Life-Cycle Analysis of Orbio® Technologies 5000-Sc

Evaluation of 5000-Sc vs Conventional Daily-Use Cleaning Chemicals in Three Cleaning Scenarios

August 28, 2011

Prepared for:

ORBIO® TECHNOLOGIES
A Tennant Company Group

Analysis By:

ecoform™

This analysis and report was prepared for Orbio Technologies by Ecoform, an environmental consulting firm committed to the design, evaluation, and adoption of clean products and materials through technical and policy research.

Results and conclusions of this report are based on data provided to Ecoform for 5000- Sc by Orbio and its suppliers. This analysis would not have been possible without the cooperation of individual Orbio suppliers and partners who voluntarily provided data and confidential business information in support of this effort. Ecoform staff would like to thank Orbio and its partners for their cooperation and assistance in this analysis. Please direct any questions or enquiries about this report to the following:

Ecoform, LLC
9417 States View Drive
Knoxville, TN 37922, USA
Jgeibig@ecoform.com

OVERVIEW OF LCA STUDY

Orbio Technologies Group (Orbio) is the sustainable cleaning technology arm of Tennant Company. Established in 2009 to execute Tennant Company's vision of becoming the global leader in chemical-free and other sustainable cleaning technologies, Orbio is dedicated to developing and marketing environmentally friendly technologies that will set the standard for sustainable cleaning around the world. With the rapidly growing emphasis on green building and human health, the market is increasingly demanding cleaning systems that reduce or eliminate our dependence on conventional cleaning chemicals.

Recent research by Orbio has led to the development of a breakthrough product called 5000-Sc with Orbio®-S, Split Stream Technology. The unit produces a multi-purpose cleaning solution on-site using tap water, electricity, and salt. Use of this product not only reduces environmental impacts across the life-cycle from the off-site production and transport of more complicated conventional chemical-based systems, but also eliminates much of the associated packaging waste.

To assist in market positioning of 5000-Sc, Orbio has contracted with Ecoform to fully evaluate the environmental and human health benefits associated with the use of the 5000-Sc. This study evaluates the relative life-cycle benefits associated with the use of 5000-Sc as compared to conventional daily-use cleaning chemicals in three different cleaning scenarios.

ORBIO 5000-Sc DESCRIPTION

Utilizing Orbio Split Stream Technology, the Orbio 5000-Sc electrically restructures tap water and salt to create and store an environmentally friendly cleaning solution which can be dispensed for use in a variety of cleaning tools such as spray bottles, carpet extractors and automatic floor scrubbers. It can effectively replace many daily-use conventional cleaning chemicals including those used in automatic scrubbers and pre-spray chemicals used with carpet extraction, plus spray and wipe cleaners such as those used with glass, stainless steel, and all-purpose cleaners. The multi-purpose cleaning solution produced is capable of cleaning many soils including fats, proteins and organic oils.

Figure 1: Orbio 5000-Sc

The 5000-Sc is shown at right. The machine generates 0.75 gallons per minute (GPM) of the ready-to-use cleaning solution, which is held in the unit's 120-gallon tank. The unit produces 0.75 gallons of cleaning solution from every gallon of incoming tap water and consumes approximately one pound of conventional water softener salt pellets for every 225 gallons of cleaning solution produced. Potential contaminants are removed from the incoming tap water stream by an input filter, while the waste stream containing a low concentration of unused chlorine is filtered using a separate activated carbon filter prior to being discharged directly to the drain.

LIFE-CYCLE ASSESSMENT SCOPE

LIFE-CYCLE APPROACH

Life-cycle impacts in a variety of human health and environmental categories resulting from the cleaning of several buildings types were evaluated in a comparative life-cycle assessment. Three separate cleaning scenarios were evaluated, each based on data from actual building maintenance operations associated with each building type. For each scenario, the impacts associated with the production, transportation and disposal of the cleaning solutions and their associated packaging were calculated to assess the environmental and human health performance of the Orbio 5000-Sc as compared to the use of conventional, daily-use cleaning chemicals. Because cleaning operations are independent of the manner in which the cleaning solutions are produced, other cleaning materials such as paper towels and cleaning clothes were scoped out of the comparative study the effect of which is considered to be minimal. The scope of the study is depicted in Figure 2.

The life-cycle analysis was performed using version 4.3 of the GaBi Life-Cycle Software. Secondary data from GaBi and Ecoinvent datasets, supplemented by proprietary Ecoform data sets, comprised the entirety of the life-cycle inventory data. Sample GaBi model diagrams are presented in Appendix A. Specific impact categories evaluated are described in Appendix B. Sensitivity analyses identified no significant gaps or uncertainties in the study.

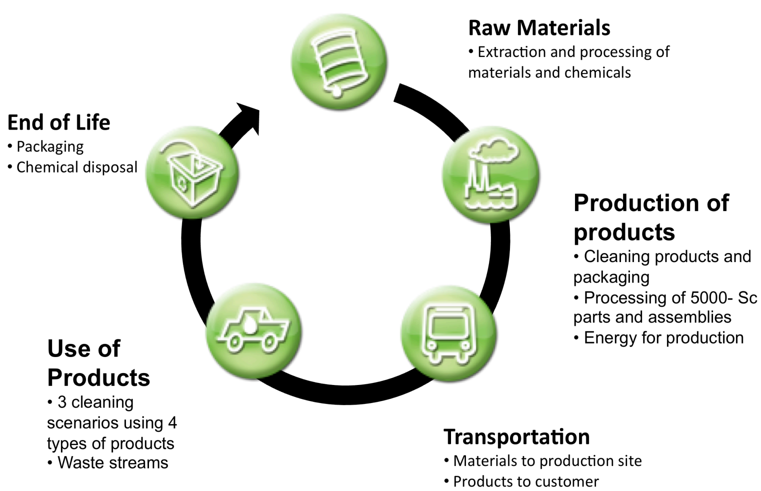


Figure 2: Scope of LCA Analysis

Overall, data quality is considered medium for this analysis, taking into account the lack of primary manufacturing data for either alternative and the average quality of a few of the secondary data sets. Overall, 87% of the total mass of the 5000-Sc was characterized in this assessment. Sensitivity analyses were conducted around these potential gaps, with minimal affect on the overall disparity in the impacts. As such, the overall confidence in the study is evaluated to be good.

LIFE-CYCLE SCENARIOS

Individual life-cycle scenarios were constructed to assess the life-cycle performance of the Orbio 5000-Sc relative to cleaning using conventional, daily-use chemicals. Scenarios characterize the critical parameters associated with building maintenance operations and are used to define a functional unit for the study. Specific parameters for each of the three scenarios evaluated in this study are presented in the Table 1.

Table 1. Life-Cycle Scenario – Building Types

Parameter	Life-Cycle Evaluation Scenarios		
	Convention Center	**Office Building**	**University**
Total Facility Size (sq ft)	3 million	1.25 million	3.2 million
Floor Area Cleaned (sq ft)	2 million	750,000	2.3 million
Carpet/Hard Floor Split (%)	33/67	50/50	40/60
Hard Flooring Type	Terrazo/ Sealed Concrete	Granite/Terrazo/Ceramic Tile	Terrazo/ VCT/Concrete
Cleaning Staff (# of workers)	50	33	110
Traffic/Use	1.5 million visitors/year	2,500 workers	11,000 students

The ***functional unit*** for the LCA for each scenario is defined as the production and transportation of cleaning solutions sufficient in volume to effectively clean the indoor building space defined in each individual scenario over the period of five years. For example, the functional unit for the convention center scenario would be the production and transportation of cleaning solutions sufficient to clean 2 million square feet of enclosed building space used for the purposes of hosting conventions for five years under the conditions described in Table 1. For the purposes of this study, cleaning operations were considered to include the need for floor, glass, all-purpose, and carpet pre-spray cleaners and their associated cleaning operations. The five-year period was selected to reflect a conservative estimate of the expected durability of the 5000-Sc.

Chemical usage data collected from actual cleaning operations on buildings identical to those described in each of the scenarios, along with key parameters such as water and energy consumption, and operating time were used to compile a bill of materials (BOM) for both the Orbio 5000-Sc and for the system of conventional cleaning chemicals. The BOMs used for this study, as well as tables containing the key parameters and data for this study are presented in Appendix C.

LIFE CYCLE INVENTORY ANALYSIS

The Life Cycle Inventory Analysis covers the life-cycle stages as shown in Figure 3.

Materials
Includes raw materials and extraction processes for all chemicals and materials identified in BOMs.

Production
Production of individual ORBIO 5000-Sc components as well as all chemical products and packaging was evaluated. No assembly processes were included.

Transport
Transport from suppliers to final use was modeled. Average transport profile for U.S. is assumed

Use
Includes use of ORBIO 5000-Sc and chemical products under 3 different cleaning scenarios. Energy and water use also included.

End of Life
ORBIO 5000-Sc is considered reclaimed under this scenario, consistent with current business model. All packaging considered to be disposed in landfill.

Figure 3. Inventory Scope by Life-cycle Stage

LIFE-CYCLE IMPACT ASSESSMENT

Impacts to a variety of key environmental and resource categories for the two compared systems are presented for each of the three cleaning scenarios. Results reflect impacts associated with the life-cycle product chain consistent with the scope of the inventory data. Detailed descriptions of individual impact categories are described in the Appendix B.

CONVENTION CENTER SCENARIO

Life-cycle impacts assessed for both the 5000-Sc and conventional, daily-use chemical cleaners are presented in Table 2. Results are based on the convention center scenario and functional unit, which specifies that enough cleaning agent be produced to clean a 3 million square foot space for a period of 5 years. Results are limited to cleaning tasks performed with glass, all-purpose, carpet, and floor cleaners. Results have been normalized, and the percent differences have been presented in Table 2, and visually depicted in Figure 4.

Table 2. Life Cycle Impacts – Convention Center

LCA Categories		Conventional Cleaners	5000-Sc	Benefit (%)
Acidification	(kg SO_2)	43.8	20.03	**54**
CO_2 Emissions	(kg CO_2)	14,400	3,900	**73**
Ecotoxicity	(ton TEQ eq)	35,410	20,300	**43**
Eutrophication	(kg PO4)	1.33	0.119	**91**
Ozone Depletion	(g CFCs)	0.0025	0.000083	**97**
Particulate	(kg PM2.5)	10.2	2.94	**72**
Smog	(kg NOx)	0.0074	0.00019	**98**

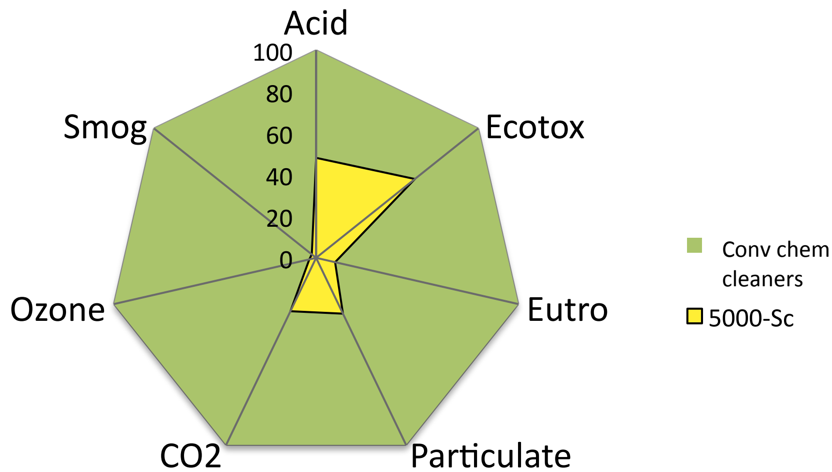


Figure 4. Chart of Relative Impacts – Convention Center

All together, this scenario required the use of all four chemical products totaling 3,725 gallons of conventional cleaning chemical product concentrates, at various dilution levels. Results indicate that production of cleaning solutions on-site with the Orbio 5000-Sc is clearly preferential to the distribution and use of conventional, daily-use cleaning chemicals in support of cleaning operations. Environmental and human health impacts ranged from 43-98 percent better than those for conventional chemicals with only the ecotoxicity score falling below the 50% level. This is directly related to the large volumes of all types of chemicals used in this cleaning scenario, as well as to a chemical product profile with an overall high average dilution rate of 2.4 ounces per gallon.

Calculation of a series of equivalent offsets (e.g. car emissions offset) for specific categories such as CO_2 emissions provide additional context for the relative results of the life-cycle comparison. Offsets are calculated by comparing the net improvement in a particular category (e.g. energy consumption) to established factors such as the energy content of coal, or emissions from an airplane. The accumulated benefits of the 5000-Sc expressed in common equivalent offsets are presented in Table 3.

Table 3. Equivalent Offsets per 5000-Sc – Convention Center

Category	Savings 1 Year	Savings 5 year	Equivalent Offsets (per unit)
Energy (MJ)	30,900	154,700	Barrels of Oil Offset (5 yr) – 25.0 barrels Months of Household Energy Offset (5 yr) – 45.5 mos Number of Households Offset (5 yr) – 3.8 households Gallons of Gasoline Offset (5 yr) – 1,180 gallons
CO_2 Emissions (kgCO2)	2,100	10,500	Months of Passenger Car Travel (5 yr) – 27.5 mos Number of Cars Offset (5 yr) – 2.3 cars

There are an estimated 535 convention center locations across North America and Europe that have over 400,000 square feet of exhibit space, which is typically maintained approximately 260 days per year. Were 40 percent of these convention centers to use an Orbio 5000-Sc machine to produce on-site the cleaning solution required to support building maintenance operations, collectively they would save enough energy to power more than 163 homes annually and offset the global warming emissions of nearly 98 cars annually.

OFFICE BUILING SCENARIO

Life-cycle impacts assessed for both the 5000-Sc and conventional, daily-use chemical cleaners are presented in Table 4. Results are based on the office building scenario and functional unit, which specifies that enough cleaning agent be produced to clean a 1.25 million square foot office building for a period of 5 years. Results are limited to cleaning tasks performed with glass, all-purpose, carpet and floor cleaners. Results have been normalized, and the percent differences have been presented in Table 4, and visually depicted in Figure 5.

Table 4. Life Cycle Impacts – Office Building

LCA Categories		Conventional Cleaners	5000-Sc	Benefit (%)
Acidification	(kg SO_2)	18.3	9.18	**50**
CO_2 Emissions	(kg CO_2)	6,200	1,870	**70**
Ecotoxicity	(ton TEQ eq)	15,200	8,530	**44**
Eutrophication	(kg PO4)	0.55	0.059	**89**
Ozone Depletion	(g CFCs)	0.0012	0.000041	**97**
Particulate	(kg PM2.5)	4.34	1.43	**67**
Smog	(kg NOx)	0.0033	0.00010	**97**

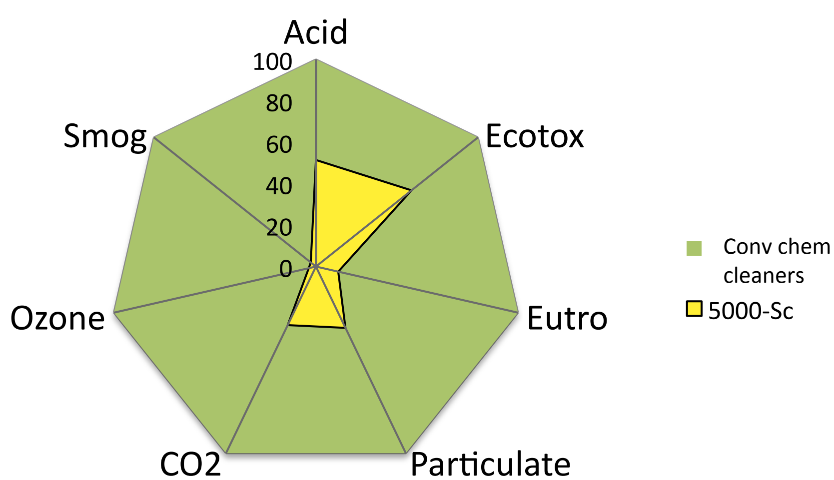


Figure 5. Chart of Relative Impacts – Office Building

All together, this scenario required the use of all four chemical products totaling 1,475 gallons of conventional cleaning product concentrates, at various dilution levels. Like the convention center scenario, the Orbio 5000-Sc is clearly preferential to the distribution and use of conventional cleaning chemicals in support of cleaning operations. This is again mostly due to the use of a more balanced chemical product profile comprised of products of various concentrations. Environmental and human health impacts ranged from 45-97 percent better than those for conventional, daily-use chemicals.

Calculation of a series of equivalent offsets (e.g. car emissions offset) for specific categories such as CO_2 emissions provide additional context for the relative results of the life-cycle comparison. Offsets are calculated by comparing the net improvement in a particular category (e.g. energy consumption) to established factors such as the energy content of coal, or emissions from an airplane. The accumulated benefits of the 5000-Sc expressed in common equivalent offsets are presented in Table 5.

Table 5. Equivalent Offsets per 5000-Sc – Office Building

Category	Savings 1 Year	Savings 5 year	Equivalent Offsets (per unit)
Energy (MJ)	13,000	65,200	Barrels of Oil Offset (5 yr) – 10.6 barrels Months of Household Energy Offset (5 yr) – 19.2 months Number of Households Offset (5 yr) – 1.6 households Gallons of Gasoline Offset (5 yr) – 497 gallons
CO_2 Emissions (kgCO2)	860	4,320	Months of Passenger Car Travel (5 yr) – 11.2 months Number of Cars Offset (5 yr) – 0.95 cars

There are an estimated 3,000 office building locations worldwide for Fortune 500 corporations. Assuming that 40 percent of these buildings were to generate on-site using the Orbio 5000-Sc the cleaning solutions required to support building maintenance operations, and that they resemble, on average, the office building modeled in this analysis (see Table 1), they would collectively save enough energy annually to power 383 homes annually and offset the global warming emissions from more than 220 cars annually.

UNIVERSITY SCENARIO

Life-cycle impacts assessed for both the 5000-Sc and conventional, daily-use chemical cleaners are presented in Table 6. Results are based on the university scenario and functional unit, which specifies that enough cleaning agent be produced to clean a 2.3 million square foot campus for a period of 5 years. Results are limited to cleaning tasks performed with all-purpose, carpet, and floor cleaners. Results have been normalized, and the percent differences have been presented in Table 6, and visually depicted in Figure 6.

Table 6. Life Cycle Impacts – University

LCA Categories		Conventional Cleaners	5000-Sc	Benefit (%)
Acidification	(kg SO_2)	25.1	18.0	**28**
CO_2 Emissions	(kg CO_2)	8,100	3,520	**57**
Ecotoxicity	(ton TEQ eq)	22,700	18,100	**20**
Eutrophication	(kg PO4)	0.57	0.11	**81**
Ozone Depletion	(g CFCs)	0.0013	0.000075	**94**
Particulate	(kg PM2.5)	5.71	2.66	**54**
Smog	(kg NOx)	0.0031	0.00017	**94**

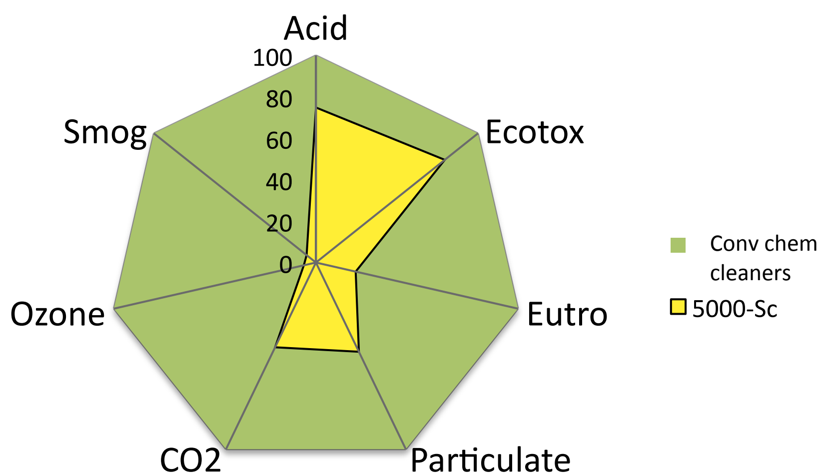


Figure 6. Chart of Relative Impacts – University

The cleaning operations performed in the maintenance of the university consumed a significant volume of chemicals, totaling 2,415 gallons of conventional, daily-use chemical product concentrates. Much like the other scenarios with a higher average chemical dilution rate, the Orbio 5000-Sc is clearly preferential under this scenario, displaying benefits in all evaluated environmental and human health categories ranging from 20-94 percent. This is again primarily due to the significant volumes of lower concentrated cleaners reported used in this scenario.

Calculation of a series of equivalent offsets (e.g. car emissions offset) for specific categories such as CO_2 emissions provide additional context for the relative results of the life-cycle comparison. Offsets are calculated by comparing the net improvement in a particular category (e.g. energy consumption) to established factors such as the energy content of coal, or emissions from an airplane. The accumulated benefits of the 5000-Sc expressed in common equivalent offsets are presented in Table 7.

Table 7. Equivalent Offsets per 5000-Sc – University

Category	Savings 1 Year	Savings 5 year	Equivalent Offsets (per unit)
Energy (MJ)	14,200	70,900	Barrels of Oil Offset (5 yr) – 11.5 barrels Months of Household Energy Offset (5 yr) – 20.9 months Number of Households Offset (5 yr) – 1.7 households Gallons of Gasoline Offset (5 yr) – 541 gallons
CO_2 Emissions (kgCO2)	900	4,480	Months of Passenger Car Travel (5 yr) – 11.6 months Number of Cars Offset (5 yr) – 1.0 cars

There are an estimated 11,160 University and higher education venues across both North America and Europe. Were 40 percent of these University campuses to use an Orbio 5000-Sc to produce the on-site cleaning solution required to support building maintenance operations for 260 days per year, collectively they would save enough energy annually to power more than 1,550 homes annually and offset the yearly global warming emissions of more than 870 passenger cars.

ANALYSIS OF LCA RESULTS

Results of the life-cycle impact assessment demonstrate clearly the significant environmental benefits associated with the use of the 5000-Sc. In each of the scenarios considered, the Orbio 5000-Sc was better in every single evaluation category making it clearly the better choice from an environmental and human health perspective. Understanding why the relative performance of the Orbio 5000-Sc was better requires a deeper analysis into the performance of the system and the drivers of that performance.

Volume of Cleaning Solution and Dilution Rate

The functional unit for this study was defined earlier in this report as the production of the volume of cleaning solution required to support the cleaning and maintenance operations for the various scenarios for a period of five years. To inform this analysis, chemical usage data from building and maintenance operations performed with conventional chemical cleaners for each scenario were used as a basis for the life-cycle modeling. The quantity of each type of chemical cleaner consumed over a five-year period for each scenario is presented in Table 8, along with the dilution rate for each product type.

Cleaning chemicals are routinely concentrated to save packaging costs and to limit impacts from transportation. Each of the cleaning chemicals in this analysis requires on-site dilution to achieve the recommended working concentration for proper cleaning performance, with dilution rates ranging from 1 ounce to 12 ounces per gallon of cleaning solution, depending on the chemical cleaner. Table 9 presents the total volume of cleaning chemical consumed for each scenario, along with an average dilution rate over the entire chemical use profile.

Table 8. Life-Cycle Scenario – Conventional, Daily-Use Cleaners (gals/ 5 yr)

Product	Life-Cycle Evaluation Scenarios		
	Convention Center	Office Building	University
Glass Cleaner (Diluted 12 oz to 1 gal)	525	250	-
Daily Floor Cleaner (Diluted 1 oz to 1 gal)	1,000	425	1,085
All-Purpose Cleaner (Diluted 4 oz to 1 gal)	1,775	500	960
Carpet Pre-Spray (Diluted 10 oz to 1 gal)	425	300	370

Table 9. Average Dilution Rate of Conventional, Daily-Use Cleaners - By Scenario

Scenarios	Conventional, Cleaner Conc. (gal)	Dilution Water (gal)	Diluted Chemical Cleaner Sol'n (gal)	Avg Dilution (oz/gal)
Convention	3,725	195,840	199,565	2.4
University	2,415	174,336	176,751	1.8
Office	1,475	76,907	78,382	2.5

To identify and better understand the correlation between the various factors presented and the results of this LCA, the relative benefits associated with the on-site production of chemicals using the Orbio 5000-Sc are presented in Table 10. These results reflect the relative differences in impact scores presented earlier in this LCA under each scenario.

Table 10. Summary of Relative Life-Cycle Benefits of Orbio 5000-Sc – By Scenario

Impact Category	Relative % Life-Cycle Benefits		
	Convention Center	Office Building	University
Acidification	54	50	28
CO2 Emissions	73	70	57
Ecotoxicity	43	44	20
Eutrophication	91	89	81
Ozone Depletion	97	97	94
Particulate	72	67	54
Smog	98	97	94

The calculation of an average dilution rate for each scenario in the Table 9 provides insight into the relative impacts of the alternatives. It is the average dilution rate, and not the total volume of concentrated chemical products that is the primary driver of the results. For example, were the driver to be total volume of concentrated chemical, we would expect the office scenario to display the lowest comparable benefits as it uses the lowest volume of concentrated chemicals. However, despite using 39% less concentrated chemical volume than that used under the university scenario, the benefits associated with the use of the Orbio 5000-Sc in the office scenario are much greater. Rather, It is the higher dilution rate associated with the office scenario that is more predicative of environmental benefit.

Dilution rate is a critical factor in the comparative analysis, in large part because it has the greatest influence on the primary drivers of impacts for the Orbio 5000-Sc, those being energy consumption and water use. Highly concentrated chemicals minimize the impacts associated with transportation and packaging for the chemical alternative, while resulting in a larger volume of cleaning solutions, a volume that the 5000-Sc must run longer and consume more resources to match in terms of production. As can be seen in the table, as the average dilution rate of the chemicals increases (i.e., concentration decreases) over the entire chemical profile, so does the relative effectiveness of the Orbio 5000-Sc. This suggests that there may be a pivotal value, or range of values, over which the 5000-Sc becomes preferential. However, other factors play a role in this determination such as overall mass and energy consumption, both of which are discussed below.

Mass

When comparing alternatives using life-cycle assessment, the results often correspond with the overall mass of materials required for each alternative, especially in comparisons with a large disparity in mass over the period of the analysis. In this case, evaluation of the overall mass involves totaling the mass of the Orbio 5000-Sc, salt and input and discharge filters compared to the overall mass of the chemical products and their associated packaging. These values are reflected in the Bill of Materials for each of the systems presented in Appendix C of this report. The total mass from the various BOMs is summarized in Table 11.

While dilution rate is the primary driver of relative life-cycle impacts, the mass of materials associated with each system plays a role in the overall life-cycle benefits, especially in situations of very low and very high chemical use. Each pound of material utilized incurs impacts throughout the life-cycle of that material including those associated with the extraction and processing of the material, its transportation and manufacture, through it use, and to its eventual disposition at end-of-life. These impacts can be significant depending on the material, and are often more influential on a comparative basis than impacts during other stages.

Table 11. Material Mass By Scenario

System	Life-Cycle Evaluation Scenarios (lbs)		
	Convention Center	Office Building	University
Orbio 5000-Sc			
Total Materials	1,960	987	1,770
Water	2,129,000	836,100	1,885,000
Total Materials/Resources	**2,131,000**	**837,100**	**1,887,000**
Conventional Cleaners			
Total Materials	6,740	2,669	4,370
Water (for dilution)	1,556,000	615,300	1,395,000
Total Materials/Resources	**1,573,000**	**617,900**	**1,399,000**

It can be seen in Table 11 that the Orbio 5000-Sc utilizes less material, excluding water, than conventional chemicals across all scenarios. Advantages in material consumption range from a low of 145 percent for the university scenario to greater than 240 percent for the convention center. The magnitude of the disparity is in part due to the fixed material mass of the 5000-Sc machine, and its decreasing importance as the volume of cleaner consumed increases. It also due to the extent to which chemical cleaning products are concentrated, maximizing the efficiency of packaging materials associated with the chemical products.

The effects of mass are more influential under both low use and extremely high use scenarios. Under low use scenarios like the office building (refer to Table 13), the impacts, though significant, were less substantial than those associated with the university scenario. And that is despite the office scenario having a significantly higher average dilution rate of 2.5 as compared to 1.8 for the university. The primary reason for this is that there is a relatively low volume of chemical use under the office scenario, making the impacts associated with mass more influential to the overall impact profiles. Likewise, in high use scenarios, the significance of differences in mass is minimized as chemical use increases.

Energy Consumption

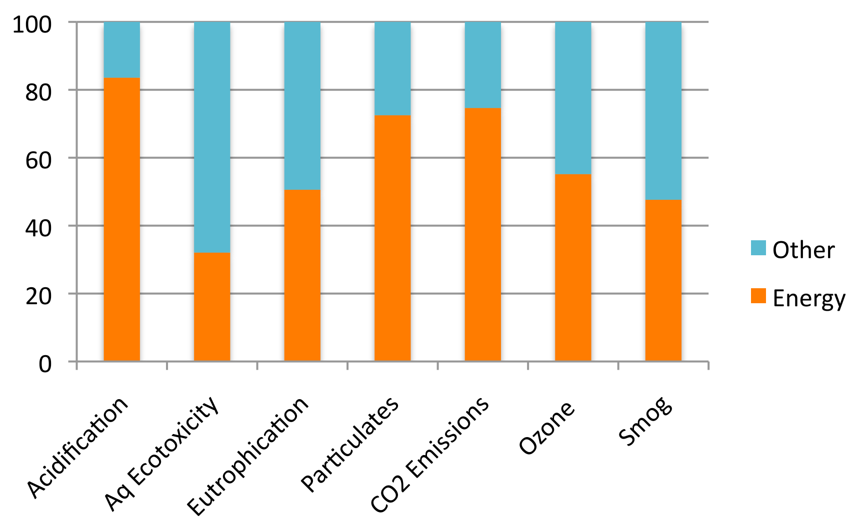
Production of Orbio 5000-Sc cleaning solution requires energy in the form of a small amount of electricity that is responsible for powering the machine during its production of solution. The 5000-Sc uses 745 watts of electricity while producing 0.75 gallon per minute of cleaning solution (see Table C3 in appendix C). The overall energy consumption is therefore directly related to the overall volume of cleaning solution required by each scenario. Table 12 presents the overall amount of ready-to-use cleaning solution required for each scenario along with the total run time and total energy consumed by the Orbio 5000-Sc.

Table 12. Key 5000-Sc Operating Parameters By Scenario – 5 years

System	Life-Cycle Evaluation Scenarios		
	Convention Center	Office Building	University
Cleaning Solution Req'd (gal)	199,600	78,380	176,800
Operating Time - 5000-Sc (hr)	4,435	1,742	3,928
Energy Consumption (kWh)	3,304	1,298	2,926

The energy use of the Orbio 5000-Sc is not large, roughly equivalent to half the amount of energy consumed by a microwave oven[1]. Yet, the overall effect of that energy consumption is a large contributor to the results. To demonstrate, the percent contributions from energy production of total impacts within each individual impact category for the convention center scenario are presented in Figure 7.

Figure 7. Percent of Life Cycle Impacts from Energy– Convention Center



The impacts associated with the production of the operating energy for the Orbio 5000-Sc account for as much as 83 percent of the acidification impacts of the entire product life-cycle, and for 72-74 percent of the particulate and CO_2 emissions. While these results represent the impacts from the convention center scenario, the importance of energy consumption is mirrored in other scenarios, as shown in Table 13.

[1] A microwave oven consumes approximately 1440 watts, while the 5000-Sc consumes only 745 watts. Source: http://michaelbluejay.com/electricity/howmuch.html

Table 13. Percent of Overall Impacts of 5000-Sc due to Energy Production

Impact Category	Impacts due to Energy Production (% of total)		
	Convention Center	Office Building	University
Acidification	83	72	82
CO2 Emissions	74	61	72
Ecotoxicity	32	30	32
Eutrophication	50	40	49
Ozone Depletion	55	44	55
Particulate	72	59	71
Smog	47	34	45

In each of the scenarios analyzed, energy is a significant driver in nearly every category. Results range from 30-72 percent for the office building scenario, the lowest chemical use scenario, to those for the convention center. The range within each impact category varied from a low of 2 percent for ecotoxicity, a category not influenced as greatly by energy, to as high as 13 percent for smog and CO_2 emissions. These results are relatively consistent, given the variation of chemical volume, type, and dilution rate across the scenarios, indicating that energy is a strong driver in the overall life-cycle impacts.

Given the overall mass of materials associated with each of the alternatives (see BOMs), and that the extraction and production of these materials also consume energy, the magnitude of the effect of the energy consumed during the use stage is somewhat surprising. It would be of interest to compare the energy consumed during the use phase to the energy consumed for each alterative during the upstream manufacturing processes, especially for chemical cleaners. However, because it was necessary to use existing life-cycle data sets for chemical manufacturing, and because energy was not broken out in sufficient detail (or in some cases, at all), comparison of these values is not possible. In fact, while energy is a fundamental portion of any life-cycle inventory (LCI) dataset, we can not be certain to what extent energy was in fact included in the datasets used in this analysis, as they are poorly documented. This is an uncertainty in this life-cycle analysis.

The impacts directly correlate to the amount of 5000-Sc operating time required to produce the cleaning solution for each scenario, and thus the results relative to conventional cleaners are indirectly linked to the factors such as the extent and frequency of cleaning operations, the type of cleaner, and the concentration of the conventional chemicals requiring dilution.

Energy Production Data Source

Given the importance of energy to the overall outcome of this study, the selection of the life-cycle dataset used in the analysis could become relevant. In this study, a life-cycle inventory was developed to represent the energy production profile of the local utility provider for Minneapolis-USA, Xcel Energy (Xcel). This profile was created by drawing from existing life-cycle inventories representing 100 percent production of various forms of electrical power (e.g. hydroelectric) and then weighting them to mirror the production profile reported by Xcel energy for the year 2009. The Xcel Energy profile is presented in Table D1 of Appendix D.

To determine the sensitivity of this analysis to the source of the energy, the convention center scenario was run with both the Xcel energy inventory, as well as with a dataset representing the US national power grid. The results for this analysis are presented in Table 14. It was found that while the source of the data did modify the overall results of the analysis somewhat as expected, the system did not display a high sensitivity to this factor.

Table 14. Effect of Energy LCI Source on Convention Center Impacts

LCA Categories		Xcel Energy	US Grid	Change (%)
Acidification	(kg SO_2)	55	53	**2**
CO_2 Emissions	(kg CO_2)	73	76	**-3**
Ecotoxicity	(ton TEQ eq)	43	41	**2**
Eutrophication	(kg PO4)	91	90	**1**
Ozone Depletion	(g CFCs)	97	98	**-1**
Particulate	(kg PM2.5)	72	73	**-1**
Smog	(kg NOx)	98	96	**2**

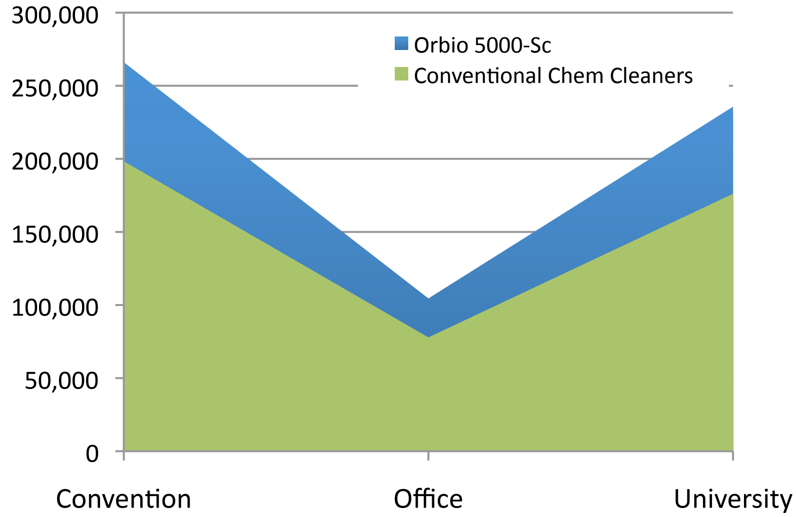
The results of similar analyses on the remaining scenarios are similar in magnitude and effect as to those for the convention scenario shown.

Water Consumption

Both of the cleaning solution production alternatives rely on significant amounts of water on-site to produce or prepare the cleaning solution at a ready-to-use concentration. Conventional, daily-use chemical cleaners are sold in concentrated form, requiring tap water to dilute the chemicals to a concentration suitable for use in addition to the water in the formulation of the concentrate. By contrast, the 5000-Sc produces a ready-to-use cleaning solution from tap water, electricity, and a small amount of salt. Figure 8 displays the water consumption by each system for the three evaluated scenarios.

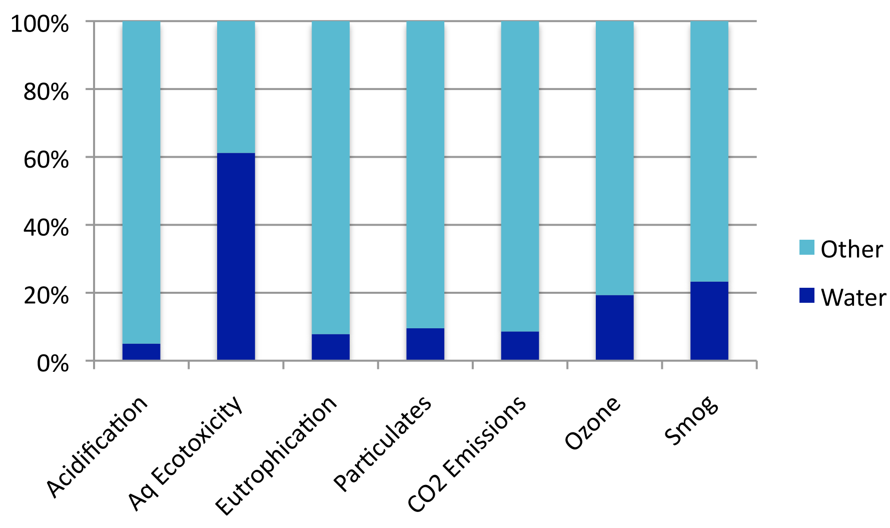
As can be seen from the figure, both systems use considerable amounts of water; the 5000-Sc uses approximately 34% percent more water regardless of the scenario over the analysis period of 5 years. This is due to the nature of the conventional cleaning chemical system, whose total volume of cleaning agent is the combination of not only the water required for dilution, but also from the chemicals themselves. For the 5000-Sc, the entire volume of the cleaning solution is derived directly from tap water. In addition, the 5000-Sc makes efficient use of 75 percent of the tap water input into the system through its conversion to cleaning solution, leaving the remaining 25 percent to be disposed to drain.

Figure 8. On-Site 5-Year Water Consumption By Scenario



The disparity in water use is directly reflected in the results of this analysis. As shown in Figure 9, water consumption is a significant contributor to the aquatic ecotoxicity impact category contributing more than 60 percent of the impacts for the entire product system, and to a lesser extent to both the smog (23%) and ozone (19%) impact categories. These results explain the lower relative benefits of the technology in the ecotoxicity impact category as compared to those of other impact categories.

Figure 9. Percent of Life Cycle Impacts due to Tap Water– Convention Center



While the additional water usage is a negative in terms of resource consumption, the displacement of chemicals results in other advantages in terms of human heath and environmental impacts, and in other life-cycle phases such as shipping.

ADDITIONAL ENVIRONMENTAL INFORMATION

Toxic Hazards

Conventional chemical cleaners are comprised of a variety of chemical compounds, some of which may pose a potential threat to human health or the environment. Cleaning chemicals are often applied during the cleaning process in a variety of methods, many of which result in inhalation exposures to chemicals of unknown toxicity, or which may leave a film of chemical residue leading to potential dermal exposures to children or other vulnerable populations. In addition, many of the chemicals applied to floor or carpet cleaning are subsequently disposed directly into the local water works where they may pose a potential hazard to aquatic ecosystems.

The cleaning solution produced by the 5000-Sc is a low concentration of sodium hydroxide, produced through the process of electrolysis. The solution has been 3rd party tested to US EPA guidelines and proven to be nonirritating to both eyes and skin (Eurofils Study Numbers 31592 and 31593, respectively). The cleaning solution is also free of VOCs such as fragrances, asthmagens or other additives that potentially contribute to reduced indoor air quality. The 5000-Sc solution is also registered by the NSF International (NSF.org) as appropriate for use in food and beverage handling environments. In addition, production of the chemicals through this on-site process prevents impacts associated with the upstream extraction of raw materials, and production and handling of the chemicals, greatly reducing the risk of human or environmental exposure to chemicals or their by-products elsewhere in the manufacturing chain.

LIMITATIONS AND UNCERTAINTIES

With any LCA, there are a number of limitations and uncertainties that should be considered as appropriate context for the study. One such limitation was the manner in which conventional chemical cleaners were characterized. Formulations for each of the chemical cleaning products were developed based on established knowledge and used for characterizing the conventional chemical cleaner alternative. While these formulations were representative of such cleaners, variations in chemical formulation are common within the market place. As such, these results reflect one such representation. The effect of the selection of a different chemical formulation as representative for any of the chemical cleaners on the final outcome of the study is unknown.

There are several limitations and uncertainties associated with this report. Some of the formulations contained chemicals for which no life-cycle inventory data exist. In such cases, chemicals were either modeled by using combinations of data sets that together mimic the synthesis process for the missing chemical, by using available data for a chemically or structurally similar chemical, or as a last resort by determining an average inventory profile from other chemicals that serve an identical function (e.g. non-ionic surfactants). Given that any such approach involves an approximation in lieu of actual inventory data for the specific chemical, the affect of this uncertainty on the overall results of this analysis can not be specifically determined, but is unlikely to be significant given the relative impacts of any of the chemicals involved.

A portion of the Orbio 5000-Sc roughly equivalent to 7 percent of the overall composition of the machine could not be modeled, mostly due to an inability to accurately characterize the material composition of a complex transformer assembly. The data gaps in the model prevented the full evaluation of the 5000-Sc. However, an alternate analysis was performed to assess this gap by modifying the overall model to account for the additional material, assuming the material had a similar impact profile to the 93 percent characterized. Reported results reflect the adjusted values.

Finally, secondary data sources were used in this analysis in lieu of data that could not be collected directly. Secondary data sources can vary significantly in quality and completeness and it is not often easy to determine the quality of a data set. Every effort was made by the authors to vet any secondary data sources for quality and completeness, but the authors cannot ultimately guarantee the accuracy of this data. For data sets that had a profound affect on the overall results of this study, such as those for energy and water production, alternative analyses were performed using substitute data sets to confirm the integrity of the results.

REFERENCES

Baird C, Cann M. 2005. *Environmental Chemistry*. 3rd ed. W.H. Freemand and Company: New York.

California Air Resources Board (CARB). California Environmental Protection Agency. http://www.arb.ca.gov/homepage.htm

Milhelcic J. 1999. *Fundamentals of Environmental Engineering*. John Wiley and Sons, Inc: New York.

Office of Air and Radiation. U.S. Environmental Protection Agency. http://www.epa.gov/air/.

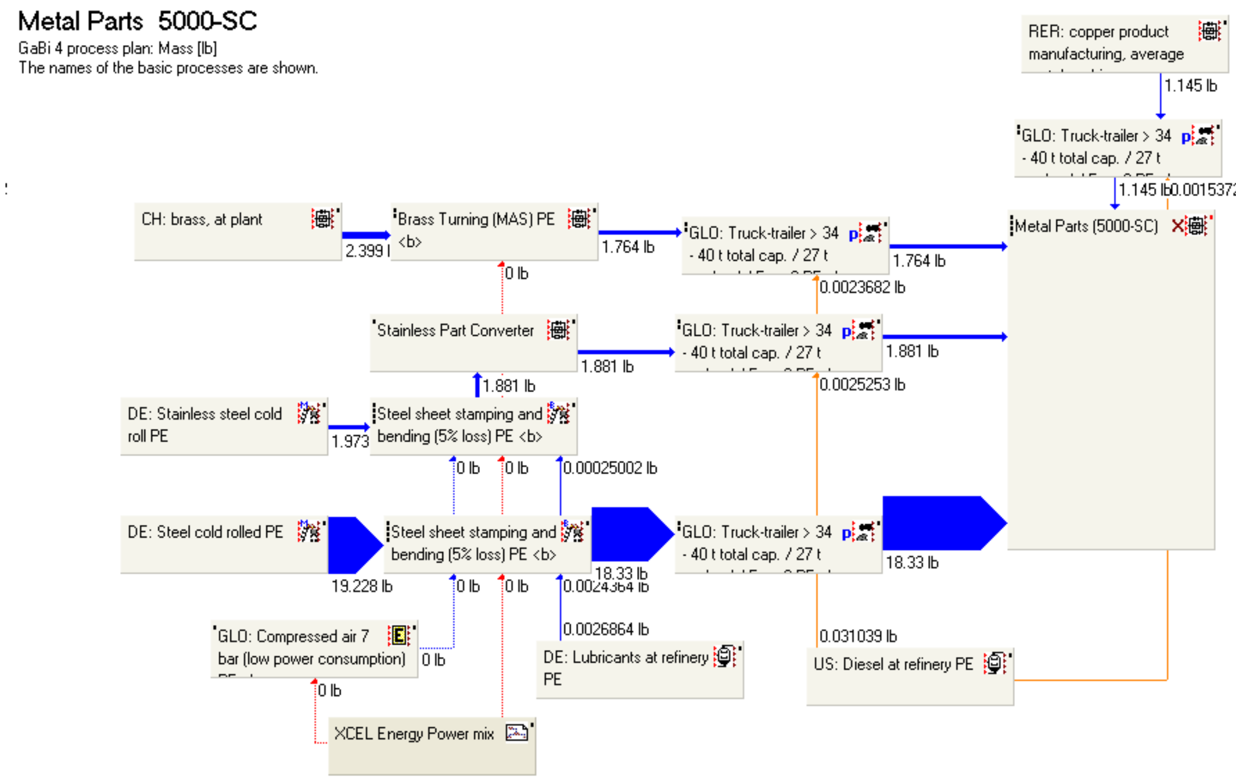
XCEL Energy. 2009 Power generation breakdown by source- MN. XCEL Energy website accessed April 4, 2011. http://www.xcelenergy.com/Minnesota/Company/ABOUT_ENERGY_AND_RATES/Power%20Generation/Pages/Power_Generation.aspx

Orbio Technologies*.* *5000-Sc Technical Data Sheet*. Orbio Technologies website accessed on-line April 4, 2011. http://www.orbiotechnologies.com/wp-content/uploads/5000-ScTechPB-Rev-3.30.111.pdf

APPENDIX A – GABI MODEL DIAGRAMS

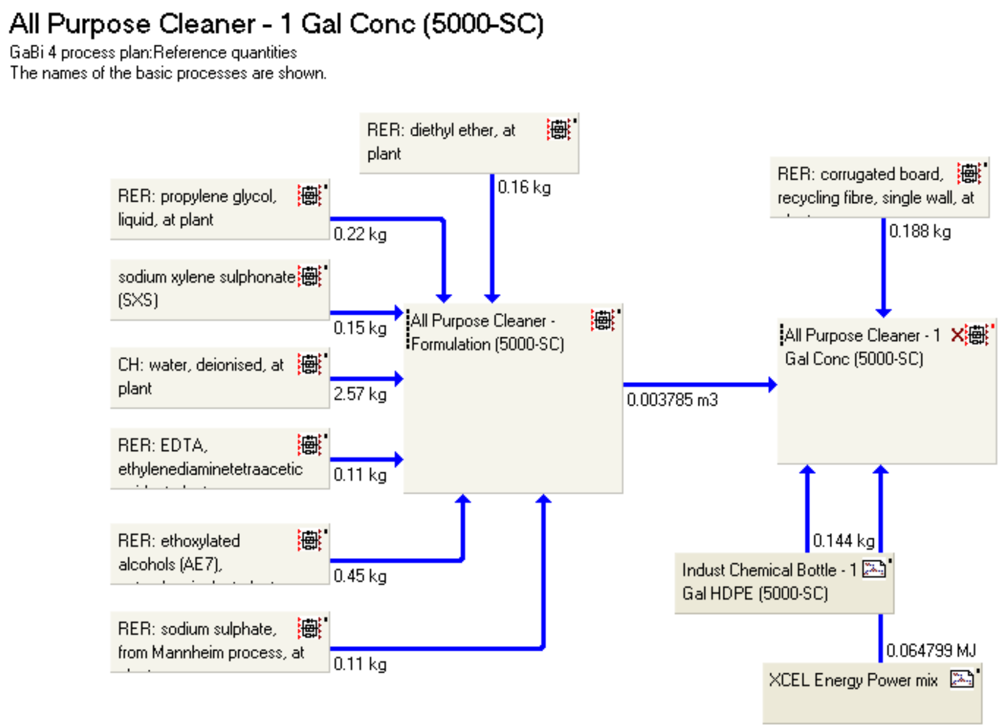
Life cycle calculations were performed using the GaBi 4.3.Life-Cycle Software. GaBi model diagrams for both the Orbio 5000-Sc and chemical-based cleaning systems are presented as samples of the life-cycle modeling performed for this analysis.

Sample 5000-Sc Model Diagram



ecoform

Sample Chemical-based Cleaning Model Diagrams



APPENDIX B – IMPACT CATEGORY

Acidification, (AP): Acidification originates from the emissions of sulfur dioxide and oxides of nitrogen. These oxides react with water vapor in the atmosphere to form acids, which subsequently fall to earth in the form of precipitation, and present a hazard to fish and forests by lowering the pH of water and soil. The most significant man-made sources of acidification are combustion processes in electricity and heating production, and transport. Acidification potentials are typically presented in g SO_2 equivalents

CO_2 Emissions, (CO2): Global warming of the atmosphere occurs when carbon dioxide, methane, or other gases contributing to global warming absorb infrared radiation from sunlight, trapping it within the atmosphere. Some of the biggest human contributors to global warming are the combustion of fossil fuels like oil, coal and natural gas. This impact category includes the contributions of all such gases, even though it is expressed as CO_2 Emissions. Global warming potential are typically presented in g CO_2 equivalents.

Ecotoxicity, (AEP): Living organisms that inhabit a given ecosystem may be harmed through exposure to chemicals and other toxins released into the aquatic ecosystem. Such toxins may have a particularly harmful affect on ecosystem health including biochemistry, physiology, and the behavior and interactions of living organisms inhabiting the ecosystem. Ecotoxicity potentials are typically presented in g TEQ equivalents.

Eutrophication, (EP): Nutrients from discharged wastewater and fertilized farmland act to accelerate the growth of algae and other vegetation in the water. Oxygen deficiency then results from the degradation of organic material in the water, posing a threat to fish and other life in the aquatic ecosystem. Oxides of nitrogen from combustion processes are of significance. Eutrophication potentials are typically presented in g NO_3 equivalents.

Ozone Depletion Potential, (ODP): Stratospheric ozone is broken down as a consequence of man-made emissions of halocarbons (CFC's, HCFC's, haloes, chlorine, bromine etc.). The ozone content of the stratosphere is therefore decreasing, resulting in a thinning of ozone layer, often referred to as the ozone hole. The consequences are increased frequency of skin cancer in humans and damage to plants. Ozone depletion potentials are typically presented in g CFC equivalents.

Particulates, (P): Particulates are released as a consequence of both mobile and point source operations, usually involving combustion of materials. When inhaled, particulates directly affect humans often resulting in respiratory irritation and even prolonged chronic respiratory illness. Smaller diameter particulates, such as those smaller than 2.5 microns (PM 2.5) pose the greatest threat. Particulates are typically presented in g PM 2.5 released.

Photochemical Smog, (POCP): Photochemical smog (also referred to as ground level ozone) is formed by the reaction of volatile organic compounds and nitrogen oxides in the presence of heat and sunlight. Smog forms readily in the atmosphere, usually during hot summer weather, and contributes to respiratory illness in humans such as chronic bronchitis and emphysema. Photochemical smog formation potentials are typically presented in g ethane equivalents.

APPENDIX C – KEY PARAMETERS AND BOMS

Life-cycle analysis was conducted on each of the alternatives for producing cleaning solutions and transporting them to the cleaning venue. The model for each scenario was based on a BOM calculated from data collected from actual cleaning operations for identical buildings, key operating parameters, or both. A BOM is a listing of the total materials and resources that make up that alternative. This appendix presents the key usage and operating data, as well as the BOMs for the Orbio 5000-Sc as well as for the system of conventional cleaning chemicals.

Orbio 5000-Sc

The Bill of Materials (BOM) in Table C1 characterizes all of the materials and resources, excluding energy, required for the 5000-Sc to produce sufficient quantities of cleaning solution to perform the required maintenance and cleaning operations for each building type over the five-year period of this analysis. Energy use for each scenario is presented in the Impact Analysis portion of this document.

Table C1. Bill of Material of Orbio 5000-Sc - By Scenario (lbs)

Chemical/Material	Life-Cycle Evaluation Scenarios		
	Convention Center	Office Building	University
Machine	363	363	363
Salt	1,580	622	1,400
Filter Media	8.5	2.2	7.3
Total Materials– Non-H20	**1,960**	**987**	**1,770**
Water Input	2,281,000	896,700	2,020,000
Total Materials	**2,283,000**	**896,800**	**2,022,000**

The Orbio 5000-Sc technology itself is comprised of a number of materials, each listed in Table C2. The total weight of 5000-Sc is measured at 363 pounds. This total includes all of the components in the machine itself, but does not include the water, salt, or any other process stream.

Table C2. Materials Breakdown – Orbio 5000-Sc

Metals	Lbs	%
Carbon Steel	38.9	11.6
Brass	3.17	0.9
Stainless Steel	1.88	0.6
Copper	19.9	5.9
Aluminum	0.02	0.006

Plastics	Lbs	%
Polyethylene – HD	182.3	54.2
Polypropylene	43.8	13.0
ABS	17.3	5.1
FIberglass	14.5	4.3
Polycarbonate	3.0	0.9
Polystyrene	1.85	0.6
Polyvinyl Chloride	1.14	0.3
Nylon	0.068	0.02

Other Materials	Lbs	%
PW Board	1.50	0.4
Activated Carbon	1.10	0.3
Paint	0.06	0.02
Other Plastics	0.103	0.03
Other materials	5.7	1.7

Additional materials such as salt, tap water, and some filter media, in addition to electrical power are required for the 5000-Sc to produce the 5000-Sc cleaning solution. The quantities of these are dependent on the amount of cleaning solution required to clean each scenario. The cleaning solution produced by the 5000-Sc can be used without modification and is thus considered a ready-to-use product, and can be used as a direct replacement for the four chemical cleaners cited in this analysis.

Table C3. Orbio 5000-Sc Operating Parameters

Parameter	Scenario Value
Cleaning Solution Prod Rate	0.75 gal/min
Water Efficiency Rate (cleaning solution prod/total water)	75 %
Energy Consumption (while generating solution)	745 Watts
Salt Usage	40 lbs Salt/ 9,000 gal cleaning solution
Filter Life	20,000 gals cleaning solution

Conventional Cleaning Chemicals

A BOM for a conventional, daily-use chemical cleaning system is presented in Table C4 for each of the three scenarios defined in this report. Values reported in the table represent the total materials and resources required to provide conventional chemical cleaning solutions in support of typical building maintenance and cleaning operations for each building type over a period of five years.

Table C4. Bill of Material of Conventional Cleaning Chemicals - By Scenario (lbs)

Chemical/Material	Life-Cycle Evaluation Scenarios		
	Convention Center	Office Building	University
Chemicals	6,195	2,453	4,016
Packaging	236	93.5	153
Corrugate	309	122	200
Total Materials– Non-H20	**6,740**	**2,669**	**4,370**
Water (dilution)	1,556,000	615,300	1,395,000
Total Materials	**1,573,000**	**617,900**	**1,399,000**

The BOMs for each scenario were based on actual chemical usage data from cleaning operations on buildings identical to those defining each scenario. Chemical usage by product is presented in Table 12 of this report for each scenario, along with the dilution rate for each product type. All values reflect gallon of concentrate consumed per year of cleaning.

The chemical content for each of the four cleaning products was broken out by chemical ingredient and totaled by scenario in table C5. Chemical ingredients for each chemical product are identified in Tables C6-C9. When combined with the chemical usage number in Table 11, these chemical formulations formed the basis for the numbers reported.

Table C5. Breakdown of Chemical Content- By Scenario

Chemical/Material	Life-Cycle Evaluation Scenarios		
	Convention Center	Office Building	University
CHEMICALS (gal conc/yr)			
Propylene glycol monobutyl ether	67	25	19.2
Isopropyl alcohol	8.4	4	-
Alcohol ethoxy sulfate	6.3	3	-
Propylene glycol monomethyl ether	5.25	2.5	-
Ammonium hydroxide	4.2	2	-
Ethyl alcohol	1.05	0.5	-
Tripropylene glycol methyl ether	17	12	14.8
Naphthalene sodium sulfonate	8.5	6	7.4
Diethylene glycol monobutyl ether	12.75	9	11.1
Linear primary alcohol ethoxylate	8.5	6	7.4
Tetrasodium ethylenediamine	2.55	1.8	2.22
Alcohol Ethoxylate	61.6	20.08	43.66
SXS	19.2	6.125	13.1
Veresene 100, EDTA	12.05	3.64	7.39
Sodium metasilicate $5H_20$	10.65	3	5.76
Water (in concentrate)	499.9	190.4	351

Tables C6-C10 present the formulations for each of the conventional daily-use chemical cleaners assessed in this study. These formulations were developed using MSDS data from multiple leading brand chemical cleaners.

Table C6. Chemical Formulation- Glass Cleaner

Glass Cleaner

Diluted 12oz cleaner to 1 gallon of water	CAS #	Wt %
Propylene glycol monobutyl ether	5131-66-8	30
Isopropyl alcohol	67-63-0	8
Alcohol ethoxy sulfate	999999-83- 5	6
Propylene glycol monomethyl ether	107-98-2	5
Ammonium hydroxide	1336-21-6	4
Ethyl alcohol	64-17-5	1
Water	7732-18-5	46

Table C7. Chemical Formulation- All-Purpose Cleaner

All Purpose Cleaner

Diluted 4 oz cleaner to 1 gallon of water	CAS #	Wt %
Water	7732-18-5	68
Alcohol Ethoxylate	68439-46-3	12
Propylene glycol monobutyl ether	5131-66-8	10
SXS	1300-72-7	4
Veresene 100, EDTA	64-02-8	3
Sodium metasilicate $5H_20$	6834-92-0	3

Table C8. Chemical Formulation- Daily Floor Cleaner

Daily Floor Cleaner

Diluted 1oz cleaner to 1 gallon of water	CAS #	Wt%
Water	7732-18-5	87.25
Alcohol Ethoxylate	68439-46-3	9.5
SXS	1300-72-7	2.5
Veresene 100, EDTA	64-02-8	0.75

Table C9. Chemical Formulation- Carpet Pre-Spray Cleaner

Carpet Pre-Spray

Diluted 10oz cleaner to 1 gallon of water	CAS #	Wt %
Tripropylene glycol methyl ether	25498-49-1	20
Naphthalene sodium sulfonate	26264-58-4	10
Diethylene glycol monobutyl ether	112-34-5	15
Linear primary alcohol ethoxylate	34398-01-1	10
Tetrasodium ethylenediamine	64-02-8	3
Water	7732-18-5	42

APPENDIX D – XCEL ENERGY PROFILE

The following table lists the percent power produced by XCEL Energy in 2009, by source of the power. XCEL is the utility provider for the Minneapolis, MN area, where Orbio Technologies is currently located.

Table D1. XCEL Energy Production Fuel Profile for 2009

Source	% of Profile
Hard coal, power plant	49.4%
Natural gas, power plant	31.6%
Nuclear, power plant	12.7%
Hydropower	4.4%
Oil, power plant	0.9%
Refuse Derived Fuel	0.8%
Wind	0.1%