Chapter 5

SUMMARY AND CONCLUSIONS

The purpose of the CDP, as stated in Chapter 1, is to provide a scientific baseline of life-cycle environmental impacts of CRTs and LCDs, help manufacturers identify areas to focus improvement assessment activities, and to develop a life-cycle model for future analyses. The primary targeted audience is the electronics industry, for whom results may provide insight into improvement opportunities in the life cycle of CRTs and/or LCDs. In addition, the general public may also find results useful when considering environmental impacts of each display type. This chapter briefly summarizes the results and draws conclusions based on those results. This report, however, does not include direct comparative assertions or improvement assessments based on the results. Alternatively, results and conclusions are described in terms of the overall LCI versus the LCIA, and details of the impact assessment, including the additional assessments of lead, mercury and liquid crystals, and the sensitivity analyses. Major uncertainties, cost and performance considerations, suggestions for improvement opportunities, and suggestions for further research are also provided.

5.1 LCI vs. LCIA

In this LCA, a life-cycle inventory (LCI) was compiled from many data sources, including both primary and secondary data sources. The primary data were obtained from component and monitor manufacturers of CRTs and LCDs. In an LCA, inventory data provide information on how much material is being consumed in the life cycle (i.e., inputs) and how much material is generated/released (i.e., outputs). The LCI results of this report are detailed in Chapter 2. The LCI provides inventory data grouped by inventory type (e.g., primary material, energy, air emission, solid waste).

The LCI alone, however, does not always translate directly into impact categories that may be of interest. That is, a given amount of one material may have different impacts (for a certain impact category) than the same amount of another material. Furthermore, some materials may affect more than one impact category. For example, an air emission could affect air acidification as well as being toxic to humans breathing it. Therefore, a life-cycle impact assessment (LCIA) is conducted to reveal potential impacts in several impact categories. In this CDP LCIA, described in detail in Chapter 3, impacts are sometimes driven by materials other than the top inventory contributors. For example, the top air emission for LCDs is carbon dioxide (Table 2-49), however the greatest global warming impact score is from SF_6 in the LCD monitor/module manufacturing process (Table 3-25).

To illustrate that the inventory results may not directly translate into impact results, the first two columns in Table 5-1 show which monitor has greater inventory amounts for each inventory type in the LCI, and the last two columns show which monitor has greater impact scores for each impact category in the LCIA. The impact categories that are affected by each inventory type are in the same rows as the associated inventory type. As seen in Table 5-1, some impact categories associated with ancillary material and water pollutant inventory types had opposing outcomes in the LCI versus the LCIA. For example, the three impact categories affected by the ancillary material inventory had greater impacts for the CRT, although the ancillary material inventory had greater amounts of inputs for the LCD. In this case, both primary and ancillary materials contribute to the impact categories, causing differing results.

Considering the wastewater outputs, which are greater for the LCD than the CRT, the impacts related to water releases are in some cases greater for the CRT than the LCD. Note that although the wastewater volume is greater for the LCD, the total mass of water pollutants in the LCI is greater for the CRT (see Table 2-24). In the LCIA, the LCD has greater impacts for water eutrophication and aquatic toxicity, but not for the two water quality categories (BOD and TSS), chronic health effects to the public, nor terrestrial toxicity, all of which include water emissions in calculating the impact score.

Table 5-1. Baseline LCI vs. LCIA: monitor with greater inventory amount and impact

Baseline life-cycle inventory (LCI)		Baseline life-cycle impact assessment (LCIA)	
Inventory type	**Monitor with greater inventory results**	**Potential impact category(ies) associated with inventory type**	**Monitor with greater impact results**
Primary materials	CRT	Renewable resource use	CRT
		Nonrenewable resource use	CRT
		Chronic health effects, occupational	CRT
Ancillary materials	LCD	Renewable resource use	CRT
		Nonrenewable resource use	CRT
		Chronic health effects, occupational	CRT
Water inputs	CRT	Renewable resource use	CRT
Fuel inputs	CRT	Energy use	CRT
		Chronic health effects, occupational	CRT
Electricity inputs	CRT	Energy use	CRT
Total energy inputs	CRT	Energy use	CRT
Air pollutant outputs	CRT	Global warming	CRT
		Ozone depletion	*a*
		Photochemical smog	CRT
		Acidification	CRT
		Air particulates	CRT
		Chronic health effects, public	CRT
		Aesthetics (odor)	CRT
		Terrestrial toxicity	CRT

Table 5-1. Baseline LCI vs. LCIA: monitor with greater inventory amount and impact

Baseline life-cycle inventory (LCI)		Baseline life-cycle impact assessment (LCIA)	
Inventory type	**Monitor with greater inventory results**	**Potential impact category(ies) associated with inventory type**	**Monitor with greater impact results**
Wastewater outputs	LCD	*none*	NA
Water pollutant outputs	CRT	Water eutrophication	LCD
		Water quality, BOD	CRT
		Water quality, TSS	CRT
		Chronic health effects, public	CRT
		Aquatic toxicity	LCD
		Terrestrial toxicity	CRT
Hazardous waste outputs	CRT	Hazardous waste landfill use	CRT
Solid waste outputs	CRT	Solid waste landfill use	CRT
Radioactive waste outputs	CRT	Radioactive waste landfill use	CRT
Radioactivity outputs	CRT	Radioactivity	CRT

[a] The LCIs for both the CRT and LCD contain data for substances that were phased out of production by 1996 due to their ozone depletion potential. Whether these emissions still occur in countries that were signatories to the Montreal Protocol and its Amendments and Adjustments (such as the United States and Japan) is not known, but considered to be unlikely. When phased-out substances are included in the inventory, the CRT has greater ozone depletion impacts than the LCD. However, if phased-out substances are removed from the inventories, the results are switched, with the LCD having greater impacts.

5.2 LCIA RESULTS

5.2.1 CRT and LCD Baseline Results

The LCIA results, presented in detail in Chapter 3, showed that the CRT has greater total life-cycle impact indicators in most of the impact categories (see Table 3-10). In the baseline scenario, the CRT has greater impacts than the LCD in all but two impact categories (eutrophication and aquatic toxicity). However, note that for the ozone depletion category, the LCIs for both the CRT and LCD contain data for substances that were phased out of production by 1996 due to their ozone depletion potential. Whether these emissions still occur in countries that were signatories to the Montreal Protocol and its Amendments and Adjustments (such as the United States and Japan) is not known, but considered to be unlikely. When phased-out substances are included in the inventory, the CRT has greater ozone depletion impacts than the LCD. However, if phased-out substances are removed from the inventories, the results are switched, with the LCD having greater impacts.

When considering which life-cycle stage has greater impacts, the LCIA results showed that the manufacturing life-cycle stage dominates impacts for most impact categories for both the CRT and LCD (refer to Section 3.3). Table 5-2 summarizes which life-cycle stages have the greatest impacts for each impact category for the CRT and LCD. As shown in Table 5-2, the CRT has nine and the LCD has 11 impact categories with greatest impacts from the manufacturing life-cycle stage. Only six categories (solid waste landfill use, global warming, ozone depletion, acidification, air particulates, and chronic public health) have greatest impacts from the CRT use stage, and four categories (solid waste landfill use, acidification, air particulates, and chronic public health) have greatest impacts from the LCD use stage. The CRT has three categories with greatest impacts from the upstream life-cycle stage and the LCD has three. The end-of-life (EOL) life-cycle stage is greatest for the same two impact categories for both the CRT and LCD (hazardous waste landfill use and radioactive waste landfill use). Note that the EOL stage impacts are generally very small contributors to the overall impacts. This is likely because of the small inventories associated with the EOL processes, but also may be a function of the incomplete and/or secondary data for the EOL (i.e., no remanufacturing data, and secondary data not completely specific to the monitors evaluated in this study).

A more detailed evaluation of lead, mercury, and liquid crystals was completed in Chapter 4. As expected, the CRT, which has lead in the glass, frit, and printed wiring boards (PWBs), has greater impacts from lead than did the LCD, which only has lead in the PWBs. Regarding mercury, there were greater inventories of mercury in the CRT life cycle than in the LCD life cycle, despite the fact that only the LCD has mercury directly in the product. The greater amount of mercury is from the release of mercury and mercury compounds from the generation of electricity. And as the CRT life cycle uses more electricity than the LCD, there was a greater quantity of mercury releases reported for the CRT than the LCD. Liquid crystals are only found in LCDs, and therefore, there are no associated impacts for the CRT. Little conclusive information was available on the liquid crystal materials. A detailed literature search was conducted, however very little data were available on the toxicity of these materials. Based on the limited toxicity data obtained, liquid crystals currently do not appear to be a significant human health or environmental hazard in the LCD life cycle. However, there were insufficient toxicity data available to make a definitive conclusion about liquid crystal toxicity.

Table 5-2. Monitor type with greatest impacts for each life-cycle stage and impact category (baseline scenario)

Impact category	Monitor type with greatest impacts			
	Upstream	Manufacturing	Use	EOL
Renewable resource use	LCD	CRT		
Nonrenewable resource use		CRT, LCD		
Energy use		CRT, LCD		
Solid waste landfill use			CRT, LCD	
Hazardous waste landfill use				CRT, LCD
Radioactive waste landfill use				CRT, LCD
Global warming		LCD	CRT	
Ozone depletion		LCD	CRT	
Photochemical smog	LCD	CRT		
Acidification			CRT, LCD	
Air particulates			CRT, LCD	
Water eutrophication	CRT	LCD		
Water quality, BOD		CRT, LCD		
Water quality, TSS		CRT, LCD		
Radioactivity	CRT, LCD			
Chronic health effects, occupational		CRT, LCD		
Chronic health effects, public			CRT, LCD	
Aesthetics (odor)		CRT, LCD		
Aquatic toxicity	CRT	LCD		
Terrestrial toxicity		CRT, LCD		
TOTALS	CRT=3 LCD=3	CRT=9 LCD=11	CRT=6 LCD=4	CRT=2 LCD=2

5.2.2 CRT Results

For the CRT, many of the impacts were driven by a single material in the inventory. As stated in Section 3.3.15 and shown in Table 3-57, in 14 of the 20 impact categories, the top individual contributor to the impacts was responsible for greater than 50% of the impacts. This shows that the CRT data are highly sensitive to a few data points. Major conclusions from the CRT LCIA are as follows:

- Energy used in glass manufacturing and associated production of LPG are driving the baseline CRT results (they dominate ten impact categories, including overall life-cycle energy use).

- The large amounts of fuel used as energy sources are driving occupational health effects. Occupational impacts are calculated from inventory input amounts, and therefore there may or may not actually be exposure to these fuels (e.g., they may be contained); however, the results illustrate the potential for health effects, especially under spill or upset conditions.
- The generation of electricity for the use stage dominates seven impact categories.
- Air emissions of sulfur dioxide from electricity generation (for the use life-cycle stage) drive chronic public health effects, acidification, and terrestrial toxicity impacts. This may be a concern, for example, in areas in nonattainment of regulated levels of sulfur dioxide in the United States.

The use of LPG fuel in glass manufacturing dominated ten impact categories: two directly from the LPG used in glass/frit manufacturing (energy use impacts and chronic occupational health effects) and eight from LPG production (renewable resource use, nonrenewable resource use, photochemical smog, air particulates, water eutrophication, BOD water quality, TSS water quality, and aesthetics). In addition, impacts from the generation of electricity during the use stage dominated seven impact categories: solid waste landfill use, radioactive waste landfill use, global warming, ozone depletion, acidification, chronic public health, and terrestrial toxicity. The CRT tube manufacturing process, which represents the most functionally and physically (by mass) significant component of the CRT monitor, only dominated one impact category (aquatic toxicity). Twenty-six percent of the aquatic toxicity score was from phosphorus outputs from tube manufacturing, while most of the rest were from the materials processing life-cycle stage. The remaining two impact categories (hazardous waste landfill use and radioactivity) had greatest impacts from the landfilling of the assumed hazardous proportion of CRT monitors, and the release of Plutonium-241 in steel production, respectively (Table 3-57). The radioactivity impacts are driven by the radionuclide Pu-241, due to the electric grid inventory included in the steel production secondary data set, which includes nuclear fuel reprocessing.

The large amount of LPG reported for glass manufacturing was originally questioned during the data collection and verification stage of this project. While no compelling reason could justify removing the LPG data in the baseline case, a sensitivity analysis was conducted in which the glass energy data were modified. Other sensitivity analyses were also conducted (i.e., manufactured life, modified LCD monitor manufacturing energy, and modified LCD EOL distributions). However, the only scenario that substantially altered the comparative results was the modified glass energy scenario (see Table 3-62 and Section 3.4.5).

The overall energy in the baseline scenario was nearly seven times greater than that in the modified scenario (from 20,800 MJ to 3,020 MJ), and the amount of LPG dropped to zero, while other energy sources increased. The basis for the modified data was removing the energy inputs from one suspect data set. As a result, the CRT modified glass energy scenario had greater energy use impacts in the *use* stage than in the *manufacturing* stage for the CRT. The amount of LPG used in glass manufacturing in the baseline scenario is 351 kg/monitor of LPG, which alone costs about $71.[1] This is a significant amount of the cost of a complete CRT monitor (the range of a few currently selling 17" CRTs is $158-316, and the average cost from primary data collected in the CDP was $541, which are presented in Section 5.4). Therefore, it is likely that the actual energy inputs to the glass manufacturing process is somewhere between the baseline and modified glass scenarios. In conclusion, more information is needed on energy used in glass manufacturing, which is driving CRT baseline results.

The additional analyses for the CRT of lead and mercury also revealed that the use of lead could present health risks, but the method of using only inputs to evaluate occupational impacts (see Section 3.1.2.13) may not adequately represent occupational exposures and risks. Further refinement of the occupational impact analysis may be warranted.

Although there is no mercury in the CRT monitor, mercury emissions from electricity generation in the CRT life cycle were greater (in mass) than the mercury used in the LCD. Therefore, to reduce mercury emissions from the CRT life cycle, efforts to reduce electricity consumption could be taken. Additionally, changes to the electric grid could also reduce mercury emissions from the CRT life-cycle.

5.2.3 LCD Results

The LCD impact results were less sensitive to an individual input or output than the CRT results, although in 11 of the 20 impact categories an individual input was still responsible for greater than 50% of the total impacts (Table 3-58). In general, the LCD results are less uncertain than the CRT results. This is because most of the CRT results are being driven by either glass input data or data from secondary sources, while LCD impacts are being driven more by data from primary sources. Some results to note are as follows:

- The LCD monitor/module manufacturing process group had greatest impacts in six impact categories (Table 3-58).
- Although the top contributor to the energy impact category was electricity consumed in the use stage (30%), the overall energy impacts were greater from the manufacturing stage than the use stage.
- In the glass energy sensitivity scenario, the use stage had greatest energy impacts, although only by a small margin over the manufacturing stage (see Figure 3-26).
- Sulfur dioxide [emitted from electricity generation for the use stage, and constituting only 0.37% of the air emission inventory (see Table 2-49)] dominates the acidification, chronic public health, and terrestrial toxicity impact categories (Table 3-58). The high public health and terrestrial toxicity scores are due to its low non-cancer toxicity value and resulting high hazard value (HV).
- Sulfur hexafluoride (SF_6) from LCD monitor/module manufacturing was the single greatest contributor to the global warming impact score; however, carbon dioxide from the use stage and the materials processing stage also contributed significantly to the global warming impacts (Table 3-25).

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[1] Based on a "daily market price" on August 29, 2001, of $0.4160/gallon of LPG (http://www.americanpowernet.com/pub_energy/futures.html). For 351 kg/functional unit in the CRT manufacturing life-cycle stage, the cost is about $71 per functional unit (i.e., one monitor), assuming a density of LPG of 2.053 kg/gallon. For the LCD, the 16.8 kg/functional unit of LPG would cost about $3.40 per monitor.

- The glass energy inputs did not directly dominate any impact categories, as they did for the CRT (due to the smaller mass of glass in the LCD); however, LPG production (required for the glass energy fuel) dominated two categories: TSS water quality and aesthetics (Table 3-58).
- LNG as an ancillary inventory material was questionably very large and had greatest impacts in two categories: nonrenewable resource use and photochemical smog (Table 3-58; shown there as "Natural Gas Production" due to that process being used as a surrogate for LNG production).

The additional analyses of lead, mercury, and liquid crystals showed that the LCIA alone is not adequate enough to determine all the potential impacts within the life-cycle of the LCD monitors. Similar to the conclusion for the CRT, lead-based occupational impacts would require further refinement of the LCIA methodology. The LCIA method in this LCA used inputs as surrogates for occupational exposure. There are outputs, within the occupational setting, that should also be considered.

For mercury, which is found in the backlights of the LCD monitors, there is nearly the same amount of mercury by mass emitted to the air during electricity generation as there is mercury used to make the backlight unit. The mass of mercury input for backlights is only about 20% greater than the mercury air emissions from electricity generation (across all life-cycle stages).

Liquid crystals were also identified by the CDP Core Group as a material for which additional information would be reviewed. The LCIA did not find the liquid crystals to be significant contributors to any impact categories; however, this could partially be due to the lack of information on them. The additional analysis also revealed limited information, but qualitatively, did not show significant potential risk.

5.2.4 CRT vs. LCD Sensitivity Analysis Results

The only sensitivity analysis to show significant difference in the results was the modified glass energy scenario. In comparing the CRT and LCD, the CRT *baseline* scenario had greater impacts than the LCD in all but two impact categories (eutrophication and aquatic toxicity) and possibly three (ozone depletion). In the *modified glass energy scenario*, nine of the 20 categories had greater impacts from the LCD life-cycle than the CRT. Energy use remained greater for the CRT; however, nonrenewable resource use, global warming, photochemical smog, eutrophication, BOD and TSS water quality, chronic occupational health effects, and aesthetics all reversed such that the LCD had greater impacts than the CRT (Table 3-62). As stated above, it is believed that a more true representation of the monitor life cycles lies somewhere between the baseline and modified glass energy scenario. Further work is recommended in clarifying and refining glass energy input information.

5.3 UNCERTAINTIES

As with any LCA, it is not uncommon for there to be uncertainty associated with such a large data collection effort. Two of the largest sources of uncertainty in this LCA that have a significant effect on the results are as follows:

- *CRT and LCD glass manufacturing energy inputs (from primary data)*: The larger amount of glass used in CRTs than LCDs results in the CRT having greater associated uncertainty than the LCD results.
- *Secondary data for upstream and fuel production processes*: When any one material is used in the life-cycle of either monitor in large quantities, the impacts associated with the inputs and outputs from the production of that material may become significant. For example, LPG and LNG production were both used in significant enough amounts to influence some impact categories. Therefore, the uncertainty in the secondary data becomes important. This highlights the need for a consistent, national (or international) LCI database that is updated regularly.

Other uncertainties associated with individual data points collected from primary data sources may be found in the data for this analysis. However, they had less effect on the overall results than the uncertainties mentioned above. For manufacturers interested in conducting improvement assessments, closer review of such uncertainties may be warranted.

Other uncertainties in the LCA pertain to uncertainties inherent in LCIA methodology. The purpose of an LCIA is to evaluate the *relative potential* impacts of a product system for various impact categories. There is no intent to measure the *actual* impacts or provide spatial or temporal relationships linking the inventory to specific impacts. Uncertainties are inherent in each impact category, and the reader is referred to the baseline LCIA results in Section 3.3 for a detailed discussion of uncertainties by impact category.

Another point that should be recognized in the overall comparison of CRTs and LCDs is that CRTs are a more mature technology than LCDs. Changes in LCD manufacturing processes have likely occurred during the development and publication of this report. Therefore, comparisons must be carefully drawn when evaluating the mature CRT to the newer LCD technology.

5.4 COST AND PERFORMANCE CONSIDERATIONS

The focus of this study has been on the environmental effects associated with CRTs and LCDs. The environmental attributes or burdens of a product are not expected to be considered alone when evaluating the marketability and commercial success of a product. The cost and performance of each monitor type are obviously critical components to a company's or consumer's decisions of whether to produce or purchase a product. This section briefly addresses a few direct costs associated with the monitors. A complete cost analysis, including all direct costs (e.g., material costs) and indirect costs (e.g., environmental costs to society) are beyond the scope of this report. Direct retail costs of the monitors and electricity costs are presented herein.

The average retail price of 1997-2000 model year monitors, collected from the manufacturers who supplied data for this project, as well as the performance information, are presented in Table 5-3. Costs collected from current monitors on the market are presented in Table 5-4. From Table 5-3, which represents primary data collected on the actual monitors included in this study, the LCD is approximately 2.7 times more costly. More recent data show that prices have come down, and the difference in prices between the CRT and LCD has also been reduced.

Table 5-3. Primary cost and performance data collected from manufacturers for the CDP

Monitor	Display Size	Resolution	Brightness range	Contrast ratio range	Number of Colors	Average cost from primary data
	(inches)	(pixels)	(cd/m^2)			(US$)
CRT monitor (functional unit aggregate)	17	1024x768	86-154	----	"Full color"	$541
LCD monitor (functional unit aggregate)	15	1024x768	200-300	200:1 - 300:1	"Full color"	$1,450

---- Not reported or not applicable.

A complete cost analysis would require assessing the costs from each life-cycle stage. The costs presented above are retail costs that presumably represent the manufacturing costs, but probably not external environmental costs, for example. The costs from the use stage can be represented by the electricity costs during the use stage. The average cost of residential and commercial electricity in the United States is approximately $0.021/MJ,[2] and the CRT and LCD monitors use about 2,290 and 853 MJ/functional unit, respectively, in the use stage baseline scenario, which assumes a total of 13,547 hours per life over a period of 6.5 years (see Section 2.4.1.2). Therefore, the electricity costs to consumers during the use stages are $48 for the CRT and $18 for the LCD. The amount of electricity consumed and the associated cost of that electricity for each life-cycle stage in the baseline scenario are presented in Table 5-5.

[2] This number was calculated from a value found at the following Web address: www.eia.doe.gov/cneaf/electricity/ esr/t11.txt.

Table 5-4. Cost and performance data for some currently selling CRTs and LCDs[a]

Monitor	Display Size	Resolution	Brightness	Contrast ratio	Number of Colors	2001 Cost
	(inches)	(pixels)	(cd/m^2)			($US)
CRTs						
Monitor 1	17/16	1280x1040	----	----	----	$158
Monitor 2	17/16.1	1280x1040	----	"High contrast, anti-static, anti-glare coating."	----	$171
Monitor 3	17/16	1600x1200	----	----	----	$316
LCDs						
Monitor 1	15.1	1024x768	----	200:1	16.7 million	$349
Monitor 2 [b]	15.1	1024x768	200	250:1	16.7 million	$400
Monitor 3	15.1	1024x768	200 [c]	200:1 [c]	16+ million	$439
Monitor 4 [b]	15.1	1024x768	200	250:1	16.7 million	$499
Monitor 5	15	1024x768	210 [c]	350:1	----	$554

[a] All information from Vol. EC23 of the eCOST.com catalog, except where noted otherwise.
[b] Data from the manufacturer's Web site except for prices, which where obtained from http://www.cdw.com on 8/29/01.
[c] Data are from the manufacturer's Web site.
---- Not reported or not applicable.

Table 5-5. Life-cycle electricity costs (baseline scenario)

	CRT			LCD		
Life-cycle stage	**Electricity use (MJ/functional unit) (see Table J-3)**	**unit cost ($/MJ)**	**Cost ($US)**	**Electricity use (MJ/functional unit) (see Table J-12)**	**unit cost ($/MJ)**	**Cost ($US)**
Upstream	73.2	0.012 [a]	$1.3	8.55	0.012 [a]	$0.10
Manufacturing	129	0.012 [a]	$1.5	278	0.012 [a]	$3.4
Use	2,290	0.021 [b]	$48	853	0.021 [b]	$18
EOL	0.229	0.012 [a]	$0.003	0	0.012 [a]	0
Total	2,492	---	$51	1,140		$22

[a] 1999 U.S. average cost of electricity for the industrial sector is $0.0443/kWh. Assuming 3.6 MJ/kWh, ($0.0443/kWh)/(3.6 MJ/kWh) = $0.012/MJ. Source: www.eia.doe.gov/cneaf/electricity/esr/t11.txt. Note that the use of the *U.S.* average cost is simply to compare costs among life-cycle stages, although the actual costs would be mostly from *Asia*.
[b] 1999 U.S. average cost of electricity for the residential and commercial sectors is $0.0771/kWh. Assuming 3.6 MJ/kWh, ($0.0771/kWh)/(3.6 MJ/kWh) = $0.021/MJ. Source: www.eia.doe.gov/cneaf/electricity/esr/t11.txt.

5.4 COST AND PERFORMANCE CONSIDERATIONS

The LCA is defined such that the monitor assessments are performed on a functionally equivalent basis. To the extent possible, data were collected on functionally equivalent monitors. The data presented in Table 5-3 are the range of specifications provided by the monitor assemblers, but not necessarily from the manufacturers of all of the component parts. Therefore, we are unsure if the specifications provided by the monitor assemblers also represent those of the component parts, since the component parts manufacturers did not consistently supply performance data as requested in the data collection questionnaire used in this study. However, when companies were approached to participate in the study, they were informed of the performance specification parameters within which the study boundaries were defined. Therefore, it is assumed that they meet the specifications as presented in Chapter 1 (Table 1-2) and in Table 5-3 and they perform relatively equivalently. In the primary data, the reported brightness of the CRT was less than the LCD, otherwise, they are functionally similar.

5.5 IMPROVEMENT ASSESSMENT OPPORTUNITIES AND TARGETED AUDIENCE USES OF REPORT

To meet the primary objective of providing the display industry with data to perform improvement assessments, the industry should look at the manufacturing life-cycle stage, while recognizing the influences of the other stages. CRT improvement opportunities could include improved energy efficiency during glass manufacturing and display use, as well as reductions in lead content. LCD improvement opportunities could also include improved energy efficiency, especially during manufacturing. Certain materials, such as SF_6 and its contribution to global warming, may also be of concern and an area to focus on in future improvement assessments.

In addition, any improvement assessment should consider how changes in one life-cycle stage will affect impacts in other stages. For example, in Chapter 4 we saw that the mercury inputs and outputs from the intentional use of mercury in an LCD backlight are less than (by mass) the mercury emissions from the CRT use stage, due to the relatively high energy usage by the CRT and the emissions of mercury from electricity generation. In this example, we can see that on a pure mass basis, a product's energy efficiency is a key consideration and any changes in manufacturing should consider if it will affect changes in use. However, this project did not conduct a quantitative risk assessment to determine where the greatest potential for mercury exposure (and therefore risk) might occur. Consequently, we cannot definitively say whether it is better to have a potentially less energy-efficient backlight that does not contain mercury or a more energy-efficient backlight that does. Nonetheless, this analysis highlights the life-cycle trade-offs that must be considered in an improvement assessment.

Another objective of this study was to provide an LCA model for future analyses. Companies or individuals who have more current data for the CRT or LCD can apply them to the model presented here. For example, changes in an individual process can be identified and incorporated into the model. The other processes that are not expected to change significantly can be left unchanged, and only limited data would need to be altered. This would reduce the time and resources that would normally be required for a complete analysis.

Finally, those interested in comparing the results of the two monitors can apply their own set of importance weights to each impact category to determine their individual decision. For example, if energy impacts are much more important than aesthetics to a particular person, they can weigh energy more heavily in concluding which monitor may have fewer environmental impacts, while keeping in mind the data limitations and uncertainties, as well as cost and performance considerations.

5.6 SUGGESTIONS FOR FUTURE RESEARCH

Areas where future research could be conducted to refine and/or continue the use of the results in this study are as follows:

- gather more information on energy use in glass manufacturing;
- develop consistent materials and fuel processing data in a national (or international) LCI database that is updated regularly;
- refine and/or update some of the LCD manufacturing data (e.g., LNG data);
- collect more complete EOL data (e.g., remanufacturing data, and primary data for incineration and landfilling) to determine better representation of the EOL impacts;
- conduct more research on EOL options for LCDs;
- collect more detailed data on landfilling and other treatment processes, such as water treatment where no impacts were calculated;
- update manufacturing data to meet more recent monitor model years;
- conduct a more focused analysis on selected areas for detailed improvement assessments; and
- evaluate process changes or other alternatives against an "average 1997-2000 model year" to evaluate impacts of changes or improvements over time.