Quantifying Environmental Benefits

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# Table of Contents

1. **Problem Statement** .................................................. 3
2. **Context** .................................................................. 3
3. **Framework** .............................................................. 4
   3.1. **Life Cycle Analysis** .............................................. 4
   3.2. **Our Methodology** ................................................ 5
4. **Production LCA (Latex Paint Application)** ...................... 8
   4.1. **Goal Definition** .................................................. 9
   4.2. **Inventory Analysis** .............................................. 9
4.2.1. **The Functional Unit** .......................................... 9
4.2.2. **Required Information** ...................................... 10
4.2.3. **Process Boundaries** ........................................ 10
4.2.4. **Impact Metrics** ................................................ 11
4.2.5. **Paint Production Process** ................................... 11
   4.3. **Impact Assessment** ............................................. 14
5. **Case Study: Cleaning Sub-Process (Numerical Example)** ...... 18
6. **Conclusion** .............................................................. 21
   6.1. **Limitations** ....................................................... 21
   6.2. **Scalability** ......................................................... 21
   6.3. **Next Steps** ....................................................... 22
Appendix A – **Commercial Paint Production Process** ............. 25
Appendix B – **Inventory Assessment** .................................. 27
Appendix C – **Numerical Model** ........................................ 28
1. Problem Statement

LiquiGlide creates permanently wet slippery surfaces based on liquid-impregnated surfaces, making its product the only durable solution currently available in the market to make viscous liquids slide easily.

LiquiGlide has tasked our S-Lab team with quantifying the sustainability benefits of their product. The LiquiGlide team believes their product could have major environmental payoffs, both by reducing waste and by decreasing friction in production and manufacturing processes, which could reduce greenhouse gas emissions as well as water and raw materials usage.

The incentive behind quantifying these sustainability benefits is twofold. First, while potential customers are motivated to license LiquiGlide’s technology to reduce costs, they will also be attracted to LiquiGlide due to its sustainability benefits, which they can in turn publicize to their stakeholders, including employees, consumers, shareholders, and other audiences including NGOs. Second, LiquiGlide can cite their product’s sustainability benefits to potential hires, engineers and material scientists who often seek a larger social benefit before signing on to work for a start-up.

Quantifying sustainability benefits reflects the recognition by many companies that sustainability strategies produce a real, sustainable competitive advantage. By prioritizing sustainability, firms can not only realize social benefits but also stand to maximize their profits and shareholder value by developing resource efficiency, business model resilience, innovative capacity, brand strength, and corporate culture.¹

2. Context

Based in Cambridge, Massachusetts, LiquiGlide was developed in the Varanasi Research Group laboratory at MIT. Dave Smith, a PhD student in Professor Kripa Varanasi’s lab, was working with a group of material science engineers to determine how to prevent clogs in oil and gas pipelines. Having seen the impact that liquid-impregnated surfaces could have in oil and gas pipelines, Smith and Varanasi decided to expand the concept to consumer-packaged goods (CPGs) to prevent adhesion and facilitate evacuation of liquid products.² Today, LiquiGlide’s patented technology, with an ever-growing IP portfolio, enables the development and licensing of a vast array of custom-designed, liquid-impregnated coatings (Figure 1).

LiquiGlide’s first commercialized coatings will be used in CPGs to enable complete and easy evacuation of products and will also be applied in production processes to improve efficiency and reduce waste. The first commercial packages with LiquiGlide’s coatings, which will likely include adhesive glue, paint, toothpaste, mayonnaise, and lotion containers, will appear on store shelves in 2015. LiquiGlide has secured licensing agreements with Elmer’s Products, Inc., and is pursuing licensing agreements with other CPG firms and

companies producing liquid products. It is also in the development phase for applications in manufacturing and oil and gas.

**A Permanently Wet Surface**

A new surface coating is designed to remain wet and slippery, allowing other liquids to slide across it easily.

A thin layer of porous material is sprayed onto the inside of a container.

A lubricating liquid is sprayed onto the porous surface, filling the tiny gaps. The liquid is held in place by capillary forces and creates a slippery surface for food or other liquids.

Figure 1 – Representation of LiquiGlide application and functionality

3. **Framework**

We have used a Life Cycle Analysis (LCA) as a framework for quantifying LiquiGlide’s sustainability benefits. In the following section we describe what LCA is and how we used this framework in our analysis.

3.1. **Life Cycle Analysis**

The National Risk Management Laboratory, a division within the U.S. Environmental Protection Agency, promotes the use of Life Cycle Analysis and has developed an extensive framework for constructing an LCA. They detail why organizations should perform LCAs, what an LCA entails, and how to find LCA data sources. We have adapted the tools presented in the LCA 101 document, “Life Cycle Assessment: Principles and Practice,” in our study.

LCA is a “cradle-to-grave” analysis of an industrial system and typically consists of four steps summarized in Figure 2:

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Many firms and institutions currently utilize LCAs to make their products and value chains more ecologically efficient, including major players such as Apple, BMW, Dow Chemical, Nike, and Xerox. LCA enables companies to make more informed decisions through a better understanding of the human health and environmental impacts of their products, processes, and activities. One such LCA was conducted by the MIT Materials System Lab together with Dyson, Inc., and compared the life cycle environmental impact of several hand-drying systems. The study found that the environmental impact of high-speed hand dryers is generally lower than that of other hand-drying systems, with the Dyson Airblade™ having the lowest impact regardless of impact assessment method. Factoring in time-based assumptions, the study found that the impact of the XLERATOR® dryer system is very close to that of Dyson Airblade™ hand dryer system.

3.2. Our Methodology

LiquiGlide has multiple sustainability benefits in the context of CPG and other products. To better understand the benefits and to provide LiquiGlide with a roadmap, we divided our analysis into three parts. Our methodology is summarized in Figure 3 and described in detail below:


1. **The ‘Global LCA’**

To categorize these benefits, we broke down the LCA into three buckets: production processes efficiency, waste reduction, and recycling improvement summarized in Figure 4 and discussed in more detail below.

- **RECYCLING**
  
  LiquiGlide’s facilitation of complete evacuation of consumer packaged goods encourages consumers to recycle packaging, and can prevent the pollution of paper products in single stream recycling communities.

- **PRODUCTION**
  
  LiquiGlide is applied throughout the production process of viscous products to create slippery surfaces that allow for more efficient pumping, increased energy and resource efficiency, and waste reduction.

- **WASTE**
  
  LiquiGlide’s application to packaging allows for full evacuation of products and prevents waste. However, this waste reduction may be mitigated if consumers repurchase these products more frequently.

Figure 4 – Summary of the three categories of LiquiGlide impacts

- **Production Processes Efficiency**: Examining LiquiGlide’s impact on production processes is in line with Varanasi and Smith’s original hypothesis that slippery surfaces would allow for more efficient pumping of viscous liquids. LiquiGlide could be applied at many touch points throughout the production process of viscous products, such tanks and pipelines. Applying LiquiGlide at these touch points...
points could increase energy and resource efficiency and reduce waste associated with the inability to fully evacuate liquid components and products.

- **Waste Reduction:** Consumer Reports in 2009 revealed that the inability to fully evacuate CPG products results in significant waste: for skin lotion, up to 25% of the product remained in the bottle, while up to 15% and up to 13% remained in condiment and toothpaste packaging, respectively. LiquiGlide’s application to CPG packaging reduces this waste. Waste reduction will be an exciting topic to explore with LCA techniques, although the methodology will have to be augmented with behavioral studies.

- **Recycling Improvement:** While glass, metal, and plastic containers with paper labels are acceptable to recycle, those containing food residue can contaminate single-stream recycling processes. Food residue is burned off during glass, metal, and plastic recycling, but not during paper recycling, where it creates oily pulp that makes poor quality, unusable recycled paper. Because single stream recycling combines all recyclable containers in the same bin, food residue on glass, metal, and plastic containers can transfer to paper, rendering it unrecyclable. Furthermore, municipalities also discourage recycling of containers with food waste due to sanitary concerns, as contamination can lead to infestation, mold, and bacteria, which can jeopardize the health of workers in recycling facilities. LiquiGlide’s facilitation of complete evacuation of CPG products encourage consumers to recycle packaging, and can prevent the pollution of paper products in single stream recycling communities.

We spoke with Dave Smith, Jason Jay, Professor Kripa Varanasi, and Karen Crofton of the Rocky Mountain Institute and determined that our LCA would focus on the impact of LiquiGlide during the production process. Thus we chose to focus on the “Production LCA” of LiquiGlide.

2. The ‘Production LCA’ (Case Study)

To perform the Production LCA, we applied the four steps of the LCA methodology to the production process for a large commercial latex paint manufacturer.

After identifying production process efficiency as our point of focus we further refined the goals and scope of the analysis. We use the LCA to compare the baseline paint production process against the process with LiquiGlide embedded. The potential benefits are twofold: direct impacts of reduced cleaning as well as reduced supply chain impacts due to efficiency in yields. As outlined in section 3.2 we applied an LCA framework to estimate LiquiGlide’s impact on waste reduction, labor intensity, resource efficiency, and GHG emissions within part of its production process and show some sample calculations on what this analysis could look like.


10 This terminology was refined after a conversation with Doctor Timothy G. Gutowski. Professor of Mechanical Engineering at MIT.
While LCAs are often used to identify steps in a process where environmental impacts can be reduced, in this case the application of LiquiGlide and the modified steps in the process have already been identified. Therefore, we use an attributional LCA framework to quantify the potential benefits of using LiquiGlide because, once we have identified the inputs and outputs of the process, we use impact averages to estimate the environmental benefits of the changes.11 This framework allows us to analyze the environmental benefits of the modified process and also serves as a means to justify the additional financial costs to the production factory.

1. **Goal Definition**: Described the latex paint production process and defined the boundaries for direct and supply chain impacts
2. **Inventory Analysis**: Categorized inputs and outputs of the paint production process and described how these will change with application of LiquiGlide coating
3. **Impact Assessment**: Given the inputs and outputs, we analyzed how the change in these variables would translate into both measurable direct and supply chain environmental effects
4. **Interpretation**: We extrapolated our analysis for the latex paint production to include supply chain impacts and recommended the necessary next steps to evaluate benefits in other industries

3. **A Detailed Illustrative Case**
   To improve our understanding, we performed a detailed analysis of a sub-process of the latex paint manufacturing by conducting a detailed inventory analysis and impact assessment based on estimates to quantify the direct impacts of the use of LiquiGlide in this sub-process. Once the direct impacts were quantified, we extrapolated these measures to track and quantify the supply chain impacts that this change generated.

4. **Production LCA (Latex Paint Application)**
   As mentioned in Section 3.2, this analysis focuses on the production process for a latex paint manufacturer that could apply the LiquiGlide coating to their plants’ large industrial tanks of latex paint where paint is made and mixed before being pumped into individual retail cans.

   After reviewing the feasibility and availability of data to perform a case study with this latex manufacturer with Dave Smith and Gary Christelis, we concluded that it was relevant to analyze the latex paint production process for several reasons:

   - Latex paint production is a water and energy intensive process. Any effort that succeeds in making this process more efficient will translate into less energy and water consumption, alleviating both global warming and water scarcity respectively.

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• Latex paint production generates significant emissions of Volatile Organic Compounds (VOC) and Particulates that are harmful to humans and contribute to global warming. An effective sustainability initiative will tackle the reduction of these emissions.
• Tanks are cleaned between mixing different batches through a labor- and water-intensive process in which an employee enters the tank and pressure sprays a mixture of water and a cleaning agent to remove paint residue. This water is reused a number of times before it is saturated with paint residue and rendered unusable as toxic waste.

4.1. Goal Definition

Objectives
The LCA is an important internal tool for LiquiGlide and will help contextualize the importance of the work that employees are doing and help attract top talent who may be interested in the environmental benefits of the LiquiGlide applications. Additionally, our analysis could be shared with a paint manufacturing company, who could incorporate this data into their cost/benefit modeling and potentially use the environmental benefits as a marketing differentiator with stakeholders.

Note: A full LCA analysis would involve working closely with the paint manufacturer to detail their exact process and would expand on the analysis provided in the following sections to include all inputs and outputs along the entire chain of production, beginning with the harvesting of the raw inputs used for production and ending with the final byproducts with and without the use of LiquiGlide’s coating. We have chosen to conduct the study utilizing assumptions and general ranges in the hopes that a follow-on study can be conducted in greater depth.

4.2. Inventory Analysis

The Functional Unit
A functional unit is a measure of the functional performance of the outputs of the product system. The best functional unit is one that describes the system in line with the goal and scope of the study. In this case, a correctly expressed functional unit is essential to compare the process with and without LiquiGlide.12

We have selected gallons of paint as our functional unit. While this allows us to incorporate all aspects of the production process improvement, it does not address complications that arise in the production process over time, such as the changes in the “slipperiness” of the LiquiGlide coating with prolonged use, the potential cleaning time-savings, and learning associated with the rollout of the new process, etc.

**Required Information**

We have chosen to use industry averages in order to mask the identity and propriety information provided by the paint manufacturer. We recognize the paint manufacturer in question may employ different practices that are either more or less efficient in terms of resource use and outputs. The averages refer to the production rate averages and process requirement inputs and outputs.

**Process Boundaries**

We will explore the paint manufacturing process in more detail but we reduced the scope of our analysis to include only the impacts associated with the paint manufacturing process that we highlight in Figure 5.

![Figure 5 - The scope of our LCA analysis](https://app.sustainableminds.com/learning-center/ecodesign-and-lca/ecodesign-overview)

For our descriptive LCA, the boundary includes all the activities performed inside the paint manufacturing plant. Our LCA begins upon the start of the paint production process at the facility and ends upon the placement of paint inside paint cans at the factory: paint processing, paint manufacture, paint service (cleaning), paint packaging and direct effluent treatment. The ultimate goal is to define the **direct impacts** of the current production process on the environment and to determine how the use of LiquiGlide coatings will reduce this overall footprint.

The **supply chain** impacts, while quite important, involve many additional stakeholders and can serve as the basis for a follow-on study. The total footprint including these **supply chain impacts** would include the energy required in the extraction of raw materials, the transportation of the raw materials, the distribution of the product, the re-use, the maintenance of facilities, consumption of the product and the recycling and waste management of the residual product. Additionally, LiquiGlide may in fact have packaging applications in the paint containers themselves. Each of these processes requires a form of energy and generates both harmful and non-harmful outputs, which leave a certain environmental impact, but we do not include that in this analysis.

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To approximate these supply chain impacts for our case study, we used the Sustainable Minds tool.\textsuperscript{14} This tool is best used for internal decisions and is designed for product development teams. One of the metrics that this tool helps calculating is the embodied energy of a product. Embodied Energy is the sum of all the energy required to produce any goods or services, considered as if that energy was incorporated or 'embodied' in the product itself giving an approximated traceability of the impacts of producing a product along the supply chain.\textsuperscript{15}

The results of this analysis cannot be used to make external environmental claims but simply show what the impacts could be if a product concept is implemented. Given that we are focused on Steps 1-3 of the LCA framework—namely goal definition, inventory analysis, and impact assessment—this tool helps provide a reasonable baseline for our model. The inventory analysis and impact assessment portions of the LCA will be studied in greater depth by MIT engineering students in the coming months with the intention to apply enough scientific and academic rigor such that step 4—Interpretation of the LCA—can be completed according to standards.

\textbf{Impact Metrics}

The key environmental resource and impact metrics we have chosen are: atmospheric emissions, waterborne waste and solid waste. The units of impact are as follows:

\begin{table}[h]
\begin{tabular}{|l|l|}
\hline
\textbf{Impact Category} & \textbf{Units} \\
\hline
Global warming potential & Kilograms C02 equivalents \\
Energy use & KWh \\
Water use & Cubic meters \\
Primary waste & Kilograms \\
Materials Efficiency & Percent \\
Recycled Content & Percent \\
\hline
\end{tabular}
\caption{Impact categories}
\end{table}

\textbf{Paint Production Process}

To understand the direct environmental impacts of the latex paint production process it is necessary to understand the steps of paint manufacturing itself. Appendix A gives an overview of what the process looks like, and each step is described in detail in the following paragraphs:

1. \textbf{Pre-Dispersion}: Pigment manufacturers send bags of fine grain pigments to paint plants. There,

\textsuperscript{14} Sustainable Minds® easy-to-use, cloud-delivered Eco-concept + Life Cycle Assessment software that is accessed by: http://www.sustainableminds.com/software

the pigment is premixed with resin (a wetting agent that assists in moistening the pigment), one or more solvents, and additives to form a paste (viscous material) to which pigments are added.

2. **Dispersion:** The paste is now routed into a high-speed dispersion tank. There, the premixed paste is subjected to high-speed agitation by a circular, toothed blade attached to a rotating shaft. This process blends the pigment into the solvent.

3. **Thinning:** The paste must now be thinned to produce the final product. Transferred to large kettles, it is agitated with the proper amount of solvent for the type of paint desired.

4. **Packaging:** The finished paint product is pumped into the canning room. Empty cans are first rolled horizontally onto labels and then set upright to pump the paint. A machine places lids onto the filled cans, and a second machine presses on the lids to seal them. Then cans are boxed and stacked before being sent to the warehouse.

5. **Tank Cleaning:** Dispersion tanks and kettles must be cleaned whenever a batch of paint is produced. This process requires cleaning the walls and removing the paint so that a batch of a new color/quality can be produced. Water sludge can be recycled for further cleaning or sent to water treatment plants or the manufacturer’s in-house treatment facility.

6. **Waste Water Treatment:** A large paint manufacturer will have an in-house wastewater treatment facility that treats all liquids generated on-site. The liquid portion of the waste is treated on-site to the standards of the local publicly owned wastewater treatment facility but can also be used to make low-quality paint. Latex sludge can be retrieved and used as fillers in other industrial products. Waste solvents can be recovered and used as fuels for other industries.

**Inputs & Outputs**

We outline inputs and outputs in the latex paint manufacturing process in Appendix B. The details are as follows:

**Inputs**

1. **Raw Materials:** Latex paint is composed of pigments, solvents, resins, and various additives. The pigments give the paint color, solvents make it easier to apply, resins help it dry and additives serve as everything from fillers to fungicidal agents. The basic white pigment is titanium dioxide and black pigment is commonly made from carbon black.

Solvents are various low viscosity, volatile liquids. They include petroleum mineral spirits and aromatic solvents such as benzoyl, alcohols, esters, ketones, and acetone. Some, like calcium carbonate and aluminum silicate, are simply fillers that give the paint body and substance without changing its properties. Other additives produce certain desired characteristics.
2. **Energy:** The direct energy used in the manufacturing process of paint comes primarily from the blending process. Depending on the type of the viscosity of the paint produced and the stage of the manufacturing process, the energy used (usually as electricity) may vary. Despite this variation, this is an energy intensive manufacturing process.

Energy is also required to move a product from one stage in the manufacturing process to the other. The electricity use will account for the amount required to keep the pumps in the manufacturing system running at the required production rate.

3. **Water:** Water is not only a primary raw material but is also required during the manufacturing process. In high-speed dispensers, ball and pebble mills and in other dispersing equipment, the temperature rises as some of the kinetic mixing energy is converted to thermal energy. This temperature rise is controlled through the use of the cold water jacket on the process vessel.

Additionally, every time a new batch of paint needs to be produced, the tanks and the pipes in the production process must be cleaned. This process is water intensive and water can only be recycled until a certain paint concentration is reached.

**Outputs**

1. **Effluent:** The processing equipment can be cleaned with solvent as many times as needed, such as after each batch of paint. Since latex paint contains acrylics, vinyl and epoxies, pouring this cleaning water down the drain is harmful to the environment. This sludge must be treated, a process that includes a series of surface impoundments that are used for equalization, neutralization, aeration, and clarification of the waste stream.

2. **Emissions:** Latex paint manufacturing releases emissions. While the most common emissions are the volatile organic compounds (VOC's) that are generated during the manufacturing process, particulate matter emissions can also occur from handling the solid powders. Specifically:

   a. VOCs and particulates are released during the material loading of mixing and grinding equipment because of the displacement of organic vapors and from mixing, grinding, blending and filling activities.

   b. Emissions can also be released due to increased heat in the blending process: the temperature rises as some of the kinetic mixing energy is converted to thermal energy and as VOCs in the mixer heat up, releasing solvent emissions from the equipment.

3. **Leftover Paint:** The process produces leftover paint, which plants dispose of by drying and hardening with an absorbent. Once the paint is hardened it is disposed in a sanitary landfill without causing harm to the environment.
4.3. Impact Assessment

Direct vs. Supply Chain Impacts

In the case of manufacturing a particular product, the environmental impact calculation will include all the effects associated with the extraction of a material, manufacturing, the transportation of the raw materials, the distribution of the product, the re-use, the maintenance, the recycling and waste management. Based on the scope of our work we classify the impacts in two broad categories:

**Direct Impacts** – Environmental impacts directly associated to the activities performed inside the paint production facility. More specifically the energy and water required used and any emissions generated during the production process, treatment and service (cleaning) performed by the company.

**Supply Chain Impacts** – The impacts associated to the raw material extraction/acquisition and transportation, waste disposal/recovery, consumption and use.

Definition of Impact Categories

We defined the relevant impact categories to evaluate the benefit of the use of LiquiGlide. Impact categories were chosen from those identified by EPA\(^{16}\) and based on a previous LCA for paint production.\(^{17}\) Seven impact categories were considered relevant to evaluate both direct and supply chain impacts. A summary of these categories and scale are summarized in Table 1:

<table>
<thead>
<tr>
<th>Impact Category</th>
<th>Scale</th>
<th>Examples of LCI Data (i.e. classification)</th>
<th>Description of Characterization Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global Warming</td>
<td>Global</td>
<td>Carbon Dioxide (CO(_2))</td>
<td>Converts LCI data to carbon dioxide (CO(_2)) equivalents</td>
</tr>
<tr>
<td>Stratospheric Ozone Depletion</td>
<td>Global</td>
<td>Chlorofluorocarbons (CFCs), Hydrochlorofluorocarbons (HCFCs), Halons, Methyl Bromide (CH(_3)Br)</td>
<td>Converts LCI data to trichlorofluoromethane (CFC-11) equivalents.</td>
</tr>
<tr>
<td>Eutrophication</td>
<td>Local</td>
<td>Phosphate (PO(_4)), Nitrogen</td>
<td>Converts LCI data to phosphate (PO(_4)) equivalents.</td>
</tr>
</tbody>
</table>


LiquiGlide – Life Cycle Assessment (Case Study)

<table>
<thead>
<tr>
<th>Photochemical Smog</th>
<th>Local</th>
<th>Non-methane hydrocarbon (NMHC)</th>
<th>Converts LCI data to ethane ($C_2H_6$) equivalents.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human Health</td>
<td>Global Regional Local</td>
<td>Total releases to air, water, and soil.</td>
<td>Converts LC data to equivalents; uses multi-media modeling, exposure pathways.</td>
</tr>
<tr>
<td>Resource Depletion</td>
<td>Global Regional Local</td>
<td>Quantity of minerals used Quantity of fossil fuels used</td>
<td>Converts LCI data to a ratio of quantity of resource used versus quantity of resource left in reserve.</td>
</tr>
<tr>
<td>Water Use</td>
<td>Regional Local</td>
<td>Water used or consumed</td>
<td>Converts LCI data to a ratio of quantity of water used versus quantity of resource left in reserve.</td>
</tr>
</tbody>
</table>

Table 1 – Impact categories chosen to evaluate environmental impact of paint production

**Explanation of Impact Categories**

1. **Direct Impacts**

   **Global Warming (GW)**
   
   VOCs: Although Latex paints are generally labeled as “Low VOC” they still release VOCs to the environment. Methane is an important component of VOCs and its environmental impact is principally related to its contribution to global warming as it is one of the most potent greenhouse gases in Earth’s atmosphere.¹⁹

   **Ozone Depletion (OD)**
   
   VOCs: CFCs, halons, and other ozone-depleting chemicals such as carbon tetrachloride and trichloroethane contribute to stratospheric ozone depletion. These substances are released during the paint manufacturing process.²⁰

   **Eutrophication (EP)**
   
   Waste Water Disposal: Eutrophication is the enrichment of an ecosystem with chemical nutrients, typically compounds containing nitrogen, phosphorus, or both.²¹ The paint industry is characterized as having hazardous water as an intrinsic byproduct of their business increasing the flux of both inorganic nutrients and organic substances if adequate treatment is not present.

   **Photochemical Smog (PS)**

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http://www.epa.gov/nrmrl/std/lca/pdfs/chapter4lca101.pdf


VOCs: Photochemical smog is the chemical reaction of sunlight, nitrogen oxides and volatile organic compounds in the atmosphere, which leaves airborne particles and ground-level ozone. These noxious mixtures of air pollutants are released in industrial processes such as paint manufacturing.\(^{22}\)

**Human Health (HH)**

*Particulate emissions:* Key signs or symptoms associated with exposure to particulates in paint manufacturing facilities include conjunctiva irritation, nose and throat discomfort, headache, allergic skin reaction, declines in serum cholinesterase levels, nausea, emesis, epistaxis, fatigue, and dizziness. These symptoms may affect workers in the paint manufacturing industry is exposed for long periods of time or without the proper protection\(^{23}\).

**Resource Depletion (RD)**

*Energy Usage:* Fossil fuels are our main sources of energy, producing the vast majority of fuel, electricity, and heat used across the globe\(^{24}\). The paint manufacturing process requires energy to power the pumps that transport the mixture within the process and energy to power the tanks that mix the paint raw materials.

**Water Use (WU)**

*Cleaning:* Although Latex paint uses water as its main solvent, for the purpose of our study, water as a solvent is considered to be a raw material; thus, this dimension is covered in supply chain impacts. Nonetheless, water is used extensively in paint production for cleaning, as mentioned in Section 4.2.

2. **Supply Chain Impact**

As mentioned in Section 4.2, Supply chain impacts are those impacts associated with:

- Raw material acquisition
- Distribution and purchase
- Use and service
- Retirement and recovery

This is a critical area for further analysis since identifying the impact of extracting and acquiring secondary materials (e.g. solvent, resin, and pigment) and the primary materials that go into these, provides a reasonable understanding of the overall environmental impact of the application of LiquiGlide.

**The Effect of LiquiGlide Coatings**

The use of LiquiGlide coatings in the walls of mixing tanks and pipelines not only will improve the efficiency of paint production but also will reduce the direct and supply chain impacts. Specifically, we

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\(^{24}\) D. Ahuja and M. Tatsutani. Sustainable energy for developing countries. Sapiens, vol.2, pp.1-16 (2009)
identified six levers that LiquiGlide can use to promote its **direct environmental benefits**. The levers and their impacts according to our categories are summarized in Table 2, and explained in detail below:

1. **Reduction of Production Time**: Average production time is reduced as a result of less friction in the walls of both tanks and pipelines. Because emissions have a direct relationship with production time, if the same product is made in less time, fewer emissions of VOCs are emitted per volume of product. Similarly, less energy will be required per volume of paint produced.

2. **Reduction of Process Energy**: Less friction in the walls of both pipes and tanks will result in less energy required not only to keep the plan running but the energy used in pumps to keep the product flowing.

3. **More Paint per Batch**: Finished product is increased for a particular batch as a result of less paint remaining on the walls of the mixing tanks. The energy requirements for the cleaning process as well as the emissions associated with it will be reduced.

4. **Less Frequent Tank Cleaning**: With the application of LiquiGlide, tanks are cleaned less frequently, as less paint accumulates on the walls of tanks and tanks are easier to clean. If tanks are cleaned less frequently, what was previously downtime translates into productive time, and less water and chemicals are used for cleaning between batches of paint. The reduction in chemicals and water used for cleaning will result in less effluent to treat and will thus reduce the energy required for the wastewater treatment process.

5. **Less Water Used for Cooling**: As a result of the reduction in friction, less kinetic energy will be converted into thermal energy, reducing the amount of water required to cool down the manufacturing equipment.

6. **Increased Water Recycling**: Water used to clean the tanks can be recycled depending on the concentration of leftover paint. If for each cleaning fewer residues remain in the water, the same amount of water can be used many more times. This directly impacts the water requirements for the water-intensive cleaning process.

<table>
<thead>
<tr>
<th>ID</th>
<th>Levers</th>
<th>GW</th>
<th>OD</th>
<th>EP</th>
<th>PS</th>
<th>HH</th>
<th>RD</th>
<th>WU</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Reduction of Production Time</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>2</td>
<td>Reduction of Process Energy</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>More Paint per Batch</td>
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<td></td>
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<tr>
<td>4</td>
<td>Less Frequent Tank Cleaning</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Less Water used for cooling</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Increased Water Recycling</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 2 – Impact matrix. See above for impact abbreviation codes. Shaded cells indicate the associated lever reduces the associated direct impact.

5. Case Study: Cleaning Sub-Process (Numerical Example)

To quantify the impacts and benefits of LiquiGlide, we have used the cleaning process of the mixing vats as an example for a numerical analysis. The model presented in Appendix C outlines the relationship of water and energy used in the process and was built based on a high-level understanding of paint manufacturing and the cleaning process, in addition to conversations with LiquiGlide on how its product could improve energy use and reduce waste. LiquiGlide’s application can improve from the perspective of reducing waste or increasing efficiency in the following dimensions:

- Gallons of residual paint per cleaning
- Time per cleaning
- Finished paint production yield per cycle
- Number of production cycles per cleaning
- Number of cleaning cycles before water change

The figures in the model are based purely on assumptions and could be orders of magnitude off. Nonetheless, the model represents an illustrative framework that could be developed further once a detailed assessment is made in concert with the client to calculate the required inputs (identified in the notes and indicated by blue text in Appendix C) and further assess their specific manufacturing process.

The model makes the following key assumptions:

- A cleaning cycle is run after every 3 production runs within the mixing vats. Each cleaning cycle takes about 20 minutes on average.
- There are approximately 150 gallons of paint that is left on the walls of the mixing vat after each cleaning cycle, which gets washed off by the cleaning solution and captured along with the cleaning solution runoff.
- The cleaning solution and runoff are held in a large storage tank of water (5,000-10,000 gallon capacity). Every 20 cleaning cycles, the tank mixture becomes too contaminated for reuse and is replaced with a fresh mix of cleaning solution. The effluent is sent to an on-site water treatment facility where it is pre-treated before being released into the municipal system.
- Other various assumptions are made about energy use for running the cleaning cycle and treatment facility (e.g., power used by high pressure water pumps, electricity used to pre-treat effluent, etc.), detailed in Appendix C.

Given the above, our model estimates the following energy use per year:
Based on the team’s observations of LiquiGlide’s performance, we believe a frictionless coating on the vats could substantially reduce the amount of paint residual left behind after each production cycle. We make the following adjustments to the line items denoted previously to illustrate how LiquiGlide’s product might increase the sustainability of paint manufacturing, only focusing on the direct impact of improving the cleaning process:

The 5% increase in yield is implied by the corresponding reduction in residual paint after a production process, as this paint is no longer sticking to the vats but rather now being captured in paint cans for sale. Similarly, the reduction in paint residual from each cleaning cycle results in directly that much less contamination per cleaning cycle.

Based on these assumptions, our model estimates that total energy use and water consumption in the vat cleaning process can be reduced 94.3% and 95.0% per year, respectively.

**Estimating the total supply chain impact**

For natural latex paints, the embodied energy is shown to be 67.6MJ/Kg\(^2\). These results show the total embodied energy considering all the factors such as the extraction cost, transport and manufacture of the product. Comparing the residual paint left in the walls with and without LiquiGlide, and assuming 1 gallon of paint weighing 6kg, Figure 8 shows the difference

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Additional Considerations

Our model highlights only a snapshot of what the full LCA would quantify. The following are some additional considerations that are not addressed by our analysis and would to be included in a follow-on analysis:

Direct Impacts:

- Fewer cleanings per production cycle will generate fewer VOC emissions as a result of a reduced process time and more usable paint per batch. As discussed in detail in Section 4.3, reduced process time and more usable finished product per batch has a direct positive reduction on several impact categories (e.g. Global Warming and Ozone Depletion).
- The treatment process also results in other byproducts as contaminants from the effluent are treated and/or removed before the water is discharged into the municipal system. This reduces the risk of eutrophication.
- Reduced discharge will reduce the energy required to run the internal water treatment process in the paint production facilities.

Supply Chain Impacts:

- The higher yield per production run means that, holding output constant, fewer raw materials would be needed to produce the same level of goods. Tracing the benefits back up the supply chain, including saved fuel from transportation, still needs to be quantified for each raw material. According to the LCA database analysis toolset Sustainable Minds, each gallon of latex paint saved in the production process translates into approximately 2.38 kg of CO2 equivalent. In the illustrative example from our model, the 150 gallons of paint residual washed away each cleaning cycle translates into approximately 357 kg of CO2 equivalent (371,000 kg per year) from a raw materials perspective.
- The solvents used in the cleaning process have not been quantified. These can sometimes include caustic compounds or result in other VOCs that would have additional implications in a full LCA.
- The reduced discharge also puts less demand on the municipal system.
- Potential energy savings from the reduced friction resulting from coating other parts of the production process, such as pumping various inputs through pipelines.

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27 Assumes one gallon of paint weights approximately ten pounds
• Labor savings of reducing time per cleaning cycle, as well as other intangible safety benefits previously mentioned.

6. Conclusion

6.1. Limitations

The scoped framework we developed for the LCA enables quantification of the realized cost savings associated with LiquiGlide’s application as well as the environmental benefits in the paint manufacturing process. However, this analysis does not examine potential changes in the machine design and processes that are enabled by LiquiGlide’s application. For example, the structure of the paint vat could be modified or additional pipes and steps in the mixing process may no longer be necessary, resulting in even greater energy efficiency gains. The slippery surface may enable additional innovations that simplify the production process and result in additional input/output savings in the production process. The LCA does not help pinpoint these areas; an engineering process analysis is necessary to understand the full implications.

Additionally, LiquiGlide may provide other human or ecological benefits which are harder to quantify and do not fit within the LCA framework. For example, workers are often prone to injury when cleaning paint tanks due to the dangerous nature of operating the high pressure cleaning machines. The application of LiquiGlide allows for the simplification and reduction in the frequency of the cleaning process, which improves worker safety. While it is difficult to place a value on the lost productivity due to injury, or the enhanced worker satisfaction from working in a safe environment, this is an important consideration and one that should be acknowledged.

Lastly, we recognize that LiquiGlide’s application in the production process may lead to unintended impacts that counteract sustainability benefits. For example, if we take a broader systems perspective we may see increased environmental impacts. If LiquiGlide enables the paint manufacturer to increase yields this may lower production costs and lead to lower paint prices, which count in turn lead to greater consumer demand, more paint production and increased environmental impacts.

Lastly, the environmental impacts of manufacturing and applying LiquiGlide to the production process will need to be considered. A full end-to-end LCA will incorporate the environmental impacts of LiquiGlide itself, something that will need to be studied in greater depth once full-scale production of the compounds is begun.

6.2. Scalability

LiquiGlide has many applications in the industrial and manufacturing sector. The slippery surface can be developed for applications in containers, pipes, funnels and hoppers, mixing tanks, and mold releases to stop adhesion of product. The LCA framework identified above can be modified for use in any of these situations. Furthermore, the boundaries of the LCA can and should be extended to the product distribution
and consumption. When LiquiGlide is used on the inside of paint cans, for example, consumer behavior and impacts are modified. An LCA that follows the products through a consumer’s hands to the ultimate “grave” in a recycling facility or municipal dump would capture the full impacts. This could also be extended to different types of paint (oil, water based), and to the paint industry as a whole.

6.3. Next Steps

This report is intended to provide an overview of the LCA process and serve as guidance for future projects and studies. The case study detailed above is focused on the production process efficiency gains, and immediate next steps are outlined below. Future analysis can extend to quantify recycling and waste impacts as well as the supply chain impacts in the production process. Taking into consideration our overall approach, we highlight the only step that we quantified (Figure 9) to lay next steps.

**Cleaning Process:**

*Improving Accuracy*

While our approach provides ballpark figures, it does not offer the level of precision and scientific rigor that would be necessary to use the findings in consumer-facing marketing claims. LiquiGlide can working with paint manufacturing companies and other customers to procure real-time data from the factory. For
example, industry averages used in our model can be replaced with actual data from the manufacturing plant on water consumption, electricity mix, etc. An MIT engineering class will take this analysis one step further to produce more exact results. In broader applications, this LCA can provide a first-pass at the benefits, and the manufacturing company itself can employ a team to conduct a thorough analysis of their particular processes. However, LiquiGlide could conduct this type of “back of the envelope” calculation for prospective manufacturing clients for internal marketing efforts.

**Considering All Impacts**

We only considered energy and water consumption when quantifying impacts. However, as explained in detail in Section 5, the impacts on other impact categories (e.g. Green house Gases, Ozone Depletion, etc.) are missing. These additional impacts would be difficult to estimate if only the cleaning sub-process is considered as industry impact averages can be found for the impact generated for the whole paint production process as a whole.

<table>
<thead>
<tr>
<th>Production Process:</th>
<th>Environmental Impact Categories</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Global Warming (GWP)</td>
</tr>
<tr>
<td></td>
<td>kg CO2-eq</td>
</tr>
<tr>
<td>High speed-mixing</td>
<td>1,220.900</td>
</tr>
<tr>
<td>In-storage tank mixing</td>
<td>87.708</td>
</tr>
<tr>
<td>Packaging</td>
<td>16,444.500</td>
</tr>
</tbody>
</table>

Table 3 – Environmental impact categories for Latex production process

**Production Process:**

**Direct Impacts**

Quantifying the direct impacts should include the full set of steps within the production process. The cleaning process provides a good approximation of what the quantification would look like but the benefits will be significantly more if all the impact categories are taken into consideration for all the processes within the paint manufacturing.

**Supply Chain Impacts**

Once the production process yields have been determined this information can be used to determine changes within the supply chain. As the raw material inputs used to make the paint are converted more

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efficiently to the end product the overall supply chain impact of the product is reduced. The forgone input costs (both raw materials and transportation) are an added benefit when considering the overall environmental impact as well as the financial costs. The paint manufacturer should work with supplier to better understand the upstream environmental impacts, and perhaps there is an opportunity to introduce LiquiGlide in the input manufacturing processes as well.

**Recycling Improvement:** If LiquiGlide is in fact used in the paint can package then further analysis should focus on the consumer impacts. Behavioral studies can be conducted to better understand the recycling impacts and potential benefits. Further study on what types of paint cans are recycled and what typically happens with the cans post-use will shed light on the impact LiquiGlide has on post-consumer use of the paint product.

**Waste Reduction:** Similar behavioral studies can examine the waste reduction impact of LiquiGlide’s use in packaging. As consumers are able to use the very last drop of paint in a can we need to better understand what impact this has on paint demand and buying decisions. Similarly, consumers will no longer be polluting the environment with residual paint in the cans and the associated landfill costs and environmental impacts will be avoided and quantifiable.
Appendix A – Commercial Paint Production Process

Key

- Raw Materials
- Final Product
- Intermediate Product
- Process
- Output / Waste
Appendix B – Inventory Assessment

Raw Material Acquisition
- Transportation
- Storage
- Mixing

Manufacturing
- Mixing
- Blending
- Packaging
- Pipeline Transportation

Use / Reuse / Maintenance
- Equipment operation
- Monitoring testing
- Parts replacement

Recycle / Waste Management
- Equipment cleaning / re-conditioning
- Sludge management
- Wastewater treatment
- Leftover paint final disposition

Raw Materials

Energy

Effluent

Recycle / Waste Management

Manufacturing

Use / Reuse / Maintenance

Raw Material Acquisition

VOC Particulates

Waterborne Wastes

Solid Wastes

Co-products

Neutralized Effluent

Other Releases

## Appendix C – Numerical Model

### Cleaning Cycle Analysis – Energy Use Per Year

<table>
<thead>
<tr>
<th>Process</th>
<th>Current</th>
<th>LiquiGlide</th>
<th>Post</th>
<th>Reduction/Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy Costs</td>
<td>$0.15</td>
<td>$0.15</td>
<td>-</td>
<td>(a) MA indust. avg., per US Energy Information Administration (Feb 2015)</td>
</tr>
<tr>
<td>Gallons of solvent per tank</td>
<td>250</td>
<td>250</td>
<td>-</td>
<td>(d) Assumption</td>
</tr>
<tr>
<td>Time per cleaning (minutes)</td>
<td>20</td>
<td>20</td>
<td>-</td>
<td>(f) Assumption</td>
</tr>
<tr>
<td>Energy use per minute (Watt hours)</td>
<td>1.04</td>
<td>0.52</td>
<td>-</td>
<td>(g) Assumption</td>
</tr>
<tr>
<td>Energy use per cleaning cycle (kWh)</td>
<td>1.5</td>
<td>0.75</td>
<td>-50.0%</td>
<td>(h) = (f)*(g)/1000</td>
</tr>
<tr>
<td>Energy use per cleaning cycle (kWh)</td>
<td>1.04</td>
<td>0.52</td>
<td>-50.0%</td>
<td>(l) = (d)*(o)</td>
</tr>
<tr>
<td>Finished paint yield per production cycle (gallons)</td>
<td>950</td>
<td>995</td>
<td>4.7%</td>
<td>(k) Assumption</td>
</tr>
<tr>
<td>Number of production runs per year</td>
<td>3,120</td>
<td>3,120</td>
<td>-</td>
<td>(l) Assumption</td>
</tr>
<tr>
<td>Number of cleaning cycles before water change</td>
<td>52</td>
<td>3</td>
<td>-95.0%</td>
<td>(m) Assumption</td>
</tr>
<tr>
<td>Energy use per year (kWh)</td>
<td>429,000</td>
<td>21,450</td>
<td>-95.0%</td>
<td>(n) = (p)*(o)</td>
</tr>
<tr>
<td>Energy use per year (kWh)</td>
<td>1,560</td>
<td>390</td>
<td>-75.0%</td>
<td>(o) = (p)*(q)</td>
</tr>
<tr>
<td>CO2 equivalent per year (kg)</td>
<td>1,076</td>
<td>269</td>
<td>-75.0%</td>
<td>(p) = (m)*(o)</td>
</tr>
</tbody>
</table>

| On-site Treatment Plant | |
| Energy use per 1,000 gallons treated (kWh) | 100 | 100 | - | (x) Assumption |
| Energy use per year (kWh) | 42,900 | 2,145 | -95.0% | (y) = (z)*(t) |
| Energy use per year (kWh) | 1,560 | 390 | -75.0% | (z) = (t)*(p) |
| CO2 equivalent per year (kg) | 1,076 | 269 | -75.0% | (t) = (y)*(z) |

| Total Impact | |
| Facility Total | 44,468 | 2,535 | -94.3% | (a) = (b)+(c) |
| Energy use per year (kWh) | $6,629 | $378 | -94.3% | (b) = (c)*(d) |
| CO2 equivalent per year (kg) | 30,677 | 1,749 | -94.3% | (d) = (b)+(c) |

| Per 1,000 gal. | |
| Energy use per year (kWh) | 15.00 | 0.82 | -94.6% | (e) = (f)*(a) |
| Energy use per year (kWh) | $2.24 | $0.12 | -94.6% | (f) = (a)*(g) |
| CO2 equivalent per year (kg) | 10.33 | 0.56 | -94.6% | (g) = (e)+(f) |

| Industry Total | 1,570,000 | 1,570,000 | - | (h) 2005 annual U.S. consumption, per EPA |
| National energy use per year (kWh) | 23,550,000 | 1,282,035 | -94.6% | (i) = (a)+(b) |
| National energy use per year (kWh) | $2,511,200 | $131,151 | -94.6% | (b) = (a)+(c) |
| National CO2 equivalent per year (kg) | 16,249,500 | 884,604 | -94.6% | (c) = (b)+(d) |