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Wire and Cable Insulation and Jacketing: Life-Cycle Assessments For Selected Applications

Chapter 4: Summary of Results

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CHAPTER 4 SUMMARY OF RESULTS

Life-cycle impact indicators were calculated for 14 impact categories to compare leaded and lead-free cable resin constructions for Category 6 CMR, CMP, and NM-B cables. Point estimate results were calculated using aggregated industry data from both primary and secondary data sources, along with documented estimates or default values for the disposition of cables at their end-of-life. For model parameters that possessed a large degree of uncertainty, a Monte Carlo-based uncertainty analysis was conducted to identify the likelihood that observed differences are real. For NM-B cables, extrusion data were not obtained and therefore, only a cradle-to-gate analysis (materials extraction to resin compounding) was conducted. Similarly, complete extrusion data were not obtained for the CMR zero-halogen alternative. Therefore, to conduct a comparable analysis, only the compounding process and the production of fuels and electricity needed to power the compounding process were included in the 3-way CMR analysis of leaded, lead-free, and zero-halogen cables.

Within this chapter, CMR, CMP, and NM-B results are presented in Sections 4.1, 4.2 and 4.3, respectively. Summary tables in each section list the total impact indicators for each impact category for the baseline and alternative cables, followed by the percent change for each category. The differences in the indicator scores within an impact category simply represent relative differences between the alternatives. The scores are not normalized to determine if they present a significant environmental impact. The scores for one category have no bearing on scores for another, which is evidenced by the differing units used in each category. Further, the percent change in one category is independent of the percent change in another category, and any difference does not indicate that one category is of greater or lesser concern than another category.

The summary results tables also provide relative quality ratings for each impact category. These are based on the quality of data used to quantify the LCI and LCIA, and the models used for each LCIA methodology. The basis for these ratings, as well as overall limitations and uncertainties are described in Chapter 5 (Section 5.3). Finally, the summary results tables in Section 4.1 and 4.2 indicate which impact categories have likely significant differences between the lead and lead-free alternative. These are only relevant to the CMR and CMP full life-cycle comparisons for which uncertainty analyses were conducted.

Additional summary tables are also presented in the following sections (4.1, 4.2, and 4.3), which indicate the process and individual flow responsible for the greatest percent of the total impact indicator. This information is provided to assist in identifying potential improvement opportunities, and should be used in conjunction with the information given in Section 5.2 (“Opportunities for Improvement”).

4.1 CMR Results Summary

The full life-cycle comparative analysis of leaded (baseline) and lead-free cables are summarized in Table 4-1. The point estimate results from the CMR impact assessment showed mixed results for both leaded and lead-free cable types, though the disparities for most impact categories were minimal. In eight impact categories, the lead-free cable construction had less environmental impacts; however, six of those categories generated inconclusive results due to the large uncertainty (i.e., the 10th and 90th percentiles of the two alternatives overlap, which eliminates the possibility of statistically significant differences). The remaining two categories that had less environmental burden and that were significantly different (at 80 percent confidence) were potential public chronic non-cancer toxicity and potential aquatic ecotoxicity. Both categories had a medium data quality rating.

Table 4-1

CMR LCIA Results – Full life cycle: Baseline and Lead-free.

Impact Category	Units per km Cable	Baseline Impact Indicator	Pb-free Impact Indicator	Percent Change	Quality Rating	Possible Signif. Diff.[a]
NRR	kg	142	121	-15%	M	
Energy	MJ	2070	1970	-5%	M	
Landfill space	m^3	0.0166	0.0181	9%	M	
Global warming	kg CO_2-equiv.	90.3	83.5	-8%	M	
Ozone depletion	kg CFC 11-equiv.	5.91E-06	4.95E-06	-16%	L	
Smog	kg ethene-equiv.	0.125	0.134	7%	M	
Acidification	kg SO_2-equiv.	0.731	0.678	-7%	M	
Air particulates	kg	0.0782	0.0815	4%	M	
Eutrophication	kg phosphate-equiv.	0.00902	0.00756	-16%	M	
Pot. occ. noncancer	kg noncancertox-equiv.	71.8	77.6	8%	M	Y
Pot. occ. cancer	kg cancertox-equiv.	3.53	3.69	5%	M-L	Y
Pot. public noncancer	kg noncancertox-equiv.	1460	279	-81%	M	Y
Pot. public cancer	kg cancertox-equiv.	0.834	0.837	0.3%	M-L	
Pot. aq. ecotox	kg aqtox-equiv.	17.5	0.113	-99%	M	Y

[a] "Y" indicates the alternatives were significantly different at 80% confidence (this confidence interval was used as it was part of a built-in program in GaBi4).
NRR = non-renewable resource use; Pot. = Potential; occ. = occupational; aq. ecotox = aquatic ecotoxicity; equiv. = equivalents; Signif. Diff. = significant difference.

Of the six categories that showed lower burden for the leaded cable, three displayed potential statistical significance (i.e., did not have overlapping 10th and 90th percentile results due to model parameter uncertainty): landfill space use, potential occupational non-cancer toxicity, and potential occupational cancer toxicity. Potential occupational non-cancer and landfill space use were assigned a medium quality rating, while potential occupational cancer toxicity was assigned a medium-low quality rating due to the scarcity of quantitative toxicity data (i.e., cancer slope factors).

The sensitivity analysis results (Section 3.4.2) revealed that the large uncertainty ranges were mostly attributable to the uncertainty in the energy needed for cable extrusion. For the leaded cable, this was the case for all categories except potential public non-cancer toxicity and potential aquatic ecotoxicity, where leachate uncertainty dominated, and landfill space use, where the percent of resins recycled after chopping had more effect on the results. For the lead-free cable, the uncertainty in all impact result categories was driven by extrusion energy, except for the landfill space use, which was most sensitive to the percent of resins recycled after chopping. These results indicate that the highly uncertain EOL parameters (e.g., percent of cables burned in a fire) did not greatly affect most of the overall comparative life-cycle CMR results.

As shown in Table 4-2, the top contributing process for several impact categories was the generation of electricity (needed to power the cable extrusion process in the cable manufacturing life-cycle stage). Electricity generation was the top process in the baseline cable case for 6 categories: non-renewable resource use, energy use, global warming, ozone depletion, air acidification, and eutrophication. For the lead-free cable alternative, the generation of electricity for cable extrusion was the top contributing process for the same 6 impact categories, plus the potential public non-cancer toxicity and potential aquatic toxicity impact categories. Jacketing resin production was the top contributing process for photochemical smog formation, air particulates, and potential public cancer toxicity for both cable alternatives. Municipal solid waste landfilling was the top contributing process to potential public non-cancer toxicity and potential aquatic ecotoxicity in the baseline case. Lead from landfilling was the top flow contributing to potential public non-cancer toxicity and potential aquatic ecotoxicity. Finally, the compounding of the jacketing was the top contributing process to the potential occupational non-cancer and cancer toxicity impact categories for both cable alternatives. This helps identify potential areas of environmental improvement; however, it must be noted that these results are in the context of the comparison of resin systems and their additives, so focusing on top contributors identified here does not provide the complete impacts from the entire cable (e.g., the copper conductor is excluded).

Table 4-2

CMR Summary of Top Contributors to LCIA Results – Full life cycle: Baseline and Lead-free.

Impact Category	Baseline		Pb-free	
	Top Process	**Top Flow**	**Top Process**	**Top flow**
NRR	Electricity generation	Inert rock	Electricity generation	Inert rock
Energy	Electricity generation	Natural gas	Electricity generation	Natural gas
Landfill space	MSW landfill	PVC waste	MSW landfill	PVC waste
Global warming	Electricity generation	Carbon dioxide	Electricity generation	Carbon dioxide
Ozone depletion	Electricity generation	CFC 11	Electricity generation	CFC 11
Smog	Jacketing resin production	VOC (unspecified)	Jacketing resin production	VOC (unspecified)
Acidification	Electricity generation	Sulfur dioxide	Electricity generation	Sulfur dioxide
Air particulates	Jacketing resin production	Dust	Jacketing resin production	Dust
Eutrophication	Electricity generation	Chemical oxygen demand	Electricity generation	Chemical oxygen demand
Pot. occ. noncancer	Jacketing compounding	FR #2 (non-halogen)[a]	Jacketing compounding	FR #2 (non-halogen)[a]
Pot. occ. cancer	Jacketing compounding	Phthalates[b]	Jacketing compounding	Phthalates[b]
Pot. public noncancer	MSW landfill	Lead (water)	Electricity generation	Sulfur dioxide (air)
Pot. public cancer	Jacketing resin production	Nitrogen oxides (air)[b]	Jacketing resin production	Nitrogen oxides (air)[b]
Pot. aq. ecotox	MSW landfill	Lead	Electricity generation	Chlorine (dissolved)

NRR = non-renewable resource use; Pot. = potential; occ. = occupational; aq. ecotox = aquatic ecotoxicity; PVC = polyvinyl chloride; MSW = municipal solid waste; CFC = chlorofluorocarbon; VOC = volatile organic compound; FR = flame retardant.

[a] Proprietary

[b] Flows given default toxicity hazard values due to lack of toxicological data

The 3-way CMR analysis (leaded versus lead-free versus zero-halogen) showed that for the cradle-to-gate analysis, the zero-halogen alternative required greater energy. This was a function of more energy required per mass of compounded resin produced, as well as the halogen-free cable having a higher mass-to-length ratio. Thus, on a functional unit basis, the total energy requirement was much larger (quantities withheld for proprietary considerations). In the CMR 3-way results, the production of electricity drove most impact categories, except for landfill space use and potential occupational non-cancer and cancer toxicity, for which the jacketing process was the top contributor. For air particulate production, the lead and lead-free cables were driven by jacketing compounding, but the zero-halogen was driven by electricity production. Note that the robustness of these data is limited, as the zero-halogen data are only based on one company's data. Further, this does not provide full life-cycle information and should not be construed to represent a full life-cycle analysis.

These results also demonstrate that only looking at one manufacturing process, even on a functionally equivalent basis, does not adequately estimate impacts over the full life cycle. This is evidenced by comparing the full life-cycle analysis with the partial life-cycle analysis, which only takes into consideration jacketing compounding and associated energy. In the full life-cycle analysis, the lead-free cable had lower impact indicators than the baseline in 8 impact categories; however for the partial analysis, only 1 category had lower impacts for the lead-free cable. Of the 5 categories in the full life-cycle analysis that had the greatest likelihood of statistically significant differences, 3 had results reversed in the partial life cycle (i.e., significantly less burden in the full life cycle versus more burden in the partial life cycle or vice versa): potential occupational cancer toxicity, potential public non-cancer toxicity, and potential aquatic ecotoxicity.

4.2 CMP Results Summary

The full life-cycle comparative analysis of leaded (baseline) and lead-free cables are summarized in Table 4-3. The point estimates from the CMP cable comparisons showed all categories except for landfill space use had fewer impacts for the lead-free compared to the leaded cables. However, only five categories did not have overlapping 10th and 90th uncertainty ranges: ozone depletion, potential occupational non-cancer toxicity, potential occupational cancer toxicity, potential public chronic non-cancer toxicity, and potential aquatic ecotoxicity, suggesting greater confidence in these results.

The sensitivity analysis results (Section 3.4.2) revealed that, as was the case with the CMR cable alternatives, the large uncertainty ranges were mostly attributable to the uncertainty in the extrusion energy. For the leaded cable, this was the case for all categories except potential public non-cancer toxicity and potential aquatic ecotoxicity, where leachate uncertainty dominated, and landfill space use, where the percent of resins recycled after chopping had more effect on the results. For the lead-free cable, the uncertainty in all impact result categories was driven by extrusion energy, except for the landfill space use, which was most sensitive to the percent of resins recycled after chopping. These results indicate that the highly uncertain EOL parameters (e.g., percent of cables burned in a fire) did not greatly affect most of the overall comparative life-cycle CMP results.

Table 4-3

CMP LCIA Results – Full life cycle: Baseline and Lead-free

Impact Category	Units per km Cable	Baseline Impact Indicator	Pb-free Impact Indicator	Percent Change	Quality Rating	Possible Signif. Diff.[a]
NRR	kg	237	219	-8%	M	
Energy	MJ	3770	3570	-5%	M	
Landfill space	m^3	0.0132	0.0144	9%	M	
Global warming	kg CO_2-equiv.	181	171	-5%	M	
Ozone depletion	kg CFC 11-equiv.	0.00116	0.00110	-5%	L	Y
Smog	kg ethene-equiv.	0.0886	0.0868	-2%	M	
Acidification	kg SO_2-equiv.	0.877	0.819	-7%	M	
Air particulates	kg	0.0746	0.0726	-3%	M	
Eutrophication	kg phosphate-equiv.	0.0125	0.0114	-9%	M	
Pot. occ. noncancer[b]	kg noncancertox-equiv.	49.2	46.8	-5%	M	Y
Pot. occ. cancer[b]	kg cancertox-equiv.	2.16	2.22	3%	M-L	Y
Pot. public noncancer	kg noncancertox-equiv.	952	358	-62%	M	Y
Pot. public cancer	kg cancertox-equiv.	0.735	0.701	-5%	M-L	
Pot. aq. ecotox	kg aqtox-equiv.	8.64	0.151	-98%	M	Y

[a] "Y" indicates the alternatives were significantly different at 80% confidence (this confidence interval was used as it was part of a built-in program in GaBi4).
[b] FEP production, which came from 2 primary datasets, was modeled with 2 industrial precursor chemicals functioning as inputs; production of PVC, the other major resin used in CMP cables, and which came from a secondary dataset, was modeled as if all of the materials came from ground (mining of inert or low-toxicity inputs), and did not explicitly include industrial precursor chemicals. In order to be more consistent across resins, the contributions from industrial precursor chemicals in the FEP supply chain were removed prior to calculation of the potential occupational toxicity results.
NRR = non-renewable resource use; Pot. = Potential; occ. = occupational; aq. ecotox = aquatic ecotoxicity; equiv. = equivalents; Signif. Diff. = significant difference.

Table 4-4 shows the generation of electricity was the top contributor to the following five impact categories for the lead-free cable: non-renewable resources, air acidification, and eutrophication, potential public non-cancer toxicity, and potential aquatic ecotoxicity impact categories. For the baseline cable, electricity generation was top contributor to three impact categories: non-renewable resources, air acidification, and eutrophication. For both CMP cable alternatives, the production of insulation resin (FEP) and jacketing resin (PVC), were each top contributors to three impact categories. FEP production was top contributor for both alternatives in energy use, global warming, and ozone depletion. PVC production was top contributor for both alternatives in photochemical smog, particulate matter, and potential public cancer toxicity. For the baseline CMP cable, the top contributing process to potential public non-cancer toxicity and potential aquatic ecotoxicity was municipal solid waste landfilling. For both of these categories, the top material flow contributor was lead assumed to leach from the landfill into groundwater. For both cable alternatives, the landfill space use impact category was also dominated by the municipal solid waste landfilling process. This information helps identify potential areas of environmental improvement; however, it must be noted that these results are in the context of the comparison of resin systems and their additives, so focusing on top contributors identified here does not provide the complete impacts from the entire cable (e.g., the copper conductor is excluded).

Table 4-4

CMP Summary of Top Contributors to LCIA Results – Full life cycle: Baseline and Lead-free.

Impact Category	Baseline		Pb-free	
	Top process	Top flow	Top Process	Top flow
NRR	Electricity generation	Inert rock	Electricity generation	Inert rock
Energy	Insulation resin production	Natural gas	Insulation resin production	Natural gas
Landfill space	MSW landfill	PVC Waste	MSW landfill	PVC Waste
Global warming	Insulation resin production	Carbon dioxide	Insulation resin production	Carbon dioxide
Ozone depletion	Insulation resin production	Refrigerant #5[a]	Insulation resin production	Refrigerant #5[a]
Smog	Jacketing resin production	VOC (unspecified)	Jacketing resin production	VOC (unspecified)
Acidification	Electricity generation	Sulfur dioxide	Electricity generation	Sulfur dioxide
Particulate matter	Jacketing resin production	Dust	Jacketing resin production	Dust
Eutrophication	Electricity generation	Chemical oxygen demand	Electricity generation	Chemical oxygen demand
Pot. occ. noncancer[c]	Natural gas production	Natural gas[b]	Natural gas production	Natural gas[b]
Pot. occ. cancer[c]	Jacketing compounding	Flame retardant #3[b]	Jacketing compounding	Flame retardant #3[b]
Pot. public noncancer	MSW landfill	Lead (water)	Electricity generation	Sulfur dioxide (air)
Pot. public cancer	Jacketing resin production	Nitrogen oxides (air)[b]	Jacketing resin production	Nitrogen oxides (air)[b]
Pot. aq. ecotox	MSW landfill	Lead	Electricity generation	Chlorine (dissolved)

NRR = non-renewable resource use; Pot. = potential; occ. = occupational; aq. ecotox = aquatic ecotoxicity; PVC = polyvinyl chloride; MSW = municipal solid waste; HCFC = hydrochlorofluorocarbon; VOC = volatile organic compound

[a] Proprietary

[b] Flows given default toxicity hazard values due to lack of toxicological data

[c] FEP production, which came from 2 primary datasets, was modeled with 2 industrial precursor chemicals functioning as inputs; production of PVC, the other major resin used in CMP cables, and which came from a secondary dataset, was modeled as if all of the materials came from ground (mining of inert or low-toxicity inputs), and did not explicitly include industrial precursor chemicals. In order to be more consistent across resins, the contributions from industrial precursor chemicals in the FEP supply chain were removed prior to calculation of the potential occupational toxicity results.

4.4 NM-B Results Summary

The NM-B results are based on cradle-to-gate data and therefore life-cycle conclusions cannot be made. The processes modeled are presented in Chapter 2 (Section 2.5.3). For the NM-B cradle-to-gate results, all categories had reduced environmental burdens for lead-free cables compared to the baseline, except potential occupational non-cancer toxicity. Since CMR and CMP full life-cycle analyses showed little impact from EOL (except landfill space use, potential public non-cancer toxicity, and potential aquatic ecotoxicity), those relevant impact categories may also not appreciably change if the entire life cycle were considered. However, impact categories with more impact from EOL processes are more likely to have differing outcomes than determined by the cradle-to-gate analysis. Therefore, landfill space use, potential public non-cancer toxicity, and potential aquatic ecotoxicity are given a lower quality rating for the NM-B partial life-cycle analysis. No uncertainty or sensitivity analyses were run for this comparison as cable extrusion, use, and end-of-life processes were excluded from the analysis.

Table 4-5

NM-B Results – Partial life cycle: Baseline and Lead-Free

Impact Category	Units per km Cable	Baseline Impact Indicator	Pb-free Impact Indicator	Percent Change	Quality Rating
NRR	kg	70.6	59.7	-15%	M
Energy	MJ	1530	1440	-6%	M
Landfill space	m^3	0.00251	0.00221	-12%	M-L
Global warming	kg CO_2-equiv.	52.2	48.3	-7%	M
Ozone depletion	kg CFC 11-equiv.	9.79E-07	6.61E-07	-33%	L
Smog	kg ethene-equiv.	0.119	0.119	0%	M
Acidification	kg SO_2-equiv.	0.479	0.449	-6%	M
Air particulates	kg	0.0862	0.0759	-12%	M
Eutrophication	kg phosphate-equiv.	0.00169	0.00135	-20%	M
Pot. occ. noncancer	kg noncancertox-equiv.	20.0	26.7	33%	M
Pot. occ. cancer	kg cancertox-equiv.	8.23	7.08	-14%	M-L
Pot. public noncancer	kg noncancertox-equiv.	189	171	-10%	M
Pot. public cancer	kg cancertox-equiv.	0.828	0.798	-4%	M-L
Pot. aq. ecotox	kg aqtox-equiv.	0.0894	0.0626	-30%	M

NRR = non-renewable resource use; Pot. = Potential; occ. = occupational; aq. ecotox = aquatic ecotoxicity; equiv. = equivalents.

In the NM-B analysis, which excludes the extrusion process and subsequent downstream processes, the production of the jacketing resin, PVC, more often dominated impacts (8 impact categories), followed by electricity generation from compounding (2 impact categories), then limestone production (1 category), insulation compounding (1 category) jacketing compounding (1 category) and phthalate production (1 category) (see Table 4-6). These results identify processes that could be the focus of environmental improvement opportunities. However, it must be noted that these results are in the context of the comparison of resin systems and their additives, so focusing on top contributors identified here does not provide the complete impacts from the entire cable (e.g., the copper conductor is excluded from the analysis).

Table 4-6

NM-B Summary of Top Contributors to LCIA Results – Partial life cycle: Baseline and Lead-free.

	Baseline		Pb-free	
Impact Category	**Top process**	**Top flow**	**Top Process**	**Top flow**
NRR	Jacketing resin production	Inert rock	Jacketing resin production	Natural gas
Energy	Jacketing resin production	Natural gas	Jacketing resin production	Natural gas
Landfill space	Limestone production	Treatment residue (mineral)	Limestone production	Treatment residue (mineral)
Global warming	Jacketing resin production	Carbon dioxide	Jacketing resin production	Carbon dioxide
Ozone depletion	Electricity generation	CFC-11	Electricity generation	CFC-11
Smog	Jacketing resin production	VOC (unspecified)	Jacketing resin production	VOC (unspecified)
Acidification	Jacketing resin production	Sulfur dioxide	Jacketing resin production	Sulfur dioxide
Air particulates	Jacketing resin production	Dust	Jacketing resin production	Dust
Eutrophication	Electricity generation	Chemical oxygen demand	Electricity generation	Chemical oxygen demand
Pot. occ. noncancer	Insulation compounding	FR #2 (non-halogen)[a]	Insulation compounding	FR #2 (non-halogen)[a]
Pot. occ. cancer	Jacketing compounding	Plasticizer #2[a,b]	Jacketing compounding	Phthalate plasticizer #5[a,b]
Pot. public noncancer	Jacketing resin production	Sulfur dioxide (air)	Jacketing resin production	Sulfur dioxide (air)
Pot. public cancer	Jacketing resin production	Nitrogen oxides (air)[b]	Jacketing resin production	VOC (unspecified) (air)[b]
Pot. aq. ecotox	Phthalate production	Copper (+1, +2)	Phthalate production	Copper (+1, +2)

NRR = non-renewable resource use; Pot. = potential; occ. = occupational; aq. ecotox = aquatic ecotoxicity; CFC = chlorofluorocarbon; VOC = volatile organic compound; FR = flame retardant.

[a] Proprietary

[b] Flows given default toxicity hazard values due to lack of toxicological data