Clean Product Evaluation of ec-H2O^{TM} Technology

Evaluation of ec-H2O^{TM} vs Traditional Cleaners in Floor Cleaning Applications

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Prepared for:

TENNANT

Analysis By:

ecoform

ecH2O
ELECTRICALLY CONVERTED WATER

This analysis and report was prepared for Tennant Company 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 ec-H2O^{TM} technology by Tennant and its suppliers. This analysis would not have been possible without the cooperation of individual Tennant suppliers who voluntarily provided data and confidential business information in support of this effort. Ecoform staff would like to thank the companies and their representatives for their cooperation and assistance in this analysis. Please direct any questions or enquiries about this report to the following:

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OVERVIEW OF LCA STUDY

Tennant Company is a leading developer of innovative cleaning systems for flooring applications. A manufacturer of premium value-added machines, Tennant equipment caters to high-end applications and clients who value quality, feature-rich equipment. With the rapidly growing emphasis on green building and human health, the market is increasingly demanding green cleaning systems that reduce or eliminate exposures to chemicals and indoor emissions.

Recent research by Tennant has led to the development of a breakthrough technology called "ec-H2O™" capable of completely eliminating chemical exposures and indoor emissions resulting from cleaning, while reducing impacts across the life-cycle. To inform the market positioning of ec-H2O, Tennant has asked Ecoform to fully evaluate the environmental and human health benefits associated with the use of ec-H2O in lieu of traditional chemical-based floor cleaning systems used in specific applications.

This study evaluates the relative life-cycle benefits associated with the use of ec-H2O as compared to a typical chemical-based floor cleaning system.

PRODUCT DESCRIPTIONS

ec-H2O TECHNOLOGY

ec-H2O technology is comprised of several components that are designed into the chassis of many floor scrubbers produced by Tennant Company. The floor scrubbers may be branded Tennant or Nobles. ec-H2O technology uses oxygen and a small electrical current to turn tap water into an effective cleaning solution capable of removing dirt and soil from hard floor surfaces.

Water is infused with oxygen to create highly oxygenated water. A small charge is applied to the water via an electrolysis cell, creating a blended stream of positively and negatively charged oxygenated water capable of attacking soil. Mechanical agitation provided by the scrubber then easily removes the soil and water from the surface. After 45 seconds, the charged water has recombined leaving only water and soil in the scrubber tank.

The ec-H2O technology required to outfit a T3 scrubber is evaluated in this analysis (see above). An ec-H2O equipped T3 has a liquid flow rate of 0.13 gallons per minute, a scrub deck 20 inches wide, and an average operating time of 2.5 hours per charge. Although ec-H2O requires energy to activate the water, the differences in energy consumption between the outfitted T3 scrubber and a standard T3 are not significant.

BILL OF MATERIALS - ec-H2O

ec-H2O technology is comprised of the materials listed below. The total weight of ec-H2O technology components is 6.49 kg. This total includes an adjustment of - 0.384 kg to the overall mass to account for specific materials on the standard T3 scrubber that are no longer needed in a ec-H2O equipped T3. The Bill of Materials (BOM) characterizes the portions of the scrubber associated with ec-H2O technology only.

Bill of Materials – ec-H2O

Metals	Kg	%
Carbon Steel	2.068	31.9
Aluminum	0.556	8.6
Copper	0.526	8.1
Brass	0.397	6.1
Stainless Steel	0.304	4.7
Platinum	0.025	0.4
Other Metals	0.223	3.4

Plastics	Kg	%
ABS	0.681	10.5
Nylon	0.465	7.2
PolyUrethane	0.150	2.3
Polycarbonate	0.100	1.5
Polypropylene	0.092	1.4
Polyethylene – LD	0.092	1.4
Polyvinyl Chloride	0.073	1.1
Polyethylene – HD	0.067	1.0

Other Materials	Kg	%
Ceramic	0.300	4.6
PW Board	0.184	2.8
Paper	0.005	0.1
Other Materials	0.188	2.9

CHEMICAL-BASED FLOOR CLEANING

Traditional resilient floor cleaning is performed using chemical-based cleaning agents which are applied using a floor scrubbing machine that mechanically agitates the surface with brushes. A variety of cleaning chemicals suitable for institutional and commercial cleaning are available on the market, each typically sold as a concentrate in one gallon bottles. Product is typically purchased in cartons of 2 or 4 bottles. This assessment evaluated a "typical" floor cleaner formulation developed from multiple floor cleaners and does not represent a particular floor cleaner on the market. Other product parameters include:

- Cleaner assumed to be concentrated with a dilution rate of 1 oz per gallon
- Cleaning product in 1-gallon bottle with HDPE weight of 0.144 kg
- Product packaged 4 bottles per carton with corrugate weight of 0.753 kg

A Tennant T3 scrubber was assumed to control variation in the analysis resulting from equipment type. The typical Tennant T3 has a liquid flow rate of 0.4 gallons per minute.

BILL OF MATERIALS – CHEMICAL-BASED FLOOR CLEANING

A traditional chemical-based floor cleaning system is comprised of the materials listed below. Two complete scenarios were constructed to adequately evaluate the ec-H2O technology across a range of cleaning conditions. Scenarios evaluated include an education scenario and a combined retail/healthcare scenario, both described in more detail later in this report. The total weight of material components for the typical chemical-based cleaning system is 3,791 Kg for the health/retail scenario and 2,077 kg for education. These totals reflect the quantity of chemicals and packaging required for the 5-year period defined by the functional unit under each scenario.

Health Care/Retail Scenario

Materials	Kg	%
Water	3,040	80
Alcohol Ethoxylate	331	8.7
Sodium Xylene Sulfonate	87	2.3
EDTA	26	0.7
Polyethylene – HD	133	3.5
Corrugate	174	4.6

Education Scenario

Materials	Kg	%
Water	1,666	80
Alcohol Ethoxylate	181	8.7
Sodium Xylene Sulfonate	48	2.3
EDTA	14	0.7
Polyethylene – HD	73	3.5
Corrugate	95	4.6

LIFE-CYCLE SCENARIOS

Individual life-cycle scenarios were constructed to describe floor cleaning in an educational setting as well as for cleaning in the retail/health care environment. Scenarios characterize the critical parameters associated with floor cleaning and are used to define a functional unit for the study. Specific parameters defined by the scenarios are presented below.

Key Scenario Parameters – Floor Cleaning

Parameter	Scenario Value
Chemical dilution rate – oz/gal	1
Liquid flow rate – gal/min	0.4 Chemical-based 0.13 ec-H2O
Floor scrub rate – sq ft/hr	9,274[a]
Floor Area Cleaned – sq ft/day	25,000
Frequency of Cleaning - Cycles/yr	365 Retail/Health Care (daily) 200 Education (5 days/wk, 40 wks/year)

[a] **The Official ISSA 447 Cleaning Times Calculator**

The **functional unit** for the LCA for each scenario is defined as the cleaning of 25,000 square feet of resilient floor over a period of five years at a frequency consistent with the parameters described in the table above. The five year evaluation period represents an average useful life for an ec-H2O equipped scrubber in the considered market applications. The functional unit establishes a fair basis of comparison between ec-H2O and the chemical-based cleaning operations based on the performance of a like amount of cleaning performed.

ENVIRONMENTAL ASSESSMENT

LIFE –CYCLE ASSESSMENT

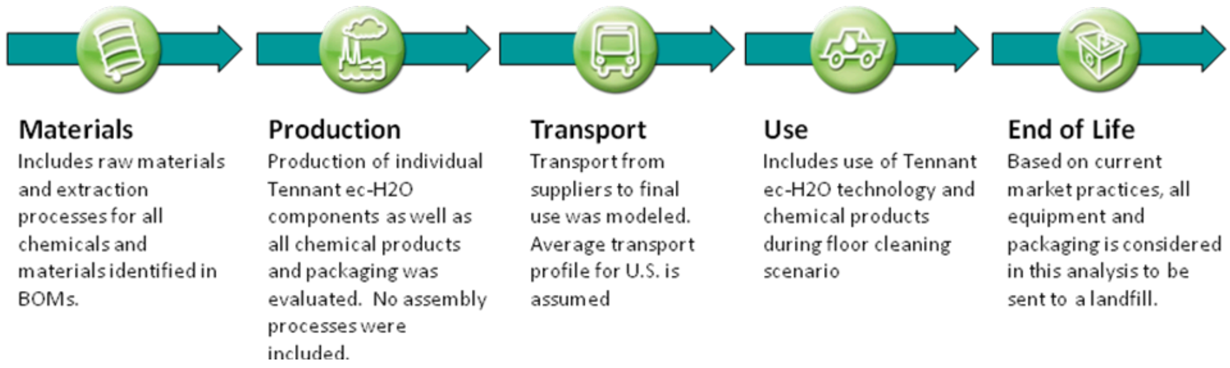
Life-cycle impacts in a variety of human health and environmental categories associated with the cleaning of resilient flooring were evaluated in a comparative life-cycle assessment under two distinct use stage scenarios: education and retail/health care. Specific impact categories evaluated are described in Appendix A.

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. Portions of the T3 scrubber not associated with the ec-H2O technology appearing in both alternatives were scoped out of the comparative LCA, the effect of which is considered to be minimal. Sensitivity analyses identified no significant gaps or uncertainties in the study.

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, 96% of the total mass of the ec-H2O 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 INVENTORY ANALYSIS

The Life Cycle Inventory Analysis covers the life-cycle stages as shown below.



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

Production Production of individual Tennant ec-H2O 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 Tennant ec-H2O technology and chemical products during floor cleaning scenario

End of Life Based on current market practices, all equipment and packaging is considered in this analysis to be sent to a landfill.

LIFE CYCLE IMPACT ASSESSMENT

Impacts to a variety of key environmental and resource categories for the two floor cleaning systems are presented for both the education and retail/health care scenarios. Results reflect impacts associated with the life-cycle product chain consistent with the scope of the inventory data. Descriptions of individual impact categories are described in the Appendix.

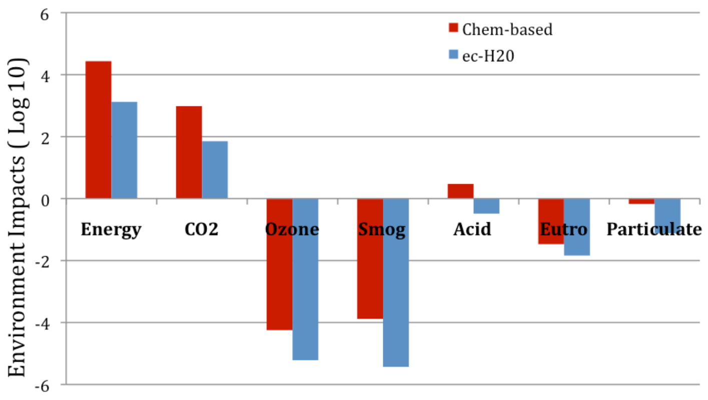
Life-Cycle Impacts - Education Scenario

Life-cycle impacts assessed for both the ec-H2O and chemical-based floor cleaning alternatives are presented below. Results are based on the education scenario and functional unit, which specifies the performance of 1,000 floor cleaning cycles over a five year period. Results of the analysis are also depicted visually in the chart below using a log scale (i.e. log 2=100, log 3=1,000) for display purposes, with lower impacts indicating better performance.

Life Cycle Impacts – Education

LCA Categories		Chemical-based	ec-H2O	Benefit (%)
Energy	(MJ)	27,193	1,323	**95**
CO_2 Emissions	(kg CO_2)	959	71	**93**
Ozone	(g CFCs)	0.0000566	0.00000609	**89**
Smog	(kg NOx)	0.000131	0.00000369	**97**
Acid	(kg SO_2)	2.97	0.326	**89**
Eutrophication	(kg PO4)	0.03	0.0145	**57**
Particulate	(kg PM2.5)	0.67	0.0757	**89**

Chart of Life Cycle Impacts – Education



Life-Cycle Equivalents - Education

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 ec-H2O’ expressed in common equivalent offsets are presented in the table below.

Equivalent Offsets per ec-H2O – Education

Category	Savings 1 Year	Savings 5 year	Equivalent Offsets (per unit)
Energy (MJ)	5,174	25,870	Barrels of Oil Offset (5 yr) – 4.19 barrels Months of Household Energy Offset (5 yr) – 7.6 mos Number of Households Offset (5 yr) – 0.63 households Gallons of Gasoline Offset (5 yr) – 197 gallons Tons of Coal Offset (5 yr) - 1.16 Metric Tons
CO_2 Emissions (kgCO2)	178	889	Months of Passenger Car Travel (5 yr) – 2.3 mos Number of Cars Offset (5 yr) – 0.19 cars per ec-H_2O unit

Education buildings are the fifth most prevalent commercial building type in the U.S., with approximately 309,000 buildings which include preschools, elementary schools, middle or junior high schools, high schools, vocational schools, and college or university classrooms. They are, on average, the largest commercial buildings, with 25,100 square feet per building, and they account for 13 percent of all commercial floor space.[1] Were 10 percent of the school buildings in the U.S. to use an ec-H2O equipped T3 scrubber to perform floor cleaning, collectively they would save enough energy annually to power more than 3,916 homes a year and offset the CO_2 emissions of more than 2,248 cars annually.

Life-Cycle Impacts - Retail/Health Care

Life-cycle impacts assessed for both the ec-H2O and chemical-based floor cleaning alternatives are presented below. Results are based on the retail/health care scenario and functional unit, which specifies the performance of 1,850 floor cleaning cycles over the five year analysis period. Benefits (%) associated with use of ec-H2O are presented for each impact category. Results of the analysis are also depicted visually in the chart below using a log scale (i.e. log 2=100, log 3=1,000) for display purposes, with lower impacts indicating better performance.

Life Cycle Impacts – Retail/Health Care

LCA Categories		Chemical-based	ec-H2O	Benefit (%)
Energy	(MJ)	49,626	1,323	**97**
CO_2 Emissions	(kg CO_2)	1,751	71	**96**
Ozone	(g CFCs)	0.000103	0.00000609	**94**
Smog	(kg NOx)	0.000240	0.00000369	**98**
Acid	(kg SO_2)	5.426	0.326	**94**
Eutrophication	(kg PO4)	0.062	0.0145	**77**
Particulate	(kg PM2.5)	1.223	0.0757	**94**

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[1] http://www.apep.uci.edu/der/buildingintegration/2/BuildingTemplates/School.aspx

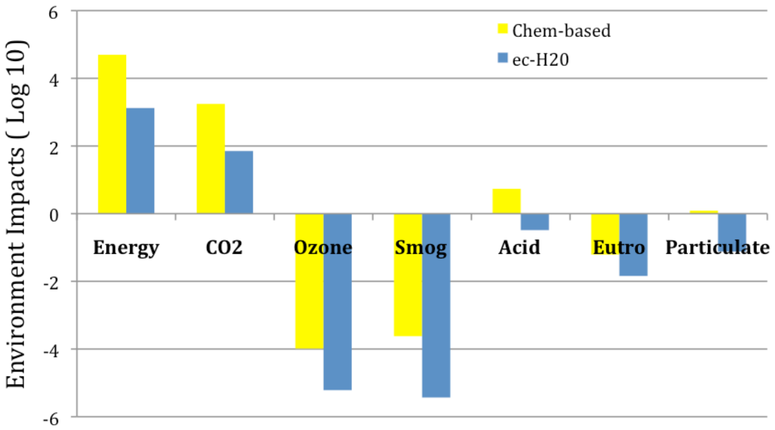

Chart of Life Cycle Impacts – Retail/Health Care

Life-Cycle Equivalents - Retail/Health Care

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 ec-H2O under the education scenario are presented below.

Equivalent Offsets per ec-H2O – Retail/Health Care

Category	Savings 1 Year	Savings 5 year	Equivalent Offsets (per unit)
Energy (MJ)	9,660	48,300	Barrels of Oil Offset (5 yr) – 7.8 barrels Months of Household Energy Offset (5 yr) – 14.2 mos Number of Households Offset (5 yr) – 1.18 households Gallons of Gasoline Offset (5 yr) – 369 gallons Tons of Coal Offset (5 yr) - 2.17 Metric Tons
CO_2 Emissions ($kgCO_2$)	336	1,680	Months of Passenger Car Travel (5 yr) – 4.4 mos Number of Cars Offset (5 yr) – 0.36 cars per ec-H_2O

There are approximately 16,400 hospitals or other primary health care facilities in the U.S. averaging nearly 74,600 square feet in total floor space. In total, they account for 3% of the overall U.S. commercial floor space[2]. Unlike some commercial buildings, hospitals typically clean their floors daily to maintain a clean and healthy indoor environment for patients and employees. If only 10 percent of the U.S. hospitals to use a pair of ec-H2O equipped T3 scrubber to perform floor cleaning, collectively they would save enough energy annually to power more than 776 homes a year and offset the CO_2 emissions of more than 238 cars annually.

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[2] http://www.apep.uci.edu/der/buildingintegration/2/BuildingTemplates/School.aspx

Analysis of LCA Results

Results of the life-cycle impact assessment demonstrate clearly the significant environmental benefits associated with the use of ec-H2O. In every category evaluated, ec-H2O resulted in only a small fraction of the overall environmental impacts associated with the chemical-based floor cleaning. Net benefits ranged from 57-97 percent depending on the category, and on the scenario evaluated.

To fully understand the disparity, a critical analysis of the life-cycle material and resource consumption of the two alternatives is useful. Key consumption data for each alternative are presented below.

Key Consumption Parameters for ec-H2O – Education and Health/Retail Scenarios

Parameter	Education Scenario		Health/Retail Scenario	
	Chemical-Based	**ec-H2O**	**Chemical-Based**	**ec-H2O**
Manufacturing				
Total Mass – Year 1	415.4 kg	6.49 kg	758.2 kg	6.49 kg
Total Mass – Years 2-5	415.4 kg/yr	None	758.2 kg/yr	None
Product Use				
Water use - year	12,940 gal/yr	4,210 gal/yr	23,620 gal/yr	7,670 gal/yr

Data for the education scenario demonstrate the large initial disparity in the materials required to manufacture the two cleaning alternatives. The 6.5 kilogram mass of ec-H2O is significantly less than the 415 kilogram mass of the floor cleaning chemicals and packaging associated with the chemical-based system leaving a margin of more than 408 kilograms in only the first year. The disparity grows to nearly 2,070 kilograms in following years, as ec-H2O operates a minimum of five years, while chemical-based cleaners are consumables requiring continuous replacement as they are depleted. The accumulated life-cycle impacts associated with the production of this additional mass of chemicals clearly dominates this analysis, and becomes even greater in the health/retail scenario.

During the use stage, both systems require the use of a scrubber to effectively clean the surface of resilient floors. Though a Tennant T3 scrubber was used for each alternative, the ec-H2O outfitted scrubber cleans a comparable surface area of floor using a much lower liquid flow rate (see Life-cycle Scenarios). The resulting savings in water during cleaning operations totals 8,730 gallons over the five year analysis period in the education scenario, and even greater for health/retail. Other parameters such as energy consumed during operation are identical between the standard and ec-H2O outfitted machine. The benefits of the reduced water consumption contribute to the overall disparity in life-cycle results for the two systems, in either scenario.

Upon review of this data, it is clear that the results are supported by the underlying data and align with expectations. It is also unlikely that the system would be sensitive to small changes in many of the key parameters that were assumed for this study given the disparity in the overall material consumption profiles. For example, even if the volume of chemicals consumed yearly was halved, the total mass of consumables use in traditional cleaning would still be 1,036 kg, or more than 150 times greater than that of ec-H2O.

Overall, the results indicate that there are significant benefits to the environment associated with the use of ec-H2O in every category as compared with traditional chemical-based floor cleaning.

ADDITIONAL ENVIRONMENTAL INFORMATION

Toxic Hazards

Chemical-based floor cleaners may be comprised of any number of chemical compounds, some of which may pose a potential threat to human health or the environment. Floor cleaning chemicals applied to the floor during the cleaning process are suctioned into the scrubber tank and subsequently disposed by drain into the local water works where they may pose a hazard to aquatic ecosystems. In addition, chemical cleaners may leave a film of chemical residue on the surface of the floor leading to potential exposures for children or other vulnerable populations.

The ec-H2O technology is a chemical-free system that cleans effectively using water from the tap, thereby avoiding any potential exposures to operators or building inhabitants. In addition, wastewater from the process contains no chemical elements, and therefore can be disposed of directly by drain without inflicting potential harm to aquatic receiving streams. Use of the ec-H2O technology eliminates any potential hazards that may result from floor cleaning operations.

Water Consumption

Both the ec-H2O technology and chemical-based floor cleaning systems rely on the use of a scrubber machine to physically scrub the surface to clean effectively. To control for variation, both systems were evaluated using the Tennant T3 scrubber. However, the ec-H2O equipped machine operates with a liquid flow rate of 0.13 gal/min, much less than the 0.4 gal/min liquid flow rate required to clean effectively with the standard T3 machine. Under the education scenario, use of the ec-H2O technology results in a savings of 43,000 gallons of water over the 5-year evaluation period, and over 73,000 gallons of water under the scenario for retail/health care.

Other Non-Renewable Resource Consumption

Chemical-based cleaners are made largely from petroleum-based chemicals and plastic packaging which ultimately are unrecovered at the end of their useful lives. After application, chemicals that do not volatilize are removed from the surface are disposed down a drain and into the local sewage system, while packaging is routinely disposed to a landfill. Over a 5 year period, a total of 316 kg of non-renewable, petroleum-based resources are consumed by chemical-based floor cleaning operations in the education scenario (see BOM), with even greater consumption in the retail/health care setting.

The ec-H2O technology represents a significant improvement over the use of chemical cleaners. While much of the BOM for ec-H2O is also comprised of non-renewable resources, together they account for only 6.4 kg in total mass. In addition, because of the high value the machines retain at the end of 5-years, they often are kept in use well beyond the warranty period and are typically repaired or rebuilt to extend the life of the product, further exaggerating the non-renewable resource benefits of the ec-H2O technology.

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APPENDIX A – IMPACT CATEGORY

Acidification, (AP): Acidification originates from the emissions of sulphur 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

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.

CO_2 Emissions, (CO2): Global warming of the atmosphere occurs when carbon dioxide, methane, or other gasses 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.

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.

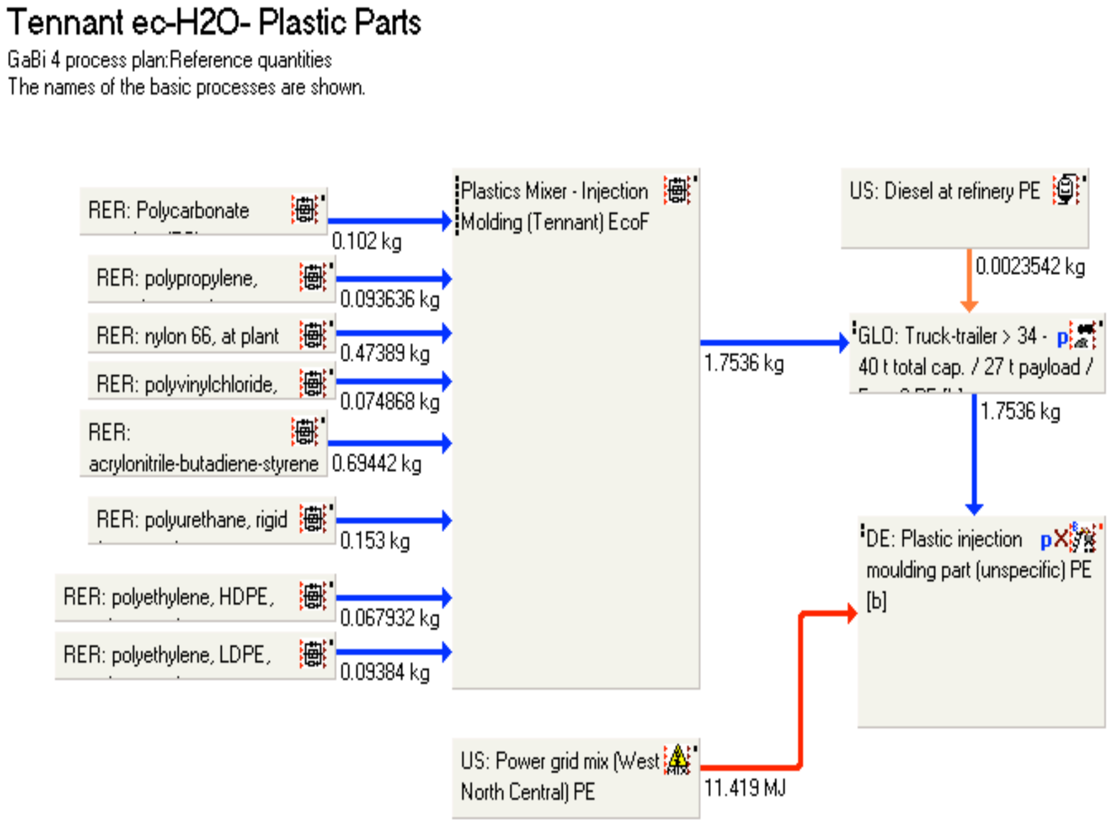
Particulates, (P): Particulates are released as a consequence of both mobile and point source operations, usually involving combustion of materials. When inhaled, particulates directly affect humans often resulting in respiratory irritation and even prolonged chronic respiratory illness. Smaller diameter 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 B – GABI MODEL DIAGRAMS

Life cycle calculations were performed using the GaBi 4.3.Life-Cycle Software. GaBi model diagrams for both the ec-H2O technology and chemical-based floor cleaning are presented as samples of the life-cycle modeling performed for this analysis.

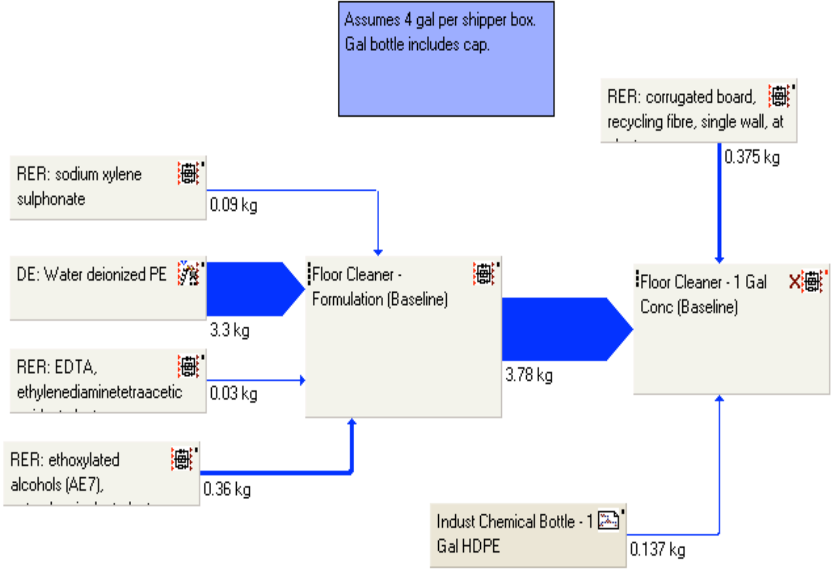
Sample ec-H2O Model Diagram



Sample Chemical-based Cleaning Model Diagrams

Floor Cleaner- 1 Gal Conc (Tennant)

GaBi 4 process plan: Mass [kg]
The names of the basic processes are shown.



Indust Chemical Bottle - 1 Gal HDPE (Tennant)

GaBi 4 process plan:Reference quantities
The names of the basic processes are shown.