancements may in fact be providing a more attractive scrap line while also making it ever more difficult to salvage the scrap. To present some of the future issues, the following section will focus on the future package and lead types that will challenge the recycling efforts for computer circuit boards. [ 16]

### *A. Ball Grid Arrays (BGAs)*

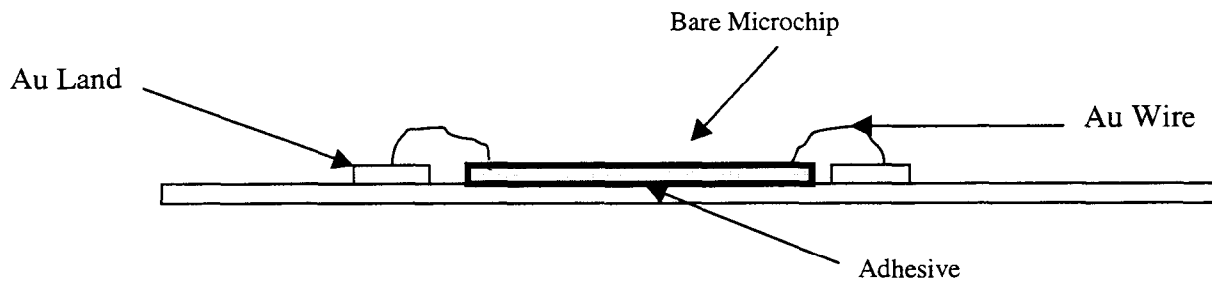
As presented earlier, the increasing use of BGAs will soon present new issues for recycling. BGAs were developed to find a lead frame that would shorten the connection between the microchip and the circuit board. Eliminating the length of lead frame typically seen in I, J, and gullwing lead types provides a more efficient connection that is less susceptible to noise. Also, using the bottom surface of a component package allows more surface area which provides higher lead counts. In typical lead frames desoldering allows removal of a readily usable component aside from possibly re-tinning the leads. With BGAs, desoldering and removal loses or smears the balls off the bottom. If recyclers wish to provide a marketable used BGA, they will need to find a way to keep from losing the balls or will have to find cheap methods to re-ball them.



**Figure 9 - Ball Grid Array Component**

*B. Chip on Board Technology*

Chip on board technology involves no longer using a package material to encase the microchip. The idea is to simply adhere the chip to the surface of the board and wire bond directly from the chip to the circuit. This is accomplished through soldering thin gold wires to the chip and board. Later, desoldering the wire bonds is not necessarily difficult, but more care must be taken to keep from overheating the chip, which is not encased in a package. The adhesive could cause a problem unless a suitable solvent can be used for safe removal.

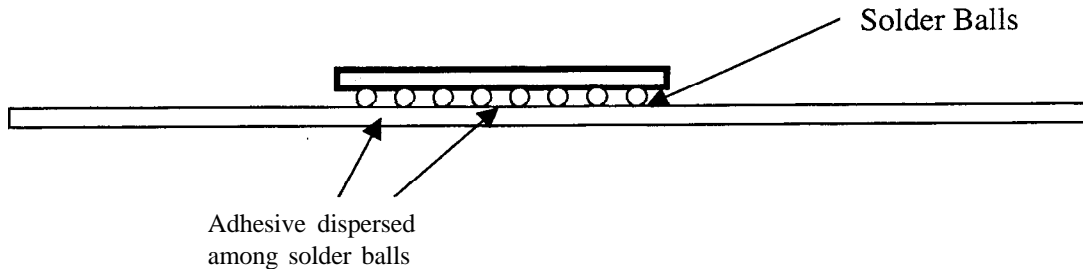


**Figure 10 – Chip-on-Board Application**

*C. Flip-Chip Technology*

Flip-chip technology is a derivative of chip-on-board technology where once again, the bare chip is no longer encased in a package medium. The difference with “flip-chip” is that the chip is actually flipped over, exposing its connections to the board. With this format, the chip is simply solder bumped to the surface. To provide mechanical integrity to safeguard from thermal

expansion, an adhesive is dispersed throughout the balls. With this connection, the introduced adhesive once again provides a problem with safe removal without damaging the chip. Even without the adhesive, dealing with a bare chip presents other handling problems during removal,



**Figure 11 - Flip-Chip Application**

## **VI. CONCLUSIONS**

As the information age enters the 21<sup>st</sup> century, it is laying a path littered with electronic waste. Personal computer use is rapidly increasing and with it brings technological advances, quickly outdating the machine. With each computer scrapped, there is the need to deal with the hazardous and sometimes valuable circuit boards that become part of that scrap.

Within the circuit board are precious metals and components which manufacturers and recyclers need and want to remove properly. For success, there is a need to understand the present processes involved in recycling. It is important to know how to characterize the components to be removed to ensure that the safest and most economical process is employed. At the same time, it is important to understand the processes employed to guarantee successful and safe disassembly.

If any attempts can be made, it is usually preferred to be able to automate the system. Unfortunately, there are many barriers that impede automation. It is necessary to prepare now for the products that will be scrapped in the near future. Advances in technology are providing used computers at an increasing rate. Unfortunately, with each advance in component and board design, the recycler is

faced with new challenges. In closure, a clear understanding of the product, processes, and future technology is crucial if productive recycling of computer circuit boards is to be conducted.

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