## 7.2 SOCIAL BENEFITS/COSTS ASSESSMENT

### 7.2.1 Introduction to Social Benefits/Costs Assessment

Social benefits/costs analysis[12] is a tool used by policy makers to systematically evaluate the impacts to all of *society* resulting from individual decisions. The decision evaluated in this analysis is the choice of an MHC technology. PWB manufacturers have a number of criteria they may use to assess which MHC technology they will use. For example, a PWB manufacturer might ask what impact their choice of an MHC alternative might have on operating costs, compliance costs, liability costs, and insurance premiums. This business planning process is unlike social benefit/cost analysis, however, because it approaches the comparison from the standpoint of the individual manufacturer and not from the standpoint of society as a whole.

A social benefits/costs analysis seeks to compare the benefits and costs of a given action, while considering both the private and external costs and benefits.[13] Therefore, the analysis will consider both the impact of the alternative MHC processes on the manufacturer itself (private costs and benefits) and the impact the choice of an alternative has on external costs and benefits, such as reductions in environmental damage and reductions in the risk of illness for the general public. External costs are not borne by the manufacturer, rather they are the true costs to society. Table 7.9 defines a number of terms used in benefit/cost assessment, including external costs and external benefits.

[12] The term "analysis" is used here to refer to a more quantitative analysis of social benefits and costs, where a monetary value is placed on the benefits and costs to society of individual decisions. Examples of quantitative benefits/costs analyses are the regulatory impact analyses done by EPA when developing federal environmental regulations. The term "assessment" is used here to refer to a more qualitative examination of social benefits and costs. The evaluation performed in the CTSA process is more correctly termed an assessment because many of the social benefits and costs of MHC technologies are identified, but not monetized.

[13] Private costs typically include any direct costs incurred by the decision-maker and are generally reflected in the manufacturer's balance sheet. In contrast, external costs are incurred by parties other than the primary participants to the transaction. Economists distinguish between private and external costs because each will affect the decision-maker differently. Although external costs are real costs to some members of society, they are not incurred by the decision-maker and firms do not normally take them into account when making decisions. A common example of these "externalities" is the electric utility whose emissions are reducing crop yields for the farmer operating downwind. The external costs experienced by the farmer in the form of reduced crop yields are not considered by the utility when making decisions regarding electricity production. The farmer's losses do not appear on the utility's balance sheet.

**Table 7.9 Glossary of Benefits/Costs Analysis Terms**

| Term | Definition |
|---|---|
| Exposed Population | The estimated number of people from the general public or a specific population group who are exposed to a chemical through wide dispersion of a chemical in the environment (e.g., DDT). A specific population group could be exposed to a chemical due to its physical proximity to a manufacturing facility (e.g., residents who live near a facility using a chemical), use of the chemical or a product containing a chemical, or through other means. |
| Exposed Worker Population | The estimated number of employees in an industry exposed to the chemical, process, and/or technology under consideration. This number may be based on market share data as well as estimations of the number of facilities and the number of employees in each facility associated with the chemical, process, and/or technology under consideration. |
| Externality | A cost or benefit that involves a third party who is not a part of a market transaction; "a direct effect on another's profit or welfare arising as an incidental by-product of some other person's or firm's legitimate activity" (Mishan, 1976). The term "externality" is a general term which can refer to either external benefits or external costs. |
| External Benefits | A positive effect on a third party who is not a part of a market transaction. For example, if an educational program results in behavioral changes which reduce the exposure of a population group to a disease, then an external benefit is experienced by those members of the group who did not participate in the educational program. For the example of nonsmokers exposed to second-hand smoke, an external benefit can be said to result when smokers are removed from situations in which they expose nonsmokers to tobacco smoke. |
| External Costs | A negative effect on a third party who is not part of a market transaction. For example, if a steel mill emits waste into a river which poisons the fish in a nearby fishery, the fishery experiences an external cost as a consequence of the steel production. Another example of an external cost is the effect of second-hand smoke on nonsmokers. |
| Human Health Benefits | Reduced health risks to workers in an industry or business as well as to the general public as a result of switching to less toxic or less hazardous chemicals, processes, and/or technologies. An example would be switching to a less volatile organic compound, lessening worker inhalation exposures as well as decreasing the formation of photochemical smog in the ambient air. |
| Human Health Costs | The cost of adverse human health effects associated with production, consumption, and disposal of a firm's product. An example is respiratory effects from stack emissions, which can be quantified by analyzing the resulting costs of health care and the reduction in life expectancy, as well as the lost wages as a result of being unable to work. |
| Illness Costs | A financial term referring to the liability and health care insurance costs a company must pay to protect itself against injury or disability to its workers or other affected individuals. These costs are known as illness benefits to the affected individual. |
| Indirect Medical Costs | Indirect medical costs associated with a disease or medical condition resulting from exposure to a chemical or product. Examples would be the decreased productivity of patients suffering a disability or death and the value of pain and suffering borne by the afflicted individual and/or family and friends. |

| Term | Definition |
|---|---|
| Private (Internalized) Costs | The direct costs incurred by industry or consumers in the marketplace. Examples include a firm's cost of raw materials and labor, a firm's costs of complying with environmental regulations, or the cost to a consumer of purchasing a product. |
| Social Costs | The total cost of an activity that is imposed on society. Social costs are the sum of the private costs and the external costs. Therefore, in the example of the steel mill, social costs of steel production are the sum of all private costs (e.g., raw material and labor costs) and the sum of all external costs (e.g., the costs associated with the poisoned fish). |
| Social Benefits | The total benefit of an activity that society receives, i.e., the sum of the private benefits and the external benefits. For example, if a new product yields pollution prevention opportunities (e.g., reduced waste in production or consumption of the product), then the total benefit to society of the new product is the sum of the private benefit (value of the product that is reflected in the marketplace) and the external benefit (benefit society receives from reduced waste). |
| Willingness-to-Pay | Estimates used in benefits valuation are intended to encompass the full value of avoiding a health or environmental effect. For human health effects, the components of willingness-to-pay include the value of avoiding pain and suffering, impacts on the quality of life, costs of medical treatment, loss of income, and, in the case of mortality, the value of life. |

Private benefits of the alternative MHC processes may include increased profits resulting from improved worker productivity and company image, a reduction in energy use, or reduced property and health insurance costs due to the use of less hazardous chemicals. External benefits may include a reduction in pollutants emitted to the environment or reduced use of natural resources. Costs of the alternative MHC processes may include private costs such as changes in operating expenses and external costs such as an increase in human health risks and ecological damage. Several of the benefit categories considered in this assessment share elements of both private and external costs and benefits. For example, use of an alternative may result in natural resource savings. Such a benefit may result in private benefits in the form of reduced water usage and a resultant reduction in payments for water as well as external benefits in the form of reduced consumption of shared resources.

### 7.2.2 Benefits/Costs Methodology and Data Availability

The methodology for conducting a social benefits/costs assessment can be broken down into four general steps: 1) obtain information on the relative human and environmental risk, performance, cost, process safety hazards, and energy and natural resource requirements of the baseline and the alternatives; 2) construct matrices of the data collected; 3) when possible, monetize the values presented within the matrices; and 4) compare the data generated for the alternative and the baseline in order to produce an estimate of net social benefits. Section 7.1 presented the results of the first task by summarizing risk, competitiveness, and conservation information for the baseline and alternative MHC technologies. Section 7.2.3 presents matrices of private benefits and costs data, while Section 7.2.4 presents information relevant to external benefits and costs. Section 7.2.5 presents the private and external benefits and costs together to produce an estimate of net social benefits.

Ideally, the analysis would quantify the social benefits and costs of using the alternative and baseline MHC technologies, allowing identification of the technology whose use results in the largest net social benefit. This is particularly true for national estimates of net social benefits or costs. However, because of resource and data limitations and because individual users of this CTSA will need to apply results to their own particular situations, the analysis presents a qualitative description of the risks and other external effects associated with each substitute technology compared to the baseline. Benefits derived from a reduction in risk are described and discussed, but not quantified. Nonetheless, the information presented can be very useful in the decision-making process. A few examples are provided to qualitatively illustrate some of the benefit considerations. Personnel in each individual facility will need to examine the information presented, weigh each piece according to facility and community characteristics, and develop an independent choice.

### 7.2.3 Private Benefits and Costs

While it is difficult to obtain an overall number to express the private benefits and costs of alternative MHC processes, some data were quantifiable. For example, the cost analysis estimated the average manufacturing costs of the MHC technologies, including the average capital costs (primary equipment, installation, and facility cost), materials costs (limited to chemical costs), utility costs (water, electricity, and natural gas costs), wastewater costs (limited to wastewater discharge cost), production cost (production labor and chemical transport costs), and maintenance costs (tank cleanup, bath setup, sampling and analysis, and filter replacement costs). Other cost components may contribute significantly to overall manufacturing costs, but were not quantified because they could not be reliably estimated. These include wastewater treatment cost, sludge recycling and disposal cost, other solid waste disposal costs, and quality costs.

Differences in the manufacturing costs estimated in the cost analysis are summarized below. However, in order to determine the overall private benefit/cost comparison, a qualitative discussion of the data is also necessary. Following the discussion of manufacturing costs are discussions of private costs associated with occupational and population health risks and other private costs or benefits that could not be monetized but are important to the decision-making process.

**Manufacturing Costs**

Table 7.10 presents the percent change in manufacturing costs for the MHC alternatives as compared to the baseline. Only costs that were quantified in the cost analysis are presented. All of the alternatives result in cost savings in the form of lower total costs; most of the alternatives result in cost savings in almost every cost category. In addition, the Performance Demonstration determined that each alternative has the capability to achieve comparable levels of performance to electroless copper, thus quality costs are considered equal among the alternatives. This is important to consider in a benefits/costs analysis since changes in performance necessarily result in changed costs in the market. This is not the case in this assessment since all alternatives yield comparable performance results.

**Table 7.10 Differences in Private Costs[a]**

| MHC Technology | Average Cost | | Capital Cost | | Chemical Cost | | Water Cost | | Electricity Cost | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $/ssf | % change | $/ssf | % change | $/ssf` | % change | $/ssf | % change | $/ssf | % change |
| Electroless Copper, non-conveyorized (BASELINE) | $ 0.51 | | $ 0.24 | | $ 0.06 | | $ 0.02 | | $ 0.008 | |
| Electroless Copper, conveyorized | $ 0.15 | -71 | $ 0.03 | -88 | $ 0.06 | 0 | $ 0.002 | -90 | $ 0.002 | -75 |
| Carbon, conveyorized | $ 0.18 | -65 | $ 0.03 | -88 | $ 0.10 | +66 | $ 0.002 | -90 | $ 0.001 | -88 |
| Conductive Polymer, conveyorized | $ 0.09 | -82 | $ 0.02 | -92 | $ 0.03 | -50 | $ 0.001 | -95 | $ 0.001 | -88 |
| Graphite, conveyorized | $ 0.22 | -57 | $ 0.01 | -96 | $ 0.17 | +183 | $ 0.001 | -95 | $ 0.004 | -50 |
| Non-Formaldehyde Electroless Copper, non-conveyorized | $ 0.40 | -22 | $ 0.11 | -54 | $ 0.20 | +233 | $ 0.01 | -50 | $ 0.004 | -50 |
| Organic-Palladium, non-conveyorized | $ 0.15 | -71 | $ 0.02 | -92 | $ 0.08 | +33 | $ 0.002 | -90 | $ 0.001 | -88 |
| Organic-Palladium, conveyorized | $ 0.17 | -67 | $ 0.02 | -92 | $ 0.08 | +33 | $ 0.002 | -90 | $ 0.002 | -75 |
| Tin-Palladium, non-conveyorized | $ 0.14 | -73 | $ 0.02 | -92 | $ 0.06 | 0 | $ 0.003 | -85 | $ 0.002 | -75 |
| Tin-Palladium, conveyorized | $ 0.12 | -77 | $ 0.01 | -96 | $ 0.07 | +17 | $ 0.001 | -95 | $ 0.001 | -88 |

| MHC Technology | Natural Gas Cost | | Wastewater Cost | | Production Cost | | Maintenance Cost | |
|---|---|---|---|---|---|---|---|---|
| | $/ssf | % change | $/ssf | % change | $/ssf | % change | $/ssf | % change |
| Electroless Copper, non-conveyorized (BASELINE) | $ - | | $ 0.04 | | $ 0.11 | | $ 0.04 | |
| Electroless Copper, conveyorized | $ - | NA | $ 0.004 | -90 | $ 0.02 | -82 | $ 0.03 | -25 |
| Carbon, conveyorized | $ 0.001 | NA | $ 0.005 | -88 | $ 0.03 | -73 | $ 0.01 | -75 |
| Conductive Polymer, conveyorized | $ - | NA | $ 0.003 | -93 | $ 0.02 | -82 | $ 0.02 | -50 |
| Graphite, conveyorized | $ 0.0004 | NA | $ 0.002 | -95 | $ 0.02 | -82 | $ 0.01 | -75 |
| Non-Formaldehyde Electroless Copper, non-conveyorized | $ - | NA | $ 0.01 | -75 | $ 0.05 | -55 | $ 0.02 | -50 |
| Organic-Palladium, non-conveyorized | $ - | NA | $ 0.005 | -88 | $ 0.02 | -82 | $ 0.03 | -25 |
| Organic-Palladium, conveyorized | $ - | NA | $ 0.004 | -90 | $ 0.02 | -82 | $ 0.03 | -25 |
| Tin-Palladium, non-conveyorized | $ - | NA | $ 0.007 | -83 | $ 0.03 | -73 | $ 0.02 | -50 |
| Tin-Palladium, conveyorized | $ - | NA | $ 0.002 | -95 | $ 0.02 | -82 | $ 0.02 | -50 |

[a] Table lists costs and percent change in cost from the baseline.
NA: Not Applicable, % change cannot be calculated because baseline has zero cost in this cost category.

## Occupational Health Risks

Reduced risks to workers can be considered both a private and external benefit. Private worker benefits include reductions in worker sick days and reductions in health insurance costs to the PWB manufacturer. External worker benefits include reductions in medical costs to workers in addition to reductions in pain and suffering associated with work-related illness. External benefits from reduced risk to workers are discussed in more detail in Section 7.2.4.

Health risks to workers were estimated for inhalation exposure to vapors and aerosols from MHC baths and for dermal exposure to MHC bath chemicals. Inhalation exposure estimates are based on the assumptions that emissions to indoor air from conveyorized lines are negligible, that the air in the process room is completely mixed and chemical concentrations are constant over time, and that no vapor control devices (e.g., bath covers) are used in non-conveyorized lines. Dermal exposure estimates are based on the assumption that workers do not wear gloves and that all non-conveyorized lines are operated by manual hoist. Dermal exposure to workers on non-conveyorized lines could occur from routine line operation and maintenance (i.e., bath replacement, filter replacement, etc.). Dermal exposure to workers on conveyorized lines was assumed to occur from bath maintenance alone. Worker dermal exposure to all MHC technologies can be easily minimized by using proper protective equipment such as gloves during MHC line operation and maintenance. In addition, many PWB manufacturers report that their employees routinely wear gloves in the process area. Nonetheless, risk from dermal contact was estimated assuming workers do not wear gloves to account for those workers who do not wear proper personal protective equipment.

Because some parts of the exposure assessment for both inhalation and dermal exposures qualify as "what-if" descriptors,[14] the entire assessment should be considered "what-if." Table 7.11 summarizes the number of chemicals of concern for the exposure pathways evaluated and lists the number of suspected carcinogens in each technology.

Based on the results of the risk characterization, it appears that alternatives to the non-conveyorized electroless copper process have private benefits due to reduced occupational risks. However, there are also occupational inhalation risk concerns for some chemicals in the non-formaldehyde electroless copper and tin-palladium non-conveyorized processes. In addition, there are occupational dermal exposure risk concerns for some chemicals in the conveyorized electroless copper process, the non-conveyorized non-formaldehyde electroless copper, and the tin-palladium and organic palladium processes with conveyorized or non-conveyorized equipment. Finally, occupational health risks could not be quantified for one or more of the chemicals used in each of the MHC technologies. This is due to the fact that proprietary chemicals in the baths are not included[15] for chemical products submitted by Atotech (except one proprietary chemical in one of Atotech's technologies), Enthone-OMI, MacDermid and Shipley,

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[14] A "what-if" risk descriptor represents an exposure estimate based on postulated questions, making assumptions based on limited data where the distribution is unknown.

[15] Electrochemicals, LeaRonal, and Solution Technology Systems provided information on proprietary chemical ingredients to the project for evaluation in the risk characterization. Atotech provided information on one proprietary chemical ingredient. Risk results for proprietary chemicals in chemical products but not chemical identities or concentrations, are included in this CTSA.

and to a lack of toxicity or chemical property data for some chemicals known to be present in the baths.

**Table 7.11 Summary of Occupational Hazards, Exposures, and Risks of Potential Concern**

| MHC Technology | No. of Chemicals of Concern by Pathway[a] | | No. of Suspected Carcinogens |
|---|---|---|---|
| | Inhalation | Dermal | |
| Electroless Copper, non-conveyorized (BASELINE) | 10 | 8 | 5[b] |
| Electroless Copper, conveyorized | 0 | 8 | 5[b] |
| Carbon, conveyorized | 0 | 0 | 1 |
| Conductive Polymer, conveyorized | 0 | 0 | 0 |
| Graphite, conveyorized | 0 | 0 | 2[c] |
| Non-Formaldehyde Electroless Copper, non-conveyorized | 1 | 2 | 0 |
| Organic-Palladium, non-conveyorized | 0 | 1 | 0 |
| Organic-Palladium, conveyorized | 0 | 1 | 0 |
| Tin-Palladium, non-conveyorized | 2 | 5 | 0 |
| Tin-Palladium, conveyorized | 0 | 5 | 0 |

[a] Number of chemicals of concern for an MHC line operator (the most exposed individual).
[b] Includes formaldehyde (EPA Group B1, probable human carcinogen) and dimethylformamide (IARC Group 2B, possible human carcinogen). Also included are the proprietary chemicals, cyclic ether, alkyl oxide, and trisodium acetate amine B.
[c] Includes the proprietary chemicals, cyclic ether and alkyl oxide.

Occupational cancer risks were estimated for inhalation exposure to formaldehyde and alkyl oxide in the non-conveyorized electroless copper process, and for dermal exposure to cyclic ether and alkyl oxide in the conveyorized graphite, conveyorized electroless copper, and non-conveyorized electroless copper processes. Formaldehyde has been classified by EPA as Group B1, a Probable Human Carcinogen. Results indicate clear concern for formaldehyde inhalation exposure; the upper bound excess individual cancer risk estimate for line operators in the non-conveyorized electroless copper process from formaldehyde inhalation may be as high as one in 1,000, but may be 50 times less, or one in 50,000.[16] Inhalation risks to other workers were assumed to be proportional to the amount of time spent in the process area, which ranged from three percent to 61 percent of the risk for a line operator. Occupational risks associated with dermal and inhalation exposure to cyclic ether and alkyl oxide were below $1 \times 10^{-6}$ (one in one million) for the graphite and electroless copper processes and are therefore considered to be of low concern. The occupational cancer risks associated with exposure to dimethylformamide, carbon black, and trisodium acetate amine B could not be quantified because cancer slope factors have not been determined for these chemicals.

[16] To provide further information on the possible variation of formaldehyde exposure and risk, an additional exposure estimate was provided in the Risk Characterization (Section 3.4) using average and median values (rather than high-end) as would be done for a central tendency exposure estimate. This results in approximately a 35-fold reduction in occupational formaldehyde exposure and risk from the estimates presented here.

**Public Health Risks**

In addition to worker exposure, members of the general public may be exposed to MHC chemicals due to their close physical proximity to a PWB plant or due to the wide dispersion of chemicals. Reduced public health risks can also be considered both a private and external benefit. Private benefits include reductions in potential liability costs; external benefits include reductions in medical costs. External benefits from reduced public health risk are discussed in more detail in Section 7.2.4.

Public health risk was estimated for inhalation exposure only for the general populace living near a facility. Environmental releases and risk from exposure to contaminated surface water were not quantified due to a lack of data; chemical constituents and concentrations in wastewater could not be adequately characterized. Public health risk estimates are based on the assumption that emissions from both conveyorized and non-conveyorized process configurations are steady-state and vented to the outside. Risk was not characterized for short-term exposures to high levels of hazardous chemicals when there is a spill, fire, or other periodic release.

The risk indicators for ambient exposures to humans, although limited to airborne releases, indicate low concern from all MHC technologies for nearby residents. The estimated upper bound excess individual cancer risk for nearby residents exposed to emissions from the non-conveyorized electroless copper process ranged from values approaching zero to $1 \times 10^{-7}$ (one in ten million) for formaldehyde, and from approaching zero to $1 \times 10^{-11}$ (one in 100 billion) for the alkyl oxide. The estimated cancer risk values for the conveyorized electroless copper process ranged from values approaching zero to $3 \times 10^{-7}$ (one in three million) for formaldehyde, and from approaching zero to $3 \times 10^{-11}$ (one in 33 billion) for the alkyl oxide. The estimated cancer risk for nearby residents exposed to emissions from the conveyorized graphite process ranged from values approaching zero to $9 \times 10^{-11}$ (one in 11 billion) for the alkyl oxide. The risk characterization for ambient exposure to other MHC chemicals also indicated low concern from the estimated air concentrations for chronic non-cancer effects.

These results suggest little change in public health risks and, thus, private benefits or costs if a facility switched from the baseline to an MHC alternative. However, it is important to note that it was not within the scope of this comparison to assess all community health risks. The risk characterization did not address all types of exposures that could occur from MHC processes or the PWB industry, including short-term or long-term exposures from sudden releases due to spills, fires, or periodic releases.

**Ecological Risks**

MHC chemicals are potentially damaging to terrestrial and aquatic ecosystems, resulting in both private costs borne by the manufacturers and external costs borne by society. Private costs could include increased liability costs while external costs could include loss of ecosystem diversity and reductions in the recreational value of streams and rivers. The CTSA evaluated the ecological risks of the baseline and alternatives in terms of aquatic toxicity hazards. Aquatic risk could not be estimated because chemical concentrations in MHC line effluents and streams were not available and could not be estimated. It is not possible to reliably estimate concentrations only from the MHC process since most PWB manufacturers combine MHC effluents with effluents from other process lines.

Table 7.12 presents the number of chemicals in each technology with a high aquatic hazard concern level. There are well documented copper pollution problems associated with discharges to surface waters and many of the MHC alternatives contain copper compounds. The lowest CC for an MHC chemical is for copper sulfate, which is found in five of the MHC technology categories: electroless copper, carbon, graphite, non-formaldehyde electroless copper, and tin-palladium. Bath concentrations of copper sulfate vary, ranging from a high of 22 g/l for the non-formaldehyde electroless copper technology to a low of 0.2 g/l in one of the tin-palladium processes (and, based on MSDS data, not present in the conductive ink, conductive polymer, or organic-palladium processes). Because the concentration of copper sulfate in different MHC line effluents is not known, the benefits or costs of using one of these MHC alternatives cannot be assessed. For example, the non-formaldehyde electroless copper process has a higher bath concentration of copper sulfate than the baseline; however, because the non-formaldehyde electroless copper process does not contain the chelator EDTA, more copper may be removed during wastewater treatment.

**Table 7.12 Number of Chemicals with High Aquatic Hazard Concern Level**

| MHC Technology | No. of Chemicals |
|---|---|
| Electroless Copper | 9 |
| Carbon | 2 |
| Conductive Ink | 2 |
| Conductive Polymer | 0 |
| Graphite | 3 |
| Non-Formaldehyde Electroless Copper | 3 |
| Organic-Palladium | 2 |
| Tin-Palladium | 9 |

## Plant-Wide Benefits or Costs

The CTSA did not determine the PWB plant-wide benefits or costs that could occur from implementing an alternative to the baseline MHC technology. However, a recent study of the Davila International PWB plant in Mountain View, California, identified a number of changes to the PWB manufacturing process that were only possible when an alternative to electroless copper was installed. These changes reduced copper pollution and water use, resulting in cost savings. A companion document to this publication, *Implementing Cleaner Technologies in the Printed Wiring Board Industry: Making Holes Conductive* (EPA, 1997), describes some of the systems benefits that can occur from implementing an MHC technology.

Improvements in the efficiency of the overall system not only provide private benefits, but also social benefits.

In addition, the baseline MHC process is a production bottleneck in many shops, but the alternative MHC technologies have substantially improved production rates. Thus, switching to an alternative improves the competitiveness of a PWB manufacturer by enabling the same number of boards to be produced faster or even enabling an increase in overall production capacity. However, the increased productivity could have social costs if increased production rates cause increased pollution rates in other process steps. Greater production rates in all the processes should be coupled with pollution prevention measures.

Another cost could be incurred if increased production results in increased amounts of scrap board. The Performance Demonstration determined that all of the alternatives have the potential to perform as well as electroless copper if operated properly. However, vendors and manufacturers who have implemented the alternatives stress the importance of taking a "whole-process" view of new MHC technology installation. Process changes upstream or downstream may be necessary to optimize alternative MHC processes (EPA, 1997). This is also important from a societal perspective because an increase in scrap boards can increase pollution generation off-site. In particular, citizens groups are concerned about potential dioxin emissions from the off-site process of secondary metal smelting which recycles scrap boards (Smith and Karras, 1997).

**Other Private Benefits and Costs**

Table 7.13 gives additional examples of private costs and benefits that could not be quantified. These include wastewater treatment, solid waste disposal, compliance, liability, insurance and worker illness costs, and improvements in company image that accrue from implementing a substitute. Some of these were mentioned above, but are included in the table due to their importance to overall benefits and costs.

### 7.2.4 External Benefits and Costs

External costs are those costs that are not taken into account in the manufacturer's pricing and manufacturing decisions. These costs are commonly referred to as "externalities" and are costs that are borne by society and not by the individuals who are part of a market transaction. These costs can result from a number of different avenues in the manufacturing process. For example, if a manufacturer uses a large quantity of a non-renewable resource during the manufacturing process, society will eventually bear the costs for the depletion of this natural resource. Another example of an external cost is an increase in population health effects resulting from the emission of chemicals from a manufacturing facility. The manufacturer does not pay for any illnesses that occur outside the plant that result from air emissions. Society must bear these costs in the form of medical care payments or higher insurance premiums.

Conversely, external benefits are those that do not benefit the manufacturer directly. For example, an alternative that uses less water results in both private and external benefits. The manufacturer pays less for water; society in general benefits from less use of a scarce resource. This type of example is why particular aspects of the MHC process are discussed in terms of both private benefits and costs and external benefits and costs.

**Table 7.13 Examples of Private Costs and Benefits Not Quantified**

| Category | Description of Potential Costs or Benefits |
| --- | --- |
| Wastewater Treatment | Alternatives to the baseline MHC technology may provide cost savings by reducing the quantity and improving the treatability of process wastewaters. In turn, these cost savings can enable the implementation of other pollution prevention measures. Alternatives to the baseline process use less rinse water and, consequently, produce less wastewater. In addition, the elimination of the chelator EDTA found in electroless copper processes simplifies the removal of heavy metal ions by precipitation. However, other processes may contain complexing agents that form bonds with metal ions, also making them difficult to remove. For example, the graphite technology contains the complexing agent ammonia. All of these factors—reducing the quantity of wastewater, reducing the amount of chelated or complexed metals in wastewater effluents, and enabling pollution prevention measures—provide social benefits as well as private benefits. |
| Solid Waste Disposal | All of the alternatives result in the generation of sludge, off-specification PWBs, and other solid wastes, such as spent bath filters. These waste streams must be recycled or disposed of, some of them as hazardous waste. For example, many PWB manufacturers send sludges to a recycler to reclaim metals in the sludge. Sludges that cannot be effectively recycled will most likely have to be landfilled. It is likely that the manufacturer will incur costs in order to recycle or landfill these sludges and other solid wastes, however these costs were not quantified. Three categories of MHC technologies generate RCRA-listed wastes, including electroless copper, conductive ink, and tin-palladium. However, other technologies may generate wastes considered hazardous because they exhibit certain characteristics. In addition, most facilities combine wastewater from various process lines prior to on-site treatment, including wastewater from electroplating operations. Wastewater treatment sludge from copper electroplating operations is a RCRA F006 hazardous waste. Reducing the volume and toxicity of solid waste also provides social benefits. |
| Compliance Costs | The cost of complying with all environmental and safety regulations affecting the MHC process line was not quantified. However, chemicals and wastes from the MHC alternatives are subject to fewer overall federal environmental regulations than the baseline, suggesting that implementing an alternative could potentially reduce compliance costs. It is more difficult to assess the relative cost of complying with OSHA requirements, because the alternatives pose similar occupational safety hazards (although non-automated, non-conveyorized equipment may pose less overall process hazards than working with mechanized equipment). |
| Liability, Insurance, and Worker Illness Costs | Based on the results of the risk characterization, it appears that alternatives to the baseline process pose lower overall risk to human health and the environment. Implementing an alternative could cause private benefits in the form of lower liability and insurance cost and increased employee productivity from decreases in incidences of illness. Clearly, alternatives with reduced risk also provide social benefits (discussed in Section 7.2.4). |
| Company Image | Many businesses are finding that using cleaner technologies results in less tangible benefits, such as an improved company image and improved community relations. While it is difficult to put a monetary value on these benefits, they should be considered in the decision-making process. |

The potential external benefits associated with the use of an MHC alternative include: reduced health risk for workers and the general public, reduced ecological risk, and reduced use of energy and natural resources. Another potential externality is the influence a technology choice has on the number of PWB plant jobs in a community. Each of these is discussed in turn below.

## Occupational Health Risks

Section 7.2.3 discussed risk characterization results for occupational exposures. Based on the results of the risk characterization, it appears that alternatives to the non-conveyorized electroless copper process have private benefits due to reduced occupational risks. However, there are also occupational inhalation risk concerns for some chemicals in the non-formaldehyde electroless copper and tin-palladium non-conveyorized processes. In addition, there are occupational dermal exposure risk concerns for some chemicals in the conveyorized electroless copper, the non-conveyorized non-formaldehyde electroless copper, and organic-palladium and tin-palladium processes with conveyorized or non-conveyorized equipment. Finally, occupational health risks could not be quantified for one or more of the chemicals used in each of the MHC technologies. This is due to the fact that proprietary chemicals in the baths were not identified by some suppliers[17] and to missing toxicity or chemical property data for some chemicals known to occur in the baths.

Reduced occupational risks provide significant private as well as social benefits. Private benefits can include reduced insurance and liability costs, which may be readily quantifiable for an individual manufacturer. External benefits are not as easily quantifiable. They may result from the workers themselves having reduced costs such as decreased insurance premiums or medical payments or society having reduced costs based on the structure of the insurance industry.

Data exist on the cost of avoiding or mitigating certain illnesses that are linked to exposures to MHC chemicals. These cost estimates can serve as indicators of the potential benefits associated with switching to technologies using less toxic chemicals or with reduced exposures. Table 7.14 lists potential health effects associated with MHC chemicals of concern. It is important to note that, except for cancer risk from formaldehyde, the risk characterization did not link exposures of concern with particular adverse health outcomes or with the number of incidences of adverse health outcomes.[18] Thus, the net benefit of illnesses avoided by switching to an MHC alternative cannot be calculated.

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[17] Electrochemicals, LeaRonal, and Solution Technology Systems provided information on proprietary chemical ingredients to the project for evaluation in the risk characterization. Atotech provided information on one proprietary chemical used in the product line. Enthone-OMI, MacDermid, and Shipley declined to provide proprietary chemical information. Risk results for proprietary chemicals, as available, but not chemical identities or concentrations, are included in this CTSA.

[18] Cancer risk from formaldehyde exposure was expressed as a probability, but the exposure assessment did not determine the size of the potentially exposed population (e.g., number of MHC line operators and others working in the process area). This information would be necessary to estimate the number of illnesses avoided by switching to an alternative from the baseline.

**Table 7.14 Potential Health Effects Associated with MHC Chemicals of Concern**

| Chemical of Concern | Alternatives with Exposure Levels of Concern | Pathway of Concern[a] | Potential Health Effects |
|---|---|---|---|
| Alkene Diol | Electroless Copper | inhalation | Exposure to low levels may result in irritation of the throat and upper respiratory tract. |
| Copper Chloride | Electroless Copper | inhalation | Long-term exposure to copper dust can irritate nose, mouth, eyes and cause dizziness. Long-term exposure to high levels of copper may cause liver damage. Copper is not known to cause cancer. The seriousness of the effects of copper can be expected to increase with both level and length of exposure. |
| | | dermal | No data were located for health effects from dermal exposure in humans. |
| Ethanolamine | Electroless Copper, Tin-Palladium | inhalation | Ethanolamine is a strong irritant. Animal studies showed that the chemical is an irritant to the respiratory tract, eyes, and skin. No data were located for inhalation exposure in humans. |
| 2-Ethoxyethanol | Electroless Copper | inhalation | In animal studies 2-ethoxyethanol caused harmful blood effects, including destruction of red blood cells and releases of hemoglobin (hemolysis), and male reproductive effects at high exposure levels. The seriousness of the effects of the chemical can be expected to increase with both level and length of exposure. No data were located for inhalation exposure in humans. |
| Ethylene Glycol | Electroless Copper | inhalation | In humans, low levels of vapors produce throat and upper respiratory irritation. When ethylene glycol breaks down in the body, it forms chemicals that crystallize and that can collect in the body and prevent kidneys from working. The seriousness of the effects of the chemical can be expected to increase with both level and length of exposure. |
| Fluoroboric Acid | Electroless Copper, Tin-Palladium | dermal | Fluoroboric acid in humans produces strong caustic effects leading to structural damage to skin and eyes. |

| Chemical of Concern | Alternatives with Exposure Levels of Concern | Pathway of Concern[a] | Potential Health Effects |
|---|---|---|---|
| Formaldehyde | Electroless Copper | inhalation | EPA has classified formaldehyde as a probable human carcinogen (EPA Group B1). Inhalation exposure to formaldehyde in animals produces nasal cancer at low levels. In humans, exposure to formaldehyde at low levels in air produces skin irritation and throat and upper respiratory irritation. The seriousness of these effects can be expected to increase with both level and length of exposure. |
| | | dermal | In humans, exposure to formaldehyde at low levels in air produces skin irritation. The seriousness of these effects can be expected to increase with both level and length of exposure. |
| Methanol | Electroless Copper | inhalation | Long-term exposure to methanol vapors can cause headache, irritated eyes and dizziness at high levels. No harmful effects were seen when monkeys were exposed to highly concentrated vapors of methanol. When methanol breaks down in the tissues, it forms chemicals that can collect in the tissues or blood and lead to changes in the interior of the eye causing blindness. |
| Nitrogen Heterocycle | Electroless Copper | dermal | No data were located for health effects from dermal exposure in humans. |
| Palladium | Electroless Copper, Tin-Palladium | dermal | No specific information was located for dermal exposure of palladium in humans. |
| Palladium Chloride | Tin-Palladium | dermal | Long-term dermal exposure to palladium chloride in humans produces contact dermatitis. |
| Palladium Salt | Organic-Palladium | dermal | Exposure may result in skin irritation and sensitivity. |
| Sodium Carboxylate | Electroless Copper | dermal | No data were located for health effects from dermal exposure in humans. |
| Sodium Chlorite | Electroless Copper, Non-Formaldehyde Electroless Copper | dermal | No specific information was located for health effects from dermal exposure to sodium chlorite in humans. Animal studies showed that the chemical produces moderate irritation of skin and eyes. |
| Stannous Chloride | Electroless Copper, Non-Formaldehyde Electroless Copper, Tin-Palladium | dermal | Mild irritation of the skin and mucous membrane has been shown from inorganic tin salts. However, no specific information was located for dermal exposure to stannous chloride in humans. Stannous chloride is only expected to be harmful at high doses; it is poorly absorbed and enters and leaves the body rapidly. |

| Chemical of Concern | Alternatives with Exposure Levels of Concern | Pathway of Concern[a] | Potential Health Effects |
|---|---|---|---|
| Sulfuric Acid | Electroless Copper, Non-Formaldehyde Electroless Copper, Tin-Palladium | inhalation | Sulfuric acid is a very strong acid and can cause structural damage to skin and eyes. Humans exposed to sulfuric acid mist at low levels in air experience a choking sensation and irritation of lower respiratory passages. |
| Tin Salt | Electroless Copper | dermal | No data were located for health effects from dermal exposure in humans. Inorganic tin compounds may irritate the eyes, nose, throat, and skin. |

[a] Inhalation concerns only apply to non-conveyorized processes. Dermal concerns may apply to non-conveyorized and/or conveyorized processes (see Table 7.3).

Health endpoints potentially associated with MHC chemicals of concern include: nasal cancer (for formaldehyde), eye irritation, and headaches. The draft EPA publication, *The Medical Costs of Selected Illnesses Related to Pollutant Exposure* (EPA, 1996), evaluates the medical cost of some forms of cancer, but not nasal cancer. Other publications have estimated the economic costs associated with eye irritation and headaches. These data are discussed below.

**Benefits of Avoiding Illnesses Potentially Linked to MHC Chemical Exposure**

This section presents estimates of the economic costs of some of the illnesses or symptoms associated with exposure to MHC chemicals. To the extent that MHC chemicals are not the only factor contributing toward the illnesses described, individual costs may overestimate the potential benefits to society from substituting alternative MHC technologies for the baseline electroless copper process. For example, other PWB manufacturing process steps may also contribute toward adverse worker health effects. The following discussion focuses on the external benefits of reductions in illness. However, private benefits may be accrued by PWB manufacturers through increased worker productivity and a reduction in liability and health care insurance costs. While reductions in insurance premiums as a result of pollution prevention are not currently widespread, the opportunity exists for changes in the future.

Exposure to several of the chemicals of concern is associated with eye irritation. Other potential health effects include headaches and dizziness. The economic literature provides estimates of the costs associated with eye irritation and headaches. An analysis by Unsworth and Neumann summarizes the existing literature on the costs of illness based on estimates of how much an individual would be willing to pay to avoid certain acute effects for one symptom day (Unsworth and Neumann, 1993). These estimates are based upon a survey approach designed to elicit estimates of individual willingness-to-pay to avoid a single incidence and not the lifetime costs of treating a disease. Table 7.15 presents a summary of the low, mid-range, and high estimates of individual willingness-to-pay to avoid eye irritation and headaches. These estimates provide an indication of the benefit per affected individual that would accrue to society if switching to a substitute MHC technology reduced the incidence of these health endpoints.

**Table 7.15 Estimated Willingness-to-Pay to Avoid Morbidity Effects for One Symptom Day (1995 dollars)**

| Health Endpoint | Low | Mid-Range | High |
|---|---|---|---|
| Eye Irritation[a] | $21 | $21 | $46 |
| Headache[b] | $2 | $13 | $67 |

[a] Tolley, G.S., et al. January 1986. *Valuation of Reductions in Human Health Symptoms and Risks*. University of Chicago. Final Report for the U.S. EPA. As cited in Unsworth, Robert E. and James E. Neumann, Industrial Economics, Incorporated. Memorandum to Jim DeMocker, Office of Policy Analysis and Review. *Review of Existing Value of Morbidity Avoidance Estimates: Draft Valuation Document*. September 30, 1993.
[b] Dickie, M., et al. September 1987. *Improving Accuracy and Reducing Costs of Environmental Benefit Assessments*. U.S. EPA, Washington, DC. Tolley, G.S., et al. *Valuation of Reductions in Human Health Symptoms and Risks*. January 1986. University of Chicago. Final Report for the U.S. EPA. As cited in Unsworth, Robert E. and James E. Neumann, Industrial Economics, Incorporated. Memorandum to Jim DeMocker, Office of Policy Analysis and Review. *Review of Existing Value of Morbidity Avoidance Estimates: Draft Valuation Document*. September 30, 1993.

## Public Health Risk

Section 7.2.3 discussed public health risks from MHC chemical exposure. The risk characterization identified no concerns for the general public through ambient air exposure with the possible exception of formaldehyde exposure from electroless copper processes. While the study found little difference among the alternatives for those public health risks that were assessed, it was not within the scope of this comparison to assess all community health risks. Risk was not characterized for exposure via other pathways (e.g., drinking water, fish ingestion, etc.) or short-term exposures to high levels of hazardous chemicals when there is a spill, fire, or other periodic release.

## Ecological Hazards

The CTSA evaluated the ecological risks of the baseline and alternatives in terms of aquatic toxicity hazards. Aquatic risk could not be estimated because chemical concentrations in MHC line effluents and streams were not available and could not be estimated. Reduced aquatic hazards can provide significant external benefits, including improved ecosystem diversity, improved supplies for commercial fisheries, and improved recreational values of water resources. There are well documented aquatic toxicity problems associated with copper discharges to receiving waters, but this assessment was unable to determine the relative reduction in copper or other toxic discharges from the baseline to the alternatives. Five processes contain copper sulfate, the most toxic of the copper compounds found in MHC lines, and other processes contain copper chloride. In order to evaluate the private and external benefits or costs of implementing an alternative, PWB manufacturers should attempt to determine what the changes in their mass loading of copper or other toxic discharges would be.[19]

[19] Copper discharges are a particular problem because of the cumulative mass loadings of copper discharges from a number of different industry sectors, including the PWB industry.

## Energy and Natural Resources Consumption

Table 7.16 summarizes the water and energy consumption rates and percent changes in consumption from the baseline to the MHC alternatives. All of the alternatives use substantially less energy and water per ssf of PWB produced, with the exception of the carbon technology which only has a slight decrease (< ten percent) in energy use from the baseline. While manufacturers face direct costs from the use of energy and water in the manufacturing process, society as a whole also experiences costs from this usage. For energy consumption, these types of externalities can come in the form of increased emissions to the air either during the initial manufacturing of the energy or the MHC processes themselves. These emissions include $CO_2$, $SO_x$, $NO_2$, CO, $H_2SO_4$, and particulate matter. Table 5.9 in the Energy Impacts section (Section 5.2) details the pollution resulting from the generation of energy consumed by MHC alternatives. Environmental and human health concerns associated with these pollutants include global warming, smog, acid rain, and health effects from toxic chemical exposure.

**Table 7.16 Energy and Water Consumption of MHC Technologies**

| MHC Technology | Water Consumption | | Energy Consumption | |
|---|---|---|---|---|
| | gal/ssf | % change | Btu/ssf | % change |
| Electroless Copper, non-conveyorized (BASELINE) | 11.7 | | 573 | |
| Electroless Copper, conveyorized | 1.15 | -90 | 138 | -76 |
| Carbon, conveyorized | 1.29 | -89 | 514 | -9.6 |
| Conductive Polymer, conveyorized | 0.73 | -94 | 94.7 | -83 |
| Graphite, conveyorized | 0.45 | -96 | 213 | -63 |
| Non-Formaldehyde Electroless Copper, non-conveyorized | 3.74 | -68 | 270 | -53 |
| Organic-Palladium, non-conveyorized | 1.35 | -88 | 66.9 | -88 |
| Organic-Palladium, conveyorized | 1.13 | -90 | 148 | -74 |
| Tin-Palladium, non-conveyorized | 1.80 | -85 | 131 | -77 |
| Tin-Palladium, conveyorized | 0.57 | -95 | 96.4 | -83 |

In addition to increased pollution, the higher energy usage of the baseline also results in external costs in the form of depletion of natural resources. Some form of raw resource is required to make electricity, whether it be coal, natural gas or oil, and these resources are non-renewable. While it is true that the price of the electricity to the manufacturer takes into account the actual raw materials costs, the price of electricity does not take into account the depletion of the natural resource base. As a result, eventually society will have to bear the costs for the depletion of these natural resources.

The use of water and consequent generation of wastewater also results in external costs to society. While the private costs of this water usage are included in the cost estimates in Table 7.10, the external costs are not. The private costs of water usage account for the actual quantities of water used in the MHC process by each different technology. However, clean water is quickly becoming a scarce resource, and activities that utilize water therefore impose external costs on society. These costs can come in the form of higher water costs for the surrounding area or for higher costs paid to treatment facilities to clean the water. These costs may also come in the form of decreased water quality available to society. In fact, in Germany, PWB manufacturers are required to use their wastewater at least three times before disposing of it because of the scarcity of water.

**Effects on Jobs**

The results of the cost analysis suggest that alternative MHC technologies are generally more efficient than the baseline process due to decreased cycle times. In addition, labor costs are one of the biggest factors causing the alternatives to be cheaper. Neither the Cost Analysis nor the CTSA analyzed the potential for job losses resulting from implementing an alternative. However, if job losses were to occur, this could be a significant external cost to the community. For example, in Silicon Valley, community groups are striving to retain clean, safe jobs through directing cost savings to environmental improvements that create or retain jobs. While the effects on jobs of wide-scale adoption of an alternative were not analyzed, anecdotal evidence from facilities that have switched from the baseline suggests that jobs are not lost, but workers are freed to work on other tasks (Keenan, 1997). In addition, one incentive for PWB manufacturers to invest in the MHC alternatives is the increased production capacity of the alternatives. Some PWB manufacturers who choose to purchase new capital-intensive equipment are doing so because of growth, and would not be expected to lay off workers (Keenan, 1997).

**Other External Benefits or Costs**

In addition to the externalities discussed above, the baseline and MHC alternatives can have other external benefits and costs. Many of these were discussed in Table 7.13 because many factors share elements of both private and external benefits and costs. For example, regulated chemicals result in a compliance cost to industry, but they also result in an enforcement cost to society whose governments are responsible for ensuring environmental requirements are met.

### 7.2.5 Summary of Benefits and Costs

The objective of a social benefits/costs assessment is to identify those technologies or decisions that maximize net benefits. Ideally, the analysis would quantify the social benefits and costs of using the alternative and baseline MHC technologies in terms of a single unit (e.g., dollars) and calculate the net benefits of using an alternative instead of the baseline technology. Due to data limitations, however, this assessment presents a qualitative description of the benefits and costs associated with each technology compared to the baseline. Table 7.17 compares some of the relative benefits and costs of each technology to the baseline, including production costs, worker health risks, public health risks, aquatic toxicity concerns, water consumption, and energy consumption. The effects on jobs of wide-scale adoption of an alternative are not included in the table because the potential for job losses was not evaluated in the CTSA. However, the results of the Cost Analysis suggest there are significantly reduced labor requirements for the alternatives. Clearly, the loss of manufacturing jobs would be a significant external cost to the community and should be considered by PWB manufacturers when choosing an MHC technology.

**Table 7.17 Relative Benefits and Costs of MHC Alternatives Versus Baseline**

| MHC Technology | Production Costs ($/ssf) | Number of Chemicals of Concern[a] | | | | Water Consumption (gal/ssf) | Energy Consumption (Btu/ssf) |
|---|---|---|---|---|---|---|---|
| | | Worker Health Risks[b,c,d] | | Public Health Risks[e] | High Aquatic Toxicity Concern[b,f] | | |
| | | Inhalation | Dermal | Inhalation | | | |
| Electroless Copper, non-conveyorized (BASELINE) | $0.51 | 10 | 8 | 0[g] | 9 | 11.7 | 573 |
| Electroless Copper, conveyorized | ↗↗ | ↗↗ | ↔ | ↔[h] | ↔ | ↗↗ | ↗↗ |
| Carbon, conveyorized | ↗↗ | ↗↗ | ↗↗ | ↗ | ↔ | ↗↗ | ↔ |
| Conductive Polymer, conveyorized | ↗↗ | ↗↗ | ↗↗ | ↗ | ↗ | ↗↗ | ↗↗ |
| Graphite, conveyorized | ↗↗ | ↗↗ | ↗↗[i] | ↗[j] | ↔ | ↗↗ | ↗↗ |
| Non-Formaldehyde Electroless Copper, non-conveyorized | ↗ | ↗ | ↗ | ↗ | ↔ | ↗↗ | ↗↗ |
| Organic-Palladium, non-conveyorized | ↗↗ | ↗↗ | ↗ | ↗ | ↗ | ↗↗ | ↗↗ |
| Organic-Palladium, conveyorized | ↗↗ | ↗↗ | ↗ | ↗ | ↗ | ↗↗ | ↗↗ |
| Tin-Palladium, non-conveyorized | ↗↗ | ↗ | ↗ | ↗ | ↔ | ↗↗ | ↗↗ |
| Tin-Palladium, conveyorized | ↗↗ | ↗↗ | ↗ | ↗ | ↔ | ↗↗ | ↗↗ |

[a] Includes proprietary chemicals that were identified.

[b] For technologies with more than one chemical supplier (i.e., electroless copper, graphite, and tin-palladium) all chemicals may not be present in any one product line.

[c] For the most exposed individual (i.e., an MHC line operator).

[d] Because the risk characterization did not estimate the number of incidences of adverse health outcomes, the amount of reduced risk benefit cannot be quantifed. However, based on the level of formaldehyde risk and the number of chemicals of concern for the baseline, it appears all of the alternatives have at least some reduced risk benefits from the baseline.

[e] Because the risk characterization did not estimate the number of incidences of adverse health outcomes, the amount of reduced risk benefit cannot be quantifed. However, based on the level of formaldehyde risk for the baseline, it appears all of the alternatives except the conveyorized electroless copper process have at least some reduced risk benefits from the baseline.

[f] Technologies using copper sulfate were assigned a neutral benefit or cost; other technologies were assigned "some benefit" because none of their chemicals are as toxic to aquatic organisms as copper sulfate. This assessment is based on hazard, not risk.

[g] No chemical risks above concern levels. However, it should be noted that formaldehyde cancer risks as high as $1 \times 10^{-7}$ were estimated.

[h] No chemical risks above concern levels. However, it should be noted that formaldehyde cancer risks as high as $3 \times 10^{-7}$ were estimated.

[i] No chemical risks above concern levels. However, it should be noted that proprietary chemical cancer risks as high as $1 \times 10^{-7}$ were estimated.

[j] No chemical risks above concern levels. However, it should be noted that proprietary chemical cancer risks as high as $9 \times 10^{-11}$ were estimated.

Key:

↔ - Neutral, less than 20 percent increase or decrease from baseline.

↗ - Some benefit, 20 to <50 percent decrease from baseline.

↗↗ - Greater benefit, 50 percent or greater decrease from baseline.

While each alternative presents a mixture of private and external benefits and costs, it appears that each of the alternatives have social benefits as compared to the baseline. In addition, at least three of the alternatives appear to have social benefits over the baseline in every category, but public health risk. These are the conveyorized conductive polymer process and both conveyorized and non-conveyorized organic-palladium processes. However, the supplier of these technologies has declined to provide complete information on proprietary chemical ingredients for evaluation in the risk characterization, meaning health risks could not be fully assessed. Little or no improvement is seen in public health risks because concern levels were very low for all technologies, although formaldehyde cancer risks as high as from $1 \times 10^{-7}$ to $3 \times 10^{-7}$ were estimated for non-conveyorized and conveyorized electroless copper processes, respectively.

In terms of worker health risks, conveyorized processes have the greatest benefits for reduced worker inhalation exposure to bath chemicals; they are enclosed and vented to the atmosphere. However, dermal contact from bath maintenance activities can be of concern regardless of the equipment configuration for electroless copper, organic palladium, and tin-palladium processes. No data were available for conveyorized non-formaldehyde electroless copper processes (the same chemical formulations were assumed), but the non-conveyorized version of this technology also has chemicals with dermal contact concerns.

The relative benefits and costs of technologies from changes in aquatic toxicity concerns were more difficult to assess because only aquatic hazards were evaluated and not risk. Several of the technologies contain copper sulfate, which has a very low aquatic toxicity concern concentration (0.00002 mg/l). However, all of the technologies contain other chemicals with high aquatic toxicity concern levels, although these chemicals are not as toxic as copper sulfate.

All of the alternatives provide significant social benefits in terms of energy and water consumption, with the exception of energy consumption for the carbon technology. The drying ovens used with this technology cause this technology to consume nearly as much energy per ssf as the baseline.