# Alternatives for Sodium Hydroxide in Hair Relaxers

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# Abstract

In recent years, lye-based hair relaxers have received media attention for their toxic side effects. However, staff in hair salons, e.g. hair stylists and apprentices, are continuously exposed to hazardous chemicals in hair relaxers. It is also worrying that black women, who are naturally born with curly hair, use hazardous relaxers to achieve a smooth and straight hairstyle, to conform to Western beauty standards and reduce discrimination. Our team has chosen to pursue safer alternatives to the use of lye in hair relaxers due to the hazards associated with its use. As alternatives for Sodium Hydroxide, the chemical that causes harm to consumers and salon workers, we found three chemicals: Thioredoxin, Ascorbic Acid, and Sodium Thiosulfate. With an evaluation of technical performance and hazard assessment of the three, we suggest that Sodium Thiosulfate is the best candidate among the alternatives. Although we have yet to conduct experiments and further analysis including clinical trials is needed, we believe that we are taking a step forward to environmental justice for personal care products.

# I. Introduction

Sodium hydroxide has been a major chemical in hair relaxers, known as "lye". Its main role in hair relaxers is to break disulfide bonds in hair "to alter the curl pattern of the hair[1]," alongside other hydroxides.[2] While it is widely used and plays a key role in the relaxers, sodium hydroxide may increase the risk of breast cancer[3], especially for Black women. Although there is no clear explanation on why "Black women are more likely than white women to develop highly aggressive breast cancers that have higher mortality rates,[4]" there seems to be a link between lye-relaxer and the disease rate.

> Using these data in our own study, my team of epidemiologists and I found that Black women who used hair products containing lye at least seven times a year for 15 or more years had an approximately 30 percent increased risk of estrogen receptor positive breast cancer compared with more infrequent users.

Even no-lye relaxers which do not contain sodium hydroxide still contain harmful chemicals such as calcium hydroxide and lithium hydroxide. Several lawsuits over such products have been filed and various campaigns to reduce the usage of lye relaxers are ongoing.

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[1] *Types of relaxers*. Knowing Different Types of Hair Relaxers | Design Essentials. (n.d.). Retrieved March 8, 2023, from https://designessentials.com/types-of-relaxers/

[2] Sishi, V. N. B., Van Wyk, J. C., & Khumalo, N. P. (2019). The pH of lye and no-lye hair relaxers, including those advertised for children, is at levels that are corrosive to the skin. *South African Medical Journal*, 109(12), 941–946. doi:10.7196/SAMJ.2019.v109i12.14010

[3] Florence T. M. (1980). Degradation of protein disulphide bonds in dilute alkali. *The Biochemical journal*, 189(3), 507–520. https://doi.org/10.1042/bj1890507

[4] Patricia F Coogan, Lynn Rosenberg, Julie R Palmer, Yvette C Cozier, Yolanda M Lenzy, Kimberly A Bertrand. (2021). Hair product use and breast cancer incidence in the Black Women's Health Study, *Carcinogenesis*, 42(7), 924–930. https://doi.org/10.1093/carcin/bgab041

In this status quo, the necessity of finding alternatives for sodium hydroxide has dramatically increased.

Some might argue that the solution is the discontinued use of hair relaxers altogether, however, this argument is dangerous because it disregards that as a society, we are to blame for black women needing to use hair relaxers. The discrimination faced by black women for their natural hair is the reason why so many seek the use of hair relaxers.[5] There are valid arguments that refusing to use these products and embracing natural hair styles will lead to normalization and the loss of an expectation of conforming to Eurocentric beauty standards, but even with these arguments in place, not everyone is going to stop using the products. Socially we need to move to a place where all hair types are respected and celebrated, but until that can happen there needs to be a safe way to relax hair.

# II. Approaches

The harmful function of sodium hydroxide is to destroy organic tissue. It is a popular strong base used in industry. Specifically regarding hair relaxers, it penetrates the cuticle of the hair to perform controlled damage on the hair's protein structure. It breaks disulfide bonds that cause a curve in the normally linear protein chain, and temporarily alters the structure of the hair (from coiled or curly to a more relaxed state). The strong basicity of the compound may cause skin sensitization and irritation with prolonged exposure. Considering the hazard of the chemical, we suggest several alternatives: Thioredoxin, sodium thiosulfate, and ascorbic acid.

## Thioredoxin

Thioredoxins (TRX) are small ubiquitous redox proteins that play key roles in redox signaling and oxidative stress responses[6]. Trx uses its cysteines to break disulfide bonds in oxidized substrate proteins.

In the first step, an intermediate thioredoxin-protein complex is formed, which is broken in the second step, releasing the substrate protein in its reduced state. In other words, the disulfide is being transferred from the substrate protein to thioredoxin, or the electrons coming from thioredoxin are shuttled to the protein substrate.

Hence, it is expected that Trx may be a possible alternative of NaOH in that both chemicals function in a similar way.

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[5] Wilcox, Amanda. Femininity, Hair Relaxers, and the Impact of Beauty Standards on Black Women's Health. (2017) *Center for the Study of Women, UCLA*, https://csw.ucla.edu/2017/10/27/femininity-hair-relaxers-impact-beauty-standards-black-womens-health/.

[6] Michelet, L., Zaffagnini, M., & Lemaire, D. (2009). Chapter 11 - Thioredoxins and Related Proteins. In E. H. Harris, D. B. Stern, & G. B. Witman (Eds.), *The Chlamydomonas Sourcebook (Second Edition)* (Second Edition, pp. 401–443). doi:10.1016/B978-0-12-370873-1.00019-8

### Ascorbic Acid

Based on the fact that breaking disulfide bonds is a reduction, we suggest a reducing agent that may replace NaOH in hair relaxers, ascorbic acid (vitamin C). With its ability to cleave the disulfide bond including various types of proteins such as tubulin, tau and microtubule-associated protein-2[7], we added the chemical to the candidates for possible alternatives.

### Sodium Thiosulfate

Along with ascorbic acid, we suggest another reducing agent, sodium thiosulfate. Considering that it is already in use for medical purpose[8], sodium thiosulfate may be a relatively safe candidate among reducing agents. This material is used in many applications including in medicine.

# III. Inspiration

### Thioredoxin

The inspiration for thioredoxin came from an enzymatic approach. Throughout the human body, millions of reactions are occurring at any given time which all require an enzyme in order to be performed at the body's standard chemical conditions. Many of the reactions done in the body can be done outside of the body, but with stronger chemicals. Most of the time these chemicals and methods are too extreme for the human body. Sodium hydroxide is the chemical used to break disulfide bonds, but it is also strong enough to damage the scalp. If a human enzyme was found that could break disulfide bonds it would be used in hair and break disulfide bonds at conditions that are safe for the body. Thioredoxin is one of the human enzymes that can break disulfide bonds. The logic behind this choice is that because it's a macromolecule already produced by the human body with a very specific purpose it could be safe for the scalp without causing unwanted side effects.

### Ascorbic Acid

For the second approach, a chemical was desired that had reductive properties, but also antioxidant properties. Oxidation is one of the ways DNA can be damaged which causes cancer. Ascorbic acid is one of the essential nutrients needed by our immune system. These properties are the reason why the team came sought out ascorbic acid also known as Vitamin C. In the simplest terms, an antioxidant is a reducing agent. This means that it could be used to reduce

[7] Giustarini, D., Dalle-Donne, I., Colombo, R., Milzani, A., & Rossi, R. (2008). Is ascorbate able to reduce disulfide bridges? A cautionary note. *Nitric Oxide*, 19(3), 252–258. doi:10.1016/j.niox.2008.07.003

[8] Sodium thiosulfate (NA2S2O3) [hypo solution formula] - properties, sodium thiosulfate formula, Structure & Uses of sodium thiosulfate. BYJUS. Retrieved April 6, 2023, from https://byjus.com/chemistry/sodium-thiosulfate/

disulfide bonds in curly hair. Likewise, because it's an antioxidant it could also provide some protection against DNA damage and at the very least not be harmful to human health. It is also the only strategy that is being considered that is an acid.

### Sodium Thiosulphate

The inspiration for the last strategy came from medicine. The logic was that if there is a medicine already approved by the FDA that has reductive properties then it could also be safe for cosmetic use because it would already have undergone extensive testing by the FDA. The chemical sodium thiosulfate was chosen for these reasons. It's the active ingredient in the medication Pedmark which is used to treat children going through chemotherapy against ototoxicity. Chemically it's a reducing agent so it will break disulfide bonds in hair and straighten it. Based on the fact that its already FDA-approved it is very likely that it will be a safe alternative to sodium hydroxide.

# IV. Technical Performance

Bad Actor: Sodium Hydroxide

Sodium hydroxide is able to quickly and effectively break disulfide bonds in hair through a pH-driven beta-elimination mechanism[9]. This works by the introduction of a high concentration of hydroxide ions into solution which then interact with the cysteine-cysteine disulfide bonds indirectly by transferring electrons to the carbon adjacent to one side of the disulfide linkage, then through subsequent electron transfers the sulfur-sulfur bond is broken[9]. Next, the extra electron density in the attacked cysteine's sulfur atom leads to the breaking of the sulfur-carbon bond and the sulfur atom eliminates from the molecule, resulting in a structure which cannot re-form a disulfide bond due to the lack of a sulfur atom in the protein residue[9]. This results in a long-lasting hair straightening result due to the irreversibility of this mechanism[9].

Strategy 1: Thioredoxin

Thioredoxins are enzymes of generally similar composition, with variation depending on species, which are unified by the function of reducing cysteine-cysteine disulfide bonds, which form

[9] Trivedi, M.V., Laurence, J.S., Siahaan, T. (2010). The role of thiols and disulfides on protein stability. Current Protein and Peptide Science, 10(6):614-25. DOI:10.2174/138920309789630534

linkages in proteins, to individual cysteine thiols[10]. Synthetic human thioredoxin is the most likely to be safe for human health, as it exists within T-cell structures in the human immune system as well as many other key protein regulation systems[10]. Since the function of sodium hydroxide is to cleave cysteine-cysteine disulfide bonds in hair proteins, it makes sense that an enzyme which performs this exact same function with the same amino acid residue in different proteins encountered by the immune system could potentially be effective when applied to hair proteins.

Enzyme-substrate compatibility is the first major unknown that would need experimental data to resolve. If the hair proteins are compatible with thioredoxin, the enzyme must be capable of performing the reduction sufficiently rapidly that it can be applied and removed within a similar time frame as currently available hair relaxer treatment sessions. Another potential issue is compatibility and storage – like many enzymes, thioredoxin functions best at physiological conditions, and generally does not perform well (or at all) in other conditions owing to temperature-driven and pH-driven protein denaturation[11]. For this reason, temperature and pH need to be tightly controlled to prevent denaturing of the enzyme[11]. Recent advancements in enzyme stabilization technology, such as the formation of single enzyme nanoparticles, enables substantial stabilization of enzymes without having to compromise enzyme effectiveness or dramatically slow down enzyme activity, but the technology is still being developed[12]. Finally, the enzyme, whether stabilized as nanoparticles or through deposition onto a carrier matrix, must be compatible with the other ingredients in the existing formulation. It would probably make sense to build an enzyme-based hair straightening product from the ground up, starting with the enzyme and the conditions needed for it to remain functional and shelf-stable, and expanding outward from that to only include additional ingredients which do not hinder these functional needs.

Strategy 2: Ascorbic Acid

Ascorbic acid is a small organic molecule which is an essential nutrient in the human diet. It is a mild reducing agent and finds applications in metallurgy as well as photography. The key factors for technical performance of ascorbic acid as a hair relaxer are dependent on its ability to reduce cysteine disulfide bonds in a sufficiently rapid manner without relying on hazardous conditions to enable the reaction. Experimental evidence indicates that under certain conditions, particularly with high pH and high concentration of the ascorbate ion, disulfide bond cleavage is possible[7]. The data from Giustarini, et al (2008) indicates that increasing the pH increases the

[10] Nakamura, H., Nakamura, K., & Yodoi, J. (1997). Redox regulation of cellular activation. Annual Review of Immunology, 15(1), 351-369. https://doi.org/10.1146/annurev.immunol.15.1.351

[11] Lee, S., Kim, S. M., & Lee, R. T. (2013). Thioredoxin and thioredoxin target proteins: from molecular mechanisms to functional significance. Antioxidants & redox signaling, 18(10), 1165–1207. https://doi.org/10.1089/ars.2011.4322

[12] Chapman, R., & Stenzel, M. (2019). All wrapped up: Stabilization of enzymes within single-enzyme nanoparticles. J. Am. Chem. Soc. 2019, 141, 7, 2754–2769. https://doi.org/10.1021/jacs.8b10338

rate of disulfide cleavage with ascorbate ions, but that even under the harshest conditions, complete cleavage of disulfide bonds on amino acid residues requires up to 3 hours[7]. This probably rules out ascorbic acid as an effective replacement for sodium hydroxide, but experimentation with hair samples and a variety of pH conditions could rectify this. It could also be that since ascorbic acid is not hazardous on contact with skin, a formulation designed around a hair straightening process with an application phase followed several hours later by a removal and washing phase could be co-developed, but this would make the product useful only in at-home application rather than being useful as a replacement for salon-use products.

Strategy 3: Sodium Thiosulfate

Sodium thiosulfate is a reducing agent which is used as a fixer in silver-based photography applications[8]. The thiosulfate ion is the substrate of an enzyme of the cytochrome group[13]. Thiosulfate is oxidized to the S-thiosulfonate ion by the action of a cysteine disulfide bond present in the enzyme[13]. In this case, the cysteine disulfide linkage is viewed as an oxidant, but generally with reduction-oxidation reactions, it can be viewed from the perspective of the thiosulfate ion behaving as a reducing agent upon the disulfide bond. Since the interaction between thiosulfate and cysteine-cysteine disulfide bonds is already known, and thiosulfate doesn't have the conformational limitations present in enzymes, it seems that this option is very likely to be a viable and effective option. Some hazards exist, such as the reaction with dilute acids to form sulfur dioxide, a toxic and hazardous gas[8]. For sodium thiosulfate to function well as a hair relaxer, it would need to be effective at reducing cysteine-cysteine disulfide bonds in hair proteins, which seems likely, and it would need to do so in a time frame similar to currently existing hair relaxers. The compatibility of thiosulfate ions with existing formulations based around sodium hydroxide is of potential concern since sodium hydroxide is so strongly basic that formulation chemists would not be concerned with adding acidic ingredients, as they would have practically no influence on the overall pH of the product, but which would produce toxic by-products if combined with sodium thiosulfate. The functionality of thiosulfate as a hair relaxer is supported by a currently expired patent filed in Canada in 1999[14]. This patent claims that an alkali thiosulfate combined with a carboxylic acid to bring the pH to around 3.5, and a catalyst containing a transition metal chloride or an alkaline earth metal chloride, effectively straightens curly hair[14]. The use of an acidifier indicates that the patent formulation is not safe for use in an enclosed space such as a hair salon, and the inclusion of a catalyst indicates that thiosulfate alone will not straighten hair in a similar time frame as currently existing hair relaxers. A formulation similar to this could potentially be modified component-by-component until it does produce good results in a reasonable time, but this would probably require extensive experimentation.

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[13] Grabarczyk, D.B., Chappell, P.E., Eisel, B., Johnson, S., Lea, S.M., Berks, B.C. (2015). Mechanism of thiosulfate oxidation in the SoxA family of cysteine-ligated cytochromes. J. Biol. Chem,290(14), 9209-9221. https://doi.org/10.1074%2Fjbc.M114.618025

[14] Thomas, Lillie C. Gradual hair relaxation composition. CA002359605A, 1999-12-02.

Comparison: Sodium Hydroxide vs Reducing Agents

Sodium hydroxide treatment of hair cleaves the disulfide bridges through three mechanism pathways, which leads to three products (figure 1). The sulfur group is missing on the attacked cysteine residue in two of the three products, which prevents the subsequent formation of disulfide bonds with the affected residues[9]. The reduction of disulfide bonds with reducing agents generally leads to a symmetrical product, with each amino acid residue retaining its sulfur atom as a thiol group which can react with other thiol groups in oxidative conditions to form a disulfide bridge[9]. This indicates that reducing agent treatment of hair is likely to be more readily reversed than sodium hydroxide treatment, meaning that the alternatives we are proposing will likely need to be applied more frequently than sodium hydroxide treatments to maintain the same result over time.

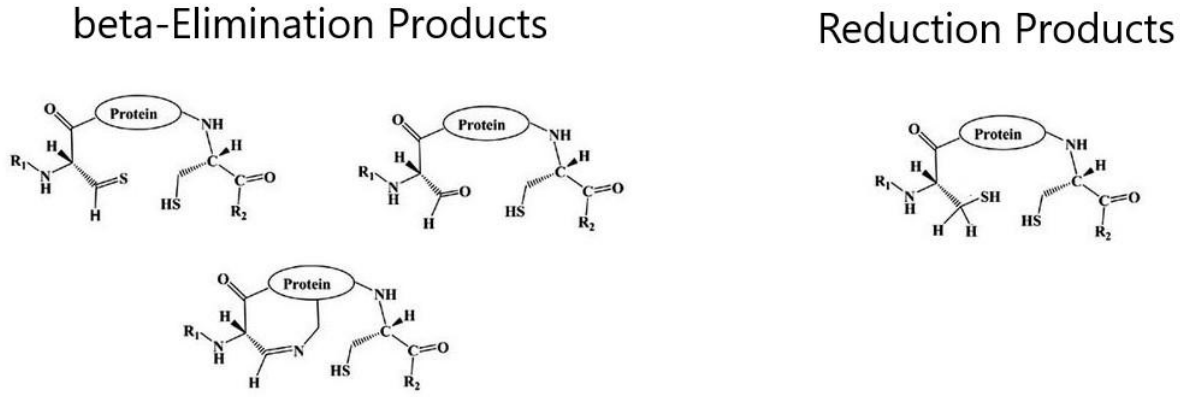


**Figure 1.** Comparison of the reaction products resulting from sodium hydroxide treatment with the products resulting from reducing agent treatment. Modification of work by Trivedi, M.V., Laurence, J.S., Siahaan, T. (2010)[9].

Comparison: Thioredoxin, Ascorbic Acid, and Sodium Thiosulfate

Of the three reducing agents we selected for closer examination, thioredoxin likely has the greatest selectivity owing to the nature of enzyme-substrate compatibility which maintains specificity for the target bond in the substrate based spatial conformation[11]. Ascorbic acid has the second greatest selectivity based on a consideration of its reduction potential and the experimental evidence linking it to extremely slow disulfide bond cleavage (table 1). Sodium thiosulfate is the strongest reducing agent of the three, with a strongly negative reduction potential, indicating that the rate of disulfide bond cleavage will be higher with sodium thiosulfate than ascorbic acid, but this might introduce non-target changes in hair chemistry which may or may not be detrimental to its applicability as a hair straightening agent (table 1). A comparison of bond dissociation energies, the amount of energy needed to break a chemical

bond, shows that the sulfur-sulfur bond is the weakest bond in our target proteins if we only consider carbon, nitrogen, oxygen, hydrogen, and sulfur (figure 2). The second weakest bond is the carbon-sulfur bond, which indicates that a lack of selectivity in the reducing agent applied to hair is likely to result in the breaking of the carbon-sulfur bond, which would then induce the desired irreversibility of disulfide bond cleavage that initially appears to be a disadvantage of using reducing agents over using sodium hydroxide (figure 2).

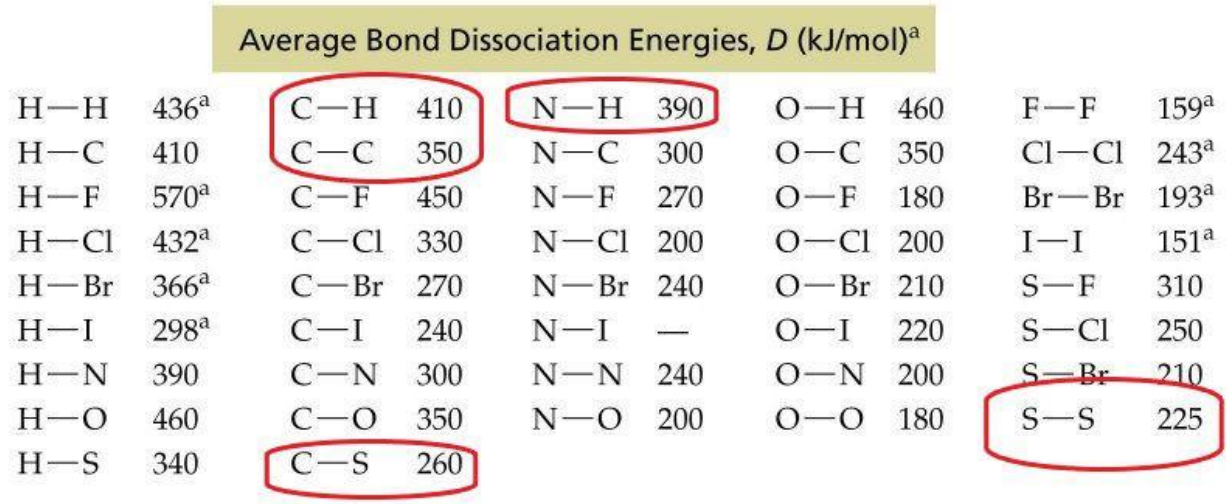


**Figure 2**. Comparison of bond dissociation energies with relevant bonds highlighted. Modification of work by Johnston, Milt[15].

| Reducing Agent | Standard Reduction Potential (vs SHE) |
|---|---|
| Human Thioredoxin → Transition State | -0.230 V[16] |
| Ascorbic Acid → Ascorbate | -0.081 V[17] |
| Sodium Thiosulfate → Thiosulfonate | -1.07 V[18] |

**Table 1**. Standard reduction potentials of the three proposed reducing agents.

[15] Johnston, Milt. https://a13-31116394.cluster13.canvas-user-content.com/courses/986898/files/31116394/course%20files/003%20Chapter%209%20Chemical%20Bonding%20I%3A%20%20Lewis%20Theory/Bond%20Dissociation%20Energies/Bond%20Dissociation%20Energies.html?download=1&inline=1 . Accessed April 28,2023.

[16] Watson, W.H., et al. (2003) Redox Potential of Human Thioredoxin 1 and Identification of a Second Dithiol/Disulfide Motif. J. Biol Chem, 35 (29), 33408-33415. Doi: 10.1074/jbc.M211107200

[17] Borsook, H., and Keighley, G. (1933). Oxidation-reduction potential of ascorbic acid (vitamin C). Proc Natl Acad Sci, 19(9): 875–878. doi: 10.1073/pnas.19.9.875

[18] Das, T., Huie, R. and Neta, P. (1999) Reduction Potentials of SO3-, SO5.-, And S4O6.3- Radicals in Aqueous Solution. Journal of Physical Chemistry A (Accessed May 2, 2023)

# V. Health and Environmental Performance

To evaluate the health and environmental performance of the three alternatives, it is crucial to compare the strength, i.e., health and environmental advantages; and weakness, i.e., hazards, Pharos was extensively used for searching and compiling hazard information of the three alternatives. To start with, the hazard table of the three proposed alternatives is as follows.

| | Group II and II* Human | | | | | Ecotox | Fate | |
|---|---|---|---|---|---|---|---|---|
| **Strategy / Inspiration** | **Acute Toxicity** | **Systemic Toxicity (Single Exposure)** | **Skin Sensitization** | **Skin Irritation** | **Eye Irritation** | **Acute Aquatic Toxicity** | **Persistence** | **Bioaccumulation** |
| Thioredoxin | pC | - | - | pC | pC | pC | - | pC |
| Ascorbic Acid | - | - | - | - | *H* | - | - | - |
| Sodium Thiosulfate | - | pC | *H* | *H* | *H* | *H* | *vH-H* | - |

Table 2. Hazard assessment for the three candidates

## Approach #1: Thioredoxin

### Strengths

First, thioredoxin is an enzyme, which is not consumed after the course of reaction. This implies that only a small amount of thioredoxin is needed in hair relaxers. This reduces chemical waste produced. Also, the optimum temperature for enzyme stability is moderate, otherwise enzymes would be denatured by heat. This means extra heating is not required, which reduces energy use. All these satisfy the principles of green chemistry.

### Weaknesses

According to the *Cayman Company Safety Data Sheet*, thioredoxin is potentially harmful when inhaled. It may potentially cause skin irritation (H315) and serious eye irritation (H319). Potential harm to aquatic life in the short term (H402) and with long-lasting effect (H412) could be possible. However, it is important to note that all the hazards information determined are of low confidence. This means scientists are unsure whether such hazards exist.

### Conclusion

While thioredoxin has some environmental advantages, its exact hazards to humans and the environment are yet to be determined from more extensive research work. As scientists are

unsure about its harm to aquatic life, thioredoxin should be broken down before discharging into the sea. This may be done by denaturation under strong heating, or chemical denaturation, e.g., with urea. Experiments shall be conducted to determine the optimum amount of thioredoxin that maximizes hair relaxing efficacy, while minimizing hazards caused.

# Approach #2: Ascorbic Acid

## Strengths

Ascorbic acid, also known as vitamin C, is one of the essential nutrients for everyday consumption. It is exempted from REACH Annex IV listing due to intrinsic safety and it is verified as "low Concern" by US EPA - DfE Safer Chemicals Ingredients list (SCIL): Green Circle. As a water-soluble vitamin, Vitamin C is generally well tolerated, with tolerable upper intake level of 2 grams per day[19] , with an oral $LD_{50}$ value is 11.9 grams per kilogram in rat populations.[20] According to GreenScreen Guidance document,[21] this corresponds to low acute mammalian toxicity. Even at ingestion, it is rapidly excreted via urine, and therefore very low acute toxicity is observed. It is reasonable to deduce that at suitable amount, hair/topical application is safe.

## Weaknesses

With reference to the data from German FEA – Substances Hazardous to Waters, there is an unspecified to low hazard of human and aquatic toxicity with persistence and bioaccumulation. Yet ascorbic acid is an acid, which could be corrosive at high concentration. According to data from *GHS – New Zealand*, ascorbic acid possesses high risk of causing eye irritation. However, it is important to note that all the hazards information determined are of low confidence, implying that scientists are unsure whether such hazards exist.

Aside from the hazard concerns, to achieve 80% of bond cleavage, high concentration of ascorbic acid may be required to apply on hair for a long time.[22] Despite being a weak acid, ascorbic acid at high concentration may cause skin and eye irritation. Therefore, it may not be desirable to use ascorbic acid for hair relaxing purposes.

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[19] Institute of Medicine (2000). "Vitamin C". Dietary Reference Intakes for Vitamin C, Vitamin E, Selenium, and Carotenoids. Washington, DC: *The National Academies Press*. pp. 95–185. ISBN 978-0-309-06935-9. Retrieved 2017-09-01.

[20] "Safety (MSDS) data for ascorbic acid". Oxford University. October 9, 2005. Retrieved 2007-02-21.

[21] Heine, L., Rossi, M., Hunsicker, A., & Franjevic, S. (2017, February). Greenscreen for Safer Chemicals Hazard Assessment Guidance. GreenScreen® for Safer Chemicals Hazard Assessment Guidance. Retrieved May 2, 2023, from https://www.greenscreenchemicals.org/static/ee_images/uploads/resources/1_GreenScreen_Guidance_v1.3_1e_2016-7-07.pdf

[22] Giustarini, D., Dalle-Donne, I., Colombo, R., Milzani, A., & Rossi, R. (2008). Is ascorbate able to reduce disulfide bridges? A cautionary note. Nitric Oxide, 19(3), 252–258. https://doi.org/10.1016/j.niox.2008.07.003

### Conclusion

Experiments shall be conducted to determine the optimum amount of ascorbic acid that maximize hair relaxing efficacy, while minimizing hazards caused.

## Approach #3: Sodium Thiosulfate

### Strengths

Sodium thiosulfate is a milder reducing agent comparing to some traditional reducing agents, e.g., ammonium thioglycolate, which according to data from GHS – Australia, has a very high hazard of acute toxicity, and high hazard of skin and eye corrosivity.

### Weaknesses

According to EU – Manufacturer REACH hazard submissions, there is potential concern for causing respiratory irritation. Also, according to data from GHS – New Zealand, there is a high hazard of skin sensitization, skin irritation (H315) and eye irritation (H319). Also, according to EC – CEPA DSL, a high hazard of environmental persistence may be caused. However, it is very important to note that all the hazards information determined are of low confidence. This means scientists are unsure whether such hazards exist.

### Conclusion

There are uncertainties on the efficacy, conditions needed to reduce disulfide bonds. Experiments shall be conducted to determine the optimum amount of sodium thiosulfate that maximize hair relaxing efficacy, while minimizing hazards arise.

# VI. Recommendations

There are numerous factors to take into account when choosing the ‘best’ alternative for sodium hydroxide in hair relaxers. Many different details must be examined to truly make the best conclusion – some of which include safety, efficiency, feasibility, cost effectiveness, and accessibility, as well as a plethora of others. To make a tangible suggestion, one must consider the weight and importance that each factor holds by recalling the overall purpose of our efforts. The foundations of green chemistry suggest that we must prioritize health and environmental safety in our decision-making process. Luckily, all three of our suggested alternatives have a lower hazard profile than the original bad actor, sodium hydroxide. Next, we hope to make sure that our new alternative has a similar effectiveness to sodium hydroxide in both a home and

salon setting, without the high risks. In this case, thioredoxin and sodium thiosulfate look like the most promising options. A final factor we must consider is through an equity lens, making sure that this alternative doesn't result in the product becoming inaccessible or too expensive for the average consumer. With this in mind, it looks like sodium thiosulfate is the best alternative that we have found to replace sodium hydroxide. However, all of these options are still feasible. Through further research and development, we should strive to continue to adapt and refine each strategy to meet the needs of our project. Although sodium thiosulfate is the most viable alternative as of now, each of these strategies have potential. In the future, with further information and iterations of the project, one of the other alternatives may even turn out to be a more favorable possibility.

# Appendices

## 1. Hazard Table

Below is the hazard table for Sodium Hydroxide.

| Common name | CAS Number | Group I Human Endpoints | | | Group II and Group II* Endpoints | | | Ecotoxicity |
|---|---|---|---|---|---|---|---|---|
| | | Carcinogenicity / Mutagenicity | Developmental and Reproductive Toxicity | Endocrine Activity | Systemic Toxicity | Neurotoxicity | Skin, Eye, Respiratory Irritation/ Sensitization | Aquatic Toxicity Acute/ chronic |
| Sodium Hydroxide | 1310-73-2 | - | - | - | M | vH-L | IrS: vH<br>IrE: vH | M |

Table 3. Hazard Table for Sodium Hydroxide

Also, below is the full version of the hazard table for the three candidates. For convenience, we split the table into two.

| Common name | CAS Number | Group I Human Endpoints | | | Group II and Group II* Endpoints | | | |
|---|---|---|---|---|---|---|---|---|
| | | Carcinogenicity / Mutagenicity | Developmental and Reproductive Toxicity | Endocrine Activity | Acute Toxicity | Systemic Toxicity | Neurotoxicity | Skin, Eye, Respiratory Irritation/ Sensitization |
| Thioredoxin | - | - | - | - | pC | - | - | pC (skin, eye) |
| Ascorbic Acid | 50-81-7 | - | - | - | - | - | - | H |
| Sodium Thiosulfate | 7772-98-7 | - | - | - | - | pC | H | H |

Table 4-1. Hazard Table for the Three Candidates

| Ecotoxicity | Fate | | Physical | | |
|---|---|---|---|---|---|
| Aquatic Toxicity Acute/ chronic | Persistence | Bio-accumulation | Reactivity | Flammability | |
| Acute: pC | - | pC | - | - | |
| - | - | - | - | - | |
| H | H | vH | - | - | |

Table 4-2. Hazard Table for the Three Candidates (contd.)

# About Us

**Rigney Miller** is a third year undergrad studying chemistry. He has a strong background in organic synthesis owing to an extensive history as an organic chemistry hobbyist and a year working as a research and development chemist and lab manager at a cannabis extraction company. He contributes to the exploration of reaction pathways that may be applicable to hair chemistry, experimental design, and technical evaluation of our alternative compounds.

**Sarah Hasham** is a third year undergraduate studying environmental science. She has extensive knowledge regarding environmental health, safety, and hazards, and is passionate about discovering greener alternatives to commonly used materials. She also has a background advocating for racial equity through climate justice research. For this project, she hopes to bring an ecologist's perspective to the group, and use her expertise to investigate more into the bio-inspired design aspect of the challenge.

**Minseo Kim** is a third year undergraduate studying computer science. Although her interests are artificial intelligence, specifically natural language processing, she has also taken several courses related to biomedical engineering. With various experiences of projects and research as a developer, she would love to suggest effective co-work tools and methodology. Also, to make up for her short knowledge of chemistry compared to other members, she would like to contribute to the team by doing research and finding quality resources about possible alternatives.

**Andreas Au** is a third year undergrad studying chemistry. His interest is in inorganic chemistry, in particular luminescent metal complexes. He participated in an undergraduate research program in Summer 2021, working on luminescent Pt(II) C^N^N complexes as mitochondria and lysosome bio-labels. With some experience in chemistry and biology, he would contribute to the team by investigating bio-inspired alternatives.

**Christopher Acosta** is a third-year undergrad studying Molecular Cellular Biology with a focus on Biochemistry, Biophysics, and Structural Biology. He has a biological background with knowledge in metabolism and biophysical chemistry which allows him to bring a biomacromolecular perspective to the project. For this project, he hopes to integrate biochemical mechanisms as greener solutions to harmful chemicals.