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Economic Sustainability Analysis of Natural Leather Industry, And Its Alternative Advancements

Yogesh Kumar Satish Kumar
Michigan Technological University, ysatishk@mtu.edu

ECONOMIC SUSTAINABILITY ANALYSIS OF NATURAL LEATHER INDUSTRY, AND ITS ALTERNATIVE ADVANCEMENTS

By

Yogesh Kumar Satish Kumar

A REPORT

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Department of Mechanical Engineering – Engineering Mechanics

Report Advisor: *Dr. Chang Kyoung Choi*

Committee Member: *Dr. Trisha Sain*

Committee Member: *Dr. Sangyoon Han*

Department Chair: *Dr. William W. Predebon*

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List of Abbreviations:

IARC - International Agency for Research on Cancer
NGO - Non-Governmental Organization
CCL - Contaminant Candidate List
BOD – Biological oxygen demand
COD – Chemical Oxygen Demand
VOC - Volatile Organic Compounds
SCW – Skin Cut Wastes
CAA - Clean Air Act
SIP - State Implementation Plan
EPA – Environmental Protection Agency
CWA – Clean Water Act
CERCLA - Comprehensive Environmental Response, Compensation, And Liability Act
NPL - National Priority List
EPCRA- Emergency Planning and Community Right-To-Know Act
SERC - State Emergency Response Commission
NPDWR – National Primary Drinking Water Regulations
LEPC - Local Emergency Planning Committee
SDWA - Safe Drinking Water Act
TSCA - Toxic Substances Control Act
CDC - Centre for Disease Control and Prevention
USHSLA - United States Hide, skin and Leather Association
CCI - Customer Confidence Index
GHG – Green House Gases

Abstract

Leather is one of the commonly worn fashion attires and accessories in the United States. But, despite the prevalence of leather fashion in United States, the annual revenue of leather industry has been decreasing steadily over the years. The purpose of this report is to investigate and discuss the probable reasons for the steady decline in the revenue. The U.S. government, after investigating the negative impact of the conventional leather manufacturing process, passed some environmental guidelines and regulations along the years. We will also discuss how these environmental regulations have been affecting the natural leather industry and also the probable measures taken by the government to stabilize the declining revenue . Synthetic leather, which is an emerging market and an ecofriendly alternative to the natural leather is explained. The future trends in both natural leather and synthetic leather industry are briefly elucidated in this report

1. Leather - An Introduction

Leather is an ancient durable material made by the tanning of animal hide/skin. Leather is obtained from the skins of many animals such as lizards, ostriches, kangaroo, alligators etc. But the most common hide used for the tanning process are from cows. Hides represent the skin of larger animals such as horse or cows. Similarly, the skin of smaller animals such as sheep is termed as skin. Leather is very flexible. It is made by a process which converts the perishable skin of animals into non decaying material called leather. Leather is used to manufacture variety of products such as clothing, automobile parts, furniture book binding, bags etc.

1.1 History of leather

Natural Leather

Natural leather was one of the most ancient items made by humans in order to protect themselves from natural elements. Leather was considered one of the most useful inventions by mankind. Primitive humans hunted animals for food and used their hides or skin to make leather.

Leather making is considered an ancient art which has been traditionally practiced for about 7000 years. Leather tanning process in considered as one of the oldest human activities. Skins obtained from animals were used for clothing or tents. But the skins became stiffer at considerably low temperature and started to rot at high temperatures. Many attempts were made by rubbing them in animal fats which led them to create a more flexible and durable leather material– the first ever tanning process.

Smoking was another process later known as formaldehyde tanning which could have almost certainly been started due to an accident, since the substance is found in the vapors produced by the burning of leaves and branches. As time went by, it was discovered that the rotting process can also be eliminated by drying it in the sunlight or by dehydrating action of salt.

Vegetable tanning is tanning process later discovered which uses the bark of plants such as oak as the tannin. One more method used in the early times was the tanning process making use of alum, a mineral which is widespread in volcanic areas.

All these developments and refinements in the processes, led to the production of very flexible, durable and comfortable leather products which was very much prevalent in the ancient times and it is still continued to this present day. Many such developments were recorded in documents, drawings and archeological findings.

Egyptians attained considerable skill in making leather clothes, gloves, tools etc. Phoenicians made good use of leather by making water bottles from it. During the roman empire, furthermore

improved and efficient tanning techniques were developed which were not developed locally. The leather made by romans were used for footwear and clothing and also used for shields.

In the 8th century, there was the development of production of Cordovan in Spain, a leather type obtained from new progresses in tanning was popular throughout Europe for many centuries. In the 14th century, leather was used along with wood in furniture like chairs, tables, arm setters etc. This was an evidence to the improvement in the craftsmanship of people as centuries passed. Another very important and revolutionary invention in tanning process was the use of rotating drums instead of tanning pits along with the discovery of new tannins.

These innovations drastically shortened the time required for tanning from eight months to few days today. By the end of 15th century, leather was more widespread in many European countries. Operations such as fleshing, splitting and dehairing were performed by machines introduced in the 19th century.

Chemical tanning was introduced at the end of 19th century, which involved the use of chrome salts, oak, hemlock tanbark etc.

1.2 Leather cross section:

The skin which is removed from large animals is referred to as hides. Hide is a unique natural substance that helps animals to protect their internal organs from injuries. Every species' hard skin / fur has its own characteristic traits. They are designed uniquely to withstand external factors such as heat, cold, abrasions etc.

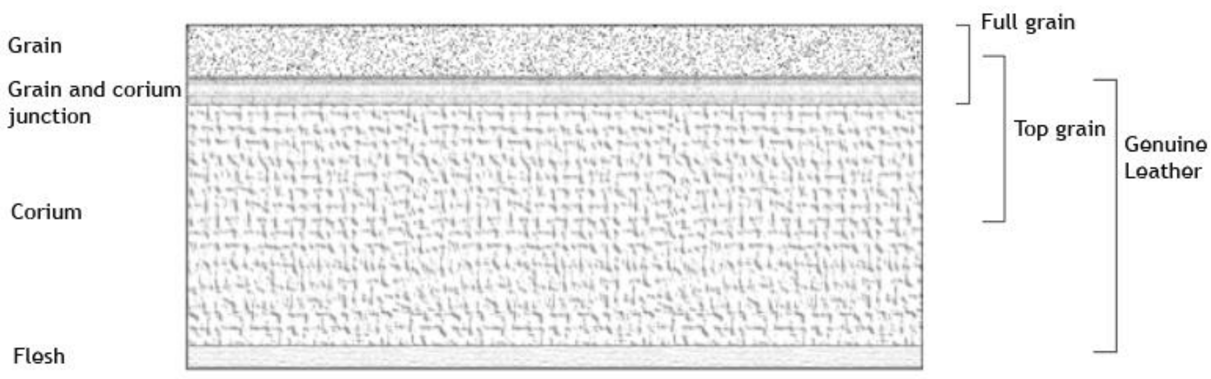


Figure 1 – Cross section of leather. **Source –** Modified from libertyleathergoods.com

The individual layers in the cross section of leather are represented in "Figure 1". The layers from outer surface to the inner surface are grain, grain and corium junction, corium, flesh.

Grain:

The most exterior surface of the leather hide which consists of hairs or fur is called the grain. The grain is the part, which is exposed to the natural elements like wind, rain, heat etc. The hair is commonly removed from the leather hide whereas the fur is commonly not removed for its unique texture.

Grain and corium junction:

This junction is the part where the outer grain of the leather hide blends smoothly into the corium. This layer comprises both grain layer material and fibrous parts of corium.

Corium:

The corium layer is present below the grain layer and is composed of collagen fibers. The corium is the thickest layer in the leather hide. It is the most utilized and useful part for producing leather.

Flesh:

The flesh layer is the layer which consists of the muscles. It does not have much use in the production of leather.

As we have discussed about the layers of a leather hide, we can differentiate the types of leather based on how they are cut, split and finished for production.

1.3 Types of natural leather:

There are 5 categories of natural leather based on the ways the leather has been split and surface treated. In other words, they are represented based on the volume or the layers of the original hide in the end product. The types are Full grain leather, top grain leather, genuine leather, split grain leather, bonded leather.

Full grain leather:

The leather material, which is cut consists of the layer called grain, which is the exterior layer of the leather hide. The external hair is generally removed the layer. The layer is not sanded to eliminate any blemishes. The grain layer has fibers that are closely and densely packed and hence they are very strong and durable. These fibers at the surface provides most of the strength to the leather material. And since the layer is not sanded for removing blemishes, it is more a hard leather than soft.

The leather without many imperfections is demanded most by the consumers since it replicates the originality of the skin. Hence any animal skin which might be torn by unforeseen circumstances

might affect the leather finish. This leather type is considered highest in terms of quality by the customers.

Top grain leather:

Top grain leather is similar to the full grain leather except for the fact that the exterior surface of the leather hide is sanded or sometimes buffed for eliminating any imperfections and blemishes. Variety of dyes are applied to it and this results in the leather becoming a soft leather. The sanding process even though makes it more attractive to human eyes, reduces the strength of the leather compared to the full grain leather. This type of leather is used in daily clothing and accessories like handbags, gloves etc.

Genuine leather:

This leather is also called corrected leather since this leather can be made from any of the layers but with proper finishing and treatment in order to provide a corrected appearance. The layer is also sanded or even buffed to remove blemishes, and this also provides a final uniform and appealing texture. This leather is not considered a very high-quality leather but is used in many accessories such as belts, watch straps etc.

Split grain leather:

If the leather layer within the lower levels of the top grain leather is used, the cut leather is called split grain leather. This layer also produces considerably useful leather material. But the layer is not as useful as the full grain or top grain leather and is comparatively less dense and thick. Due to this factor, this leather is usually used in leather finishes that are colored and has some altered surface. It helps in bringing out some useful qualities of good leather also providing visually attractive texture.

Bonded leather:

Bonded leather is usually made from the leftovers from the manufacturing of real leather. These leftover or scraps are then bond with a polyurethane coating or binder. These scraps in order to bind perfectly, are rolled using adhesives onto a backing. In order to increase the texture of the material, a Polyurethane coating might also be added sometimes. This leather only consists of 10-20% real leather. This affects the properties of the final product both functional and aesthetic.

1.4 Manufacturing process:

Leather making is a very complicated process that requires great skill and expertise. The employers working in tanneries require years of expertise in order to produce a perfectly well manufactured leather material starting from leather hides. Although leather has developed a lot along the years, the primary leather manufacturing process of leather is divided into 3 stages – The preparatory stages, The tanning process, The crushing process. Some of the real leather undergoes a few subprocesses. One of the common sub processes would be surface coating process. The stages of leather manufacture are explained individually in the following sections.

▪ Preparatory stages:

The animal hides are removed from the animals and are carefully prepared before sending them to the tanning process. There is a list of preparatory stages a leather hide goes through before undergoing tanning. During these preparatory stages, most of the undesired skin/hair is eliminated [1]. The preparatory stages include [2],

- **Preservation:** The skin / hide of animals are preserved or cured in order to prevent them from deteriorating before the tanning process begins. Preserving agents like biocides are used sometimes. Salting, chilling etc. are also a few methods of preservation.

- **Soaking:** In order to wash the skin from dirt or salts and rehydrate the leather, soaking process is used. The leather skin loses its water content during the preservation process. These skins are hence soaked in water for several hours or days in order for them to retain the water they had lost.

- **Liming:** The liming process removes the excess hair and also keratinous matter on the skin. Some of the chemical crosslinks of collagen are also broken as a result of alkaline swelling of the pelt due to the liming process [3].

- **Fleshing:** The pelt after liming process is sent through a machine which will remove the fleshy tissue from the side of flesh. Hides might sometimes be split into the layers in this process.
- **Deliming:** Now in this process, the alkali in the leather pelt is neutralized. This avoids rapid changes in the pH value which could lead to the tissue disruption or distortion.

- **Bating:** Based on the final use of the leather, the skin might be treated with specific enzymes to soften them. This process is called bating.
- **Pickling:** The pelt is required to be brought to a weak acidic state for most of the tanning process. Hence salt solutions and weak acids are used for it. In order to preserve the pelts for storage and transport, strong pickling solutions are utilized.

- **Degreasing:** Excess grease is removed by using solvents. The natural oil/fasts must be eliminated before the tanning process.

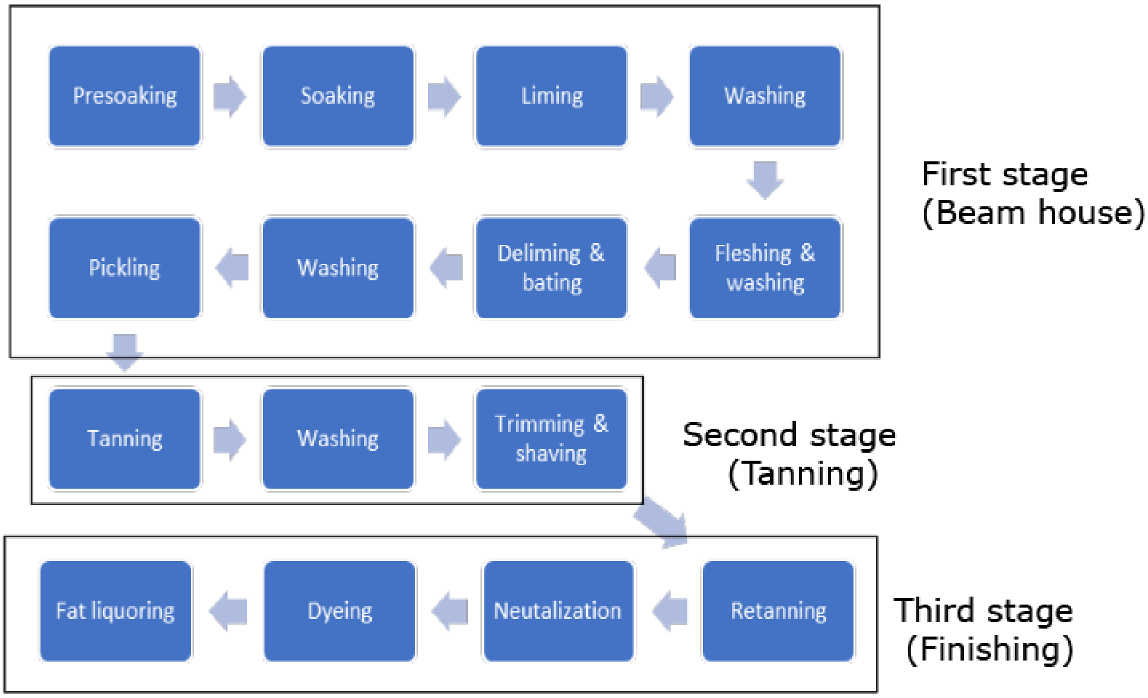


Figure 2 – Manufacturing cycle of natural leather from animal skin.

- ## Tanning Process:

Tanning is the process by which the protein in the hide (raw) is converted into a stable material, which makes it apt for a wide variety of finish products [4]. The reason why the leather is tanned is because, the raw hides when dried over time result in losing its flexibility which could start to decay when its wetted again. Meanwhile when tanned leather is dried out, it maintains its flexibility and when wetted back, it doesn't become putrid. The type of leather tanning process depends upon the type of end product we are trying to achieve. There are three types of leather tanning process – chrome tanning, vegetable tanning, and smoke tanning.

- **Chrome tanning:**

From its name, chrome tanning is used to process the leather using a chemical called chromium (III) sulphate ([Cr (H2O)6]2(SO4)3). This was an ancient method. This method was over the years

replaced my chromium tanning or Chrome tanning in the year 1858 in order to speed up the process and save money for the process [5]. German technologist, Friedrich Knapp and Sweden Scientist, Hylten Cavallin developed the chrome tanning process. But the process was patented by an American Scientist- Augustus Schultz.

The chrome tanning is nothing but processing the leather using chemicals, salts and acids in order to properly dye the skin. This process expedited the time taken to complete the entire steps in a matter of few days.

Characteristics of chrome tanned leather:

- Chrome tanned leather can be produced in a variety of color and texture.
- It is water resistant, heat resistant and also is resistant to stains.
- The color of the leather does not stay the same over time. It slowly evolves into different color.
- It is usually thinner and more flexible than other tanned leather.
- Rich appearance.

- **Vegetable tanning:**

Vegetable tanned leather was more ancient compared to chrome tanning process. It was one of the traditional ways of processing leather before the fastest tanning method. It is a tanning process that involves the use of natural and traditional ingredients as raw materials. Hence, it's an organic tanning method that involves the use of tannins from variety of tree barks, and other plants such as oak, Tara pods, olive leaves, mimosa, quebracho etc. These organic tannins are placed in a pit along with the raw hide/skin. Vegetable tanned leather is less harmful to the environment and it provides a natural look to its end products.

Vegetable tanning has existed for over 5000 years using natural ingredients as tannins. The discovery of Otzi, in the ice of Alps provided enough evidence that variety of leather types were prepared and processed for many uses even before 5000 years. But due to the modernization and use of modern industrial tanning process, only 10 to 15% of leather is being vegetable tanned due to its longer processing time and less monetary benefit.

Vegetable tanning process requires trained and skilled artisans since it is a time consuming and complicated process. The hides are soaked in a large bath consisting of concentrated tannins for several months. This time consumption for leather processing produces a well-made vegetable tanned natural leather. Features of vegetable tanned leather include,

- It develops a neat platina during its life span.
- It gives a soft, natural feel and texture to the user
- This leather is biodegradable and eco-friendly.

- Vegetable tanned leather is hard and thick.
- It has a traditional and ancient approach

- **Smoke tanning:**

This leather tanning process was most approached by North Americans who used smoke to preserve the hides. It was a great development when people realized that leather can also be processed using smoke, ash, quicklime etc. The application of smoke eliminates the hair in the animal skin. It also helps in preventing the leather from becoming hard due to moisture. It provides good water resistance to the surface and leather does not look very dirty due to the dark color of the smoke on the surface.

But in order to process a leather hide using smoke, there are a set of rules that must be followed.

- Hardwood is the best.
- The wood must be decayed or rotten up to an extent where we can easily break the wood with our fingers.
- There should not be any flames. Only low heat is necessary since hide and fire doesn't do well with one another upon contact.
- Time is also an important factor. The time at which the leather is smoked also is based on the quality of leather obtained.

▪ Post tanning process:

- **Splitting and Shaving:**

In this process the thick leather is split into 2 or more pieces using a machine. In that, the layer which has no grain surface will be converted into suede. After the splitting process, shaving is performed to provide the leather with a uniform thickness.

- **Neutralization:**

In this step, the pH value of the leather is increased up to the closest range of 5 – 6.5, preparing it for some other final leather finishing phases.

- **Fat liquoring:**

Fat liquoring fixes the waxes and oil in the fiber of the finished leather. This keeps the leather very flexible with a soft texture and prevents it from drying out completely.

- **Samming and Setting:**

In this process, a huge amount of water content is extracted from the leather. In order to make the grain side smoother, the leather is also stretched out.

- **Drying:**

The leather is even further dried to about 10%- 25% moisture level. Drumming, a common method to do this is used which makes the leather gradually softer by separating the fibers, mostly inside a rotary drum.

- **Finishing:**

Finishing is the final phase of leather processing where any small notable changes/defect are fixed. Some of the changes are uniform color, uniformity in thickness, adding protective layers/coating in order to provide the leather surface better water resistance and abrasion resistance.

1.5 Pros and cons of real leather:

Pros:

- Good real / animal leather has a long-life span, and it gets better as it ages because it acquires a good depth of patina [6].
- Leather is very easy to repair. The maintaining of leather products is also not difficult. It does not require much expenditure for maintenance like laundry, drying etc.
- Leather is more breathable and helps in regulating the body temperature. It holds the moisture away from the skin naturally until it evaporates on the outside.
- Leather is naturally attractive and beautiful which evolves as it ages.
- Leather provides a touch of luxury and radiance on the wearer. Leather is considered as one of the most stylish fabric attires ever made.

Cons:

- Real leather has very less resistance to water and sunlight. It must always be protected from wetness [7].
- Leather is heavy compared to other fabrics. Natural leather is made of animal hides which adds more weight to the product.
- Leather products are more expensive when compared to its non-leather counterparts.
- Real leather production is considered unethical by some people since it involved slaughtering of animals for their hide / skin.

2. Tanning Industry and environmental regulations:

Leather is one of the most traded products in the world. Leather, a byproduct of the meat of animals, is processed in slaughterhouses and tanned in the tanneries. The processed hides are shipped and converted into desired product like jackets, gloves belt etc. in leather manufacturing industries or sold to traders.

The leather hide is sold based on specific terms and measurements. Sometimes the leather hide is measured in terms square meters or square feet and millimeters / used for thickness. Scrap leather is usually sold by considering weight.

2.1 Global Leather production:

The global leather production per year according to a data from 2003 was about 18 billion square feet with an estimated value – 40 billion USD. Almost 60 % of the world's leather requirements is satisfied by developing countries.

Considering how leather, being an important aspect in the fashion industry, it is also important to take into account, the place of its origin. There are hundreds of tanneries in the world having various differences such as scale of production, quality of leather, price, techniques, treatment methods etc. Even though different countries claim to the best in their leather business, some of them really do stand out compared to their competitors across the globe [8]. The list of countries which produces the most leather and are well known for its position in the big leagues are discussed below.

- **China:**

China is biggest producer of hides in the world. Heavy skins which are used in belts, shoes, jackets etc. are produced in China. China has a skin production of 4 million square feet of hides. The country producing the second largest hide supply (Brazil) does not even produce half of China's production capacity. Majority of China's skin is light bovine hide which is more than 2364.7 million square feet annually. Next is the light sheep leather and goat leather of about 1347.3 million square feet per year. It produces almost 201.2 million square feet of bovine skin annually.

- **Brazil:**

Brazil is the second largest producer of animal hide after China. The hide production in Brazil is about 1832.7 million square feet of leather. The majority of production and the biggest contributor to the leather industry in Brazil is light bovine skin of about 1721.5 million square feet. The skin of goats and sheep contribute to 4% which is approximately 67.1 million square feet. Heavy leather contributes to 2% of total hide production.

- **Italy:**

Ranking in the third position is Italy. Italy produces about 1.5 billion square feet of animal hide per year. Majority of the animal hide is light bovine skin with about 1119.3 million sq. feet of hide per year. Approximately 402 million square feet of animal hide which is 25% of total skin production comes from sheep and goats. Heavy skin contributes to 3% of the total animal hide production.

- **Russia:**

Russia is at the 4th position among the largest producers of animal hides. Russia was considered the largest producer of animal skin until 1990s when the production started to decline. Annual production of Russia is 1.4 billion sq. feet of skin. Almost 38.3 million sq. feet of hides, which is 3% of total production is heavy hide. Majority of the production is light skin from bovine animals which is about 1304 million sq. feet. Sheep and goat skins contribute to 8% of total production which is around 118 million sq. feet.

- **India:**

India currently at the 5th position, is now blooming at a faster rate and is almost ready to take up the 4th position in the list. The skin production in India is 1.4 billion sq. feet of hide. Majority is the bovine skin of about 52.4 million sq. feet. One unique trait in India is, unlike other countries, the heavy skins from bovine and the light skins from goats, sheep are almost showing the same figures of 674.25 million sq. feet and 670.85 million sq. feet, respectively. India produces more amount of light leather even compared to Brazil and is only second to China in this aspect.

- **South Korea:**

South Korea standing at the 6th position, produces around 1083.1 million sq. feet of hide per year. The difference in figures between the quantity of light hides and heavy hides is very high. South Korea produces 10.6 million sq. feet of heavy bovine leather and 19.9 million sq. feet of light goat and sheep leather. The bovine animals in South Korea contributes to the skin production of 1052.5 million sq. feet.

- **Argentina:**

Argentina being at the 7th position focuses on production of light skin from bovine animals. It produces around 715.1 million sq. feet of hides per year. Argentina produces 651.4 million square feet of light bovine hide and 35.1 million sq ft of light hide from goats and sheep. Heavy hides contribute to only 28.6 million sq. feet and they are not as popular as light skin production.

- **USA:**

In the list of countries producing the largest amount of animal hides, USA stands in the eighth position producing 669.1 million sq feet of hides. Majority of the production is light bovine leather hide which is around 586.2 million square feet. 61.7 million sq. feet of skin is of light skin from sheep and goat and 23.1 million sq. feet is heavy leather from bovine animals.

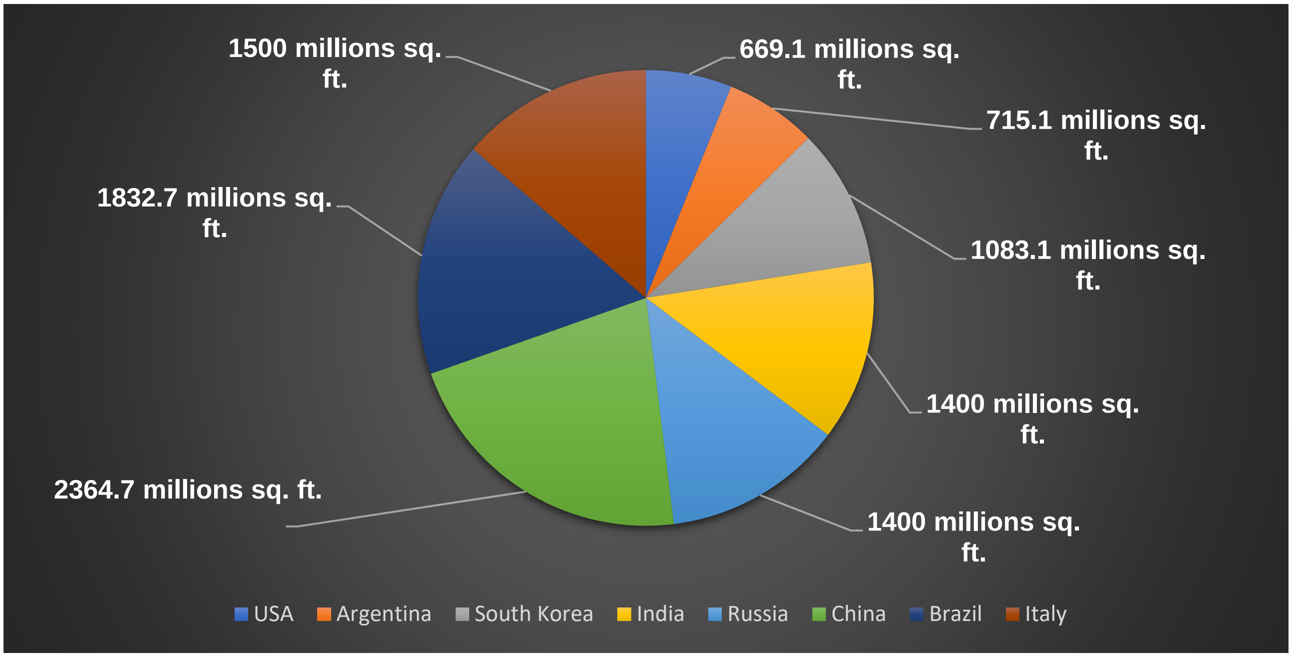


Figure 3 – Major leather producing countries in the world

Source : Modified from Michael, et al. "Top Leather Producing Countries and Industries in Which It Used." *CountriesToday.com*, 8 Apr. 2019, www.countriestoday.com/leather-producing/.

2.2 Tanneries in US:

There are approximately 111 leather tanning and finishing facilities in US [9]. The Figure 4 below gives the breakdown of leather facilities in each state in United States. In the Midwest and Northeast states, such as Pennsylvania, Massachusetts, New York, Michigan, and Wisconsin, the leather tanning and finishing are more prevalent.

However, due to the development of synthetic or artificial leather over the years, the environmental regulations and increased leather imports etc., the number of tanneries has significantly reduced in the last 40 years in Unites States. The leather produces in the domestic tanneries are used for leather bags, shoes, jackets, upholstery etc.

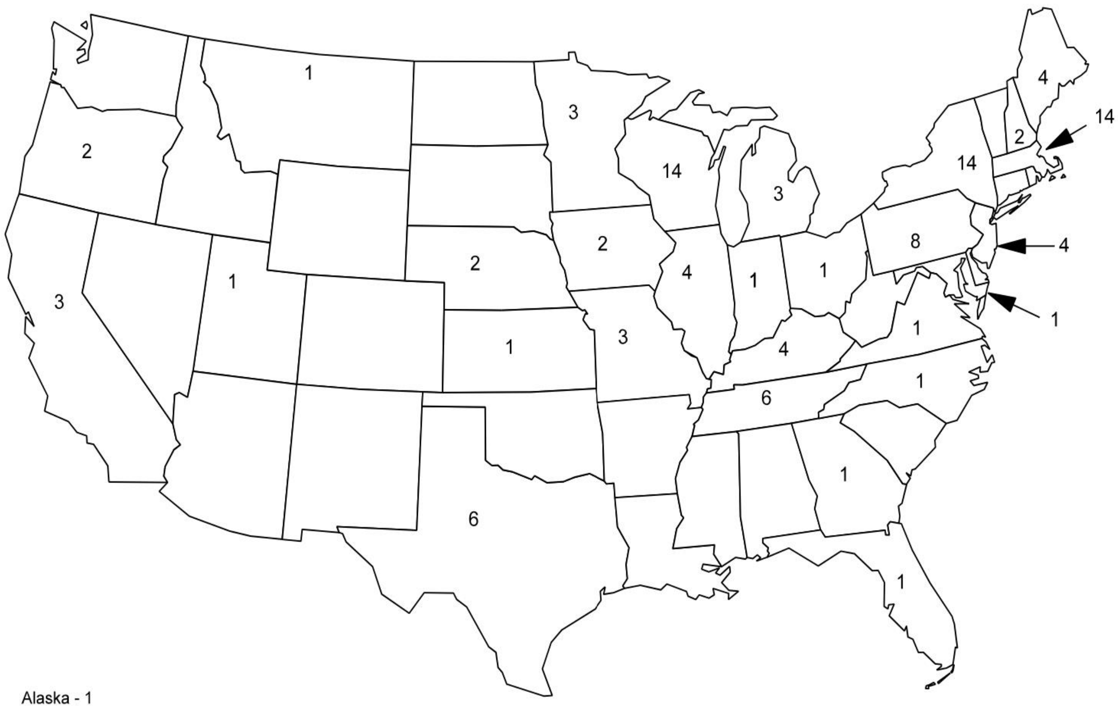


Figure 4 – List of leather facilities in US
Source : 2016 Membership Directory, Leather Industries of America.

Below are the list of leather tanning and finishing companies in United States based on the type of skin or hide used for leather products[10].

Horse, Moose and Deer Hide Companies	**Sheep/Goat Skin Companies**
AJ Hollander Enterprises	AJ Hollander Enterprises
Boston Hide & Furs, Ltd.	Boston Hides & Furs, Ltd.
Ohsman & Sons Company, Inc.	Harland M. Braun & Co.
Quaker City Hide Company	Southern Tier Hide & Tallow, Inc.
Sanimax	
Southern Tier Hide & Tallow, Inc.	
Southwest Hide Company	
West Coast Reduction Ltd.	
Western Hide Company, Inc.	

Bovine Hide, Kip Skin, Etc. Companies	**Pig/Sow Skin Companies**
AB Foods, LLC	AJ Hollander Enterprises
AJ Hollander Enterprises	Boston Hide & Furs, Ltd.
Bank Brothers & Son, Ltd.	CAM Trading Company
Boston Hides & Furs, Ltd.	Central International Co., LLC
CAM Trading Company	D.R. Diedrich & Co.
Cargill Meat Solutions	Eastone Investment Ltd.
Central International Co., LLC	George H. Elliott
Darling Ingredients	Harland M. Braun & Co.
DLP Advisors	Mohawk Trading, Co., Inc.
George H. Elliott	Northwoods Intl, LLC
Harland M. Braun & Co.	Ohsman & Sons Company, Inc.
JBS	Quaker City Hide Company
Mohawk Trading, Co., Inc.	Southern Tier Hide & Tallow, Inc.
National Beef Packing Company	Tyson Foods Inc.
Northwoods Intl, LLC	Western Hide Company, Inc.
Ohsman & Sons Company, Inc.	
Packers Hide Association, Inc.	
Quaker City Hide Company	
Sanimax	
Southern Tier Hide & Tallow, Inc.	
Southwest Hide Company	
Texpac Hide and Skin	
Trans Hide Enterprises	
Twin City Hide, Inc.	
Tyson Foods Inc.	
Union Hide Company	
West Coast Reduction Ltd.	
Western Hide Company, Inc.	

Table 1 - List of leather tanning and finishing companies in United States
Source : 2016 Membership Directory, Leather Industries of America.

2.3 Factors affected by tanneries:

2.3.1 Employee health factor:

The work in tanneries involves random exposure to various toxic chemicals used in the tanning process. Couple of them are suspected to be carcinogens. Among the tannery workers, more increased number of cancers have been reported over the years.

According to the (IARC) International Agency for Research on Cancer, [11] leather processing and tanning process are not related to the carcinogenicity in humans, but the production process involves the exposure of toxic chemicals, where some of them show proof of carcinogenicity in humans. From previous studies, tannery workers have been known to have the potential for occupational carcinogen exposure, such as hexavalent chromium salts, arsenic, organic solvents like benzene, formaldehyde toluene, acetone etc. The two major sources of chromium particulates in the tanneries are chemicals used in the tanning process in the form of Baychrom and $Cr(OH)SO_4$

One of the basic tanning agents, chromium is also available in a trivalent form as chromium sulphate and in organic form and in protein bound form called the leather dust. This leather dust produced by processes like buffing and shaving consists of 3% protein bound chromium. These exposures[12]-[14] have resulted in the development of different cancers including lung, bladder, pancreatic oval cavity, kidney, nasal and soft tissue sarcoma and skin along with dermatitis ulcers, respiratory illness etc.

Arsenic is also one of the common chemicals used in tanneries which is responsible for various cancers to the workers who are exposed to it on a daily basis. Due to these hazardous chemical exposures and its potential negative effects on human health, most of the European countries and US have started to discontinue the production of leather.

Processes	Chemicals used	Purpose
Preparation of the hide for tanning	DDT, zinc chloride, phenols, formaldehyde, mineral oil, arsenious anhydride	Hides are treated for defestation and disinfection
Tanning process	Calcium hydroxide, sodium sulfide, sulfuric acid, formic acid, hydrogen sulfide and solvents such as benzene, ethanol, tetrachloride, trichloroethylene and dichloromethane	For conversion of hides and skins to leather by removing the epidermis and subcutaneous layer and subsequently stabilizing the middle portion of the skin
Finishing process 1. Casein finishing 2. Nitrocellulose finishing.	Formaldehyde as fixer, aniline and resins	Includes coloring and producing surface effects to ensure brightness, softness, elasticity and impermeability

Table 2 – Processes and chemicals used in leather production
Source – Reprinted from "Rastogi SK, Pandey A, Tripathi S. Occupational health risks among the workers employed in leather tanneries at Kanpur. Indian journal of occupational and environmental medicine. 2008 Dec;12(3):132."

2.3.2 Public health:

The groundwater near tanneries become toxic due to the chemical effluents mixing with the water sources and has caused health problems in the residents in surrounding areas. It was found by the US Centers for Disease Control and Prevention that in Kentucky, in the areas around a tannery, incidents of leukemia were five times more than the national average [15].

M. Harun Chowdhury, President of Bangladesh Tanners association, said [16] "Most of the European countries and USA are discontinuing leather processing, as the leather industry is an environmentally hazardous one". Due to this, the people's health in many parts of the world are being threatened by these tanning industries. 90 percent of the leather export in Bangladesh, comes from a slum where the wastewater from tanneries is not even treated. Based on Human Rights Watch Report, these toxic wastewaters flow into the river nearby and, "While the government takes a hands-off approach, local residents fall sick, and workers suffer daily from their exposure to harmful tannery chemicals" [17].
According to a report from Blacksmith Institute, (an NGO to reduce pollution in developing countries) in Ranipet, India, the health of 3.5 million people has been threatened by a factory that produces salts used in nearby tanneries. This group found that the groundwater and land has been

contaminated by the water runoff from the factory. Also, it was reported that local farmers were suffering from skin ulcerations upon contact with the water supply. In 2012, tanneries were listed as number 4 on the top 10 list of worlds "toxic pollution problems" by the institute.

Some studies showed that even the finished leather products, particularly the ones which are in contact with the skins such as gloves shoes etc. consisted of hexavalent chromium – a strong allergen which leads to skin problems such as eczema.

2.3.3 Chemicals in effluents:

The transformation of raw hide into leather requires many chemical and mechanical operations. These operations involve different chemicals in aqueous medium which includes tannins, solvents, acids, natural and synthetic tanning agents, sulfonated oils, auxiliaries, surfactants etc. For every kg of hide produced, the quantity of effluent generated is about 30 liters [18]. There are 3 types of tannery effluents based on the type of operations such as beamhouse operations, tanning and finishing. [BOD – Biological oxygen demand; COD – Chemical Oxygen Demand]

- Process like unhairing and deliming produces wastewater which has high sulfide content and lime content and also has high pH [accounts for 45 percent of volume of effluent and also contributes to 30 percent of overall BOD and COD].
- Wastewater from tanning which has high chromium levels and more salinity.
- Dyeing, Fat-liquoring and Re-tanning wastewater (accounts for 20% of overall COD).

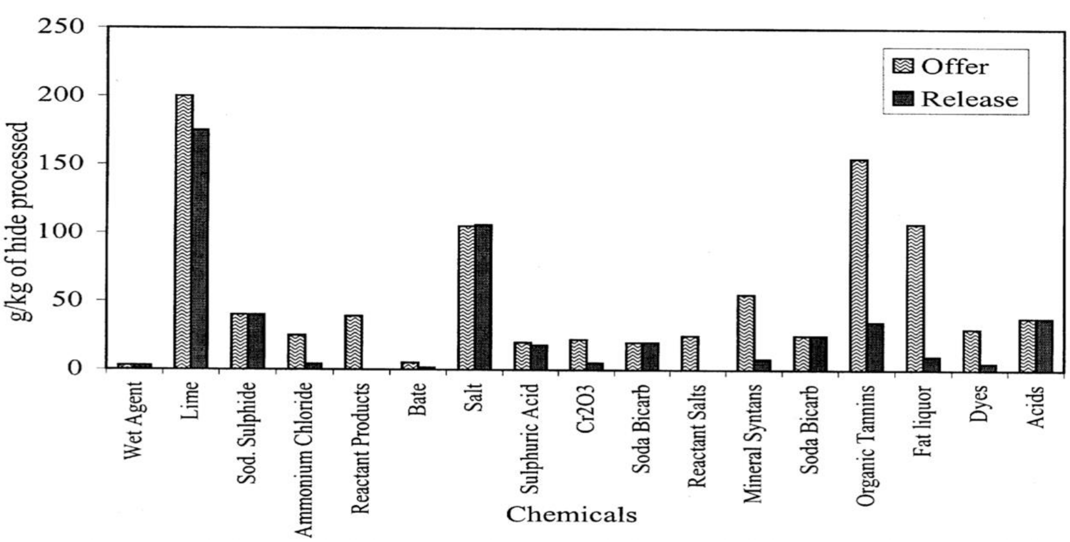


Figure 5- List of chemicals that are offered and released in the hide processing.

Source: Reprinted from "Doble M, Kumar A. Tannery effluent (Chap. 12). Biotreatment of industrial effluents. Butterworth-Heinemann. 2005:133-43."

One of the last operations in the beam house operations involves the treatment of the hide with sodium sulfide and lime as primary chemicals in order to dissolve the hair in the skin. These chemicals are also mixed with the wastewater. Out of all the tanning agents added, 15 percent does not get fixed or attached to the leather and is hence discharged with the effluent. Solid waste, especially trimmings, degraded skin, hair particles from the beamhouse etc. are generated accounting to 70% of the wet weight of the original leather hide.

Process	Water pollutants	Solid Pollutants	Air Pollutants
Liming / Unhairing		Hair, lime, and organic sludge	H_2S
Fleshing	Alkalinity, sulfides, BOD, COD, TDS, SS	Fat containing lime	
Bating / Deliming	BOD, COD, TDS, and Ammonia		NH_3
Pickling			
Degreasing			
Tanning	Vegetable tans, syntans, acidity of added chemicals removed as a waste		
Chrome splitting		Cr containing organic matter	
Re - tanning	Fats, dyes, vegetable tans, Syntans, BOD, COD, DS and SS removed as a waste		
Drying			
Bating / trimming		Formaldehyde and chrome trimming	
Leather product	All other finished agents, formaldehyde and solvents		CH_2O and solvents

Table 3 – List of pollutants involved in the leather processing
Source – Modified from UNEP 1994

2.3.4 Air Emissions:

There are a number of different potential sources of air emissions in leather tanning and leather finishing industry. During finishing processes, due to the use of many organic solvents, emissions of volatile organic compounds (VOC) happen. This also happens during drying process and fat liquoring process. During soaking process in suede leather manufacturing, if the organic degreasing solvents are used, then the VOC may even evaporate to the atmosphere. In order to reduce the VOC emissions, many tanneries are incorporating water-based solvents. Control devices such as thermal oxidizers are not much frequently used to mitigate or reduce the VOC emissions[19].

In wet processing operations such as deliming, unhairing or even drying process, the emission of ammonia may also occur if ammonia is used during coloring in order to aid dye penetration. Sulfide emissions also happens during deliming or unhairing and other subsequent operations. If the pH is less than 8, the alkaline sulfides in wastewater from tanneries can be converted to hydrogen sulfide, which results in the release of this gas. Also, in drying, shaving and buffing operations, particulate emissions might occur.

During chrome tanning, chromium emissions due to chromate reduction, handling of basic chromate sulfate powder, and buffing process; might take place. Trivalent chromium dust emission may occur during storage, handling and mixing of dry chromic sulfate in plants, which purchase the chromic sulfate in powdered form. Chromium containing particulate emission might occur in buffing operation[20].

2.3.5 Animal health and wildlife:

The solid waste such as keratin wastes, skin trimmings, fleshing wastes, chrome shaving wastes, generated from tanneries are commonly used as feed source for poultry. The major component of this waste is protein. This waste is transformed into protein concentrate and it is commonly used in organic fertilizers production, fish feed and poultry feed [21]. The sliced cut pieces of dry hides are known as tanned skin cut wastes (SCW). The SCW is water boiled and dried for a couple of days, then crushed into fine powder to form the protein concentrate. It is mixed with edible products like, ground rice, soya oil cake, dried fish to feed the poultry and fish. Feed manufacturers use SCW as poultry feed because of their high protein content.

Tannery waste consists of complicated mix of both inorganic and organic pollutants which flows directly to the rivers and canals with no treatments. Due to this, heavy metals start to accumulate in the surrounding environment. One of the most widely used meat in the world is chicken and their main source is poultry farms. For almost a decade in Bangladesh, tannery waste in a certain

tanned SCW containing high chromium levels, have been used in the manufacturing of the poultry feed which could be the direct Cr contamination source. The metals which relate to the harmful effects to health are called “Heavy metals”.

	Cr Content (mg/kg)		Cd Content (mg/kg)		Pb Content (mg/kg)	
Sample Group	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
Broiler Chicken						
Liver	0.162	1.260	<0.01	0.037	0.432	0.515
Gizzard	0.216	0.666	<0.01	0.025	0.314	0.827
Meat	0.242	0.721	<0.01	0.016	0.672	0.931
Skin	0.186	0.474	<0.01	0.044	0.573	0.723
Mean	**0.202**	**0.780**	**0.01**	**0.031**	**0.498**	**0.749**
Deshi Chicken						
Liver	0.100	0.712	<0.01	0.027	0.642	0.845
Gizzard	0.252	0.663	<0.01	0.018	0.424	0.823
Meat	<0.100	0.283	<0.01	<0.010	0.293	0.606
Skin	<0.100	0.10	<0.01	0.022	0.257	0.579
Mean	**0.138**	**0.440**	**0.01**	**0.019**	**0.404**	**0.713**
Free-ranging Chicken						
Liver	0.100	1.66	<0.010	0.015	1.673	1.750
Gizzard	0.100	0.926	0.021	0.026	1.270	1.391
Meat	0.134	0.573	<0.010	0.024	1.362	1.565
Skin	0. 216	2.440	0.018	0.032	0.767	0.992
Mean	**0.111**	**1.400**	**0.015**	**0.024**	**1.27**	**1.424**

Table 4 - Ranges of Estimated Minimum and Maximum Cr, Pb and Cd Concentrations in Liver, Gizzard, Meat and Skin of Three Types of Chicken (mg/kg) Fed with Contaminated Feed (Cr=0.98 mg/kg; Cd=0.03 mg/kg; Pb=10.32 mg/kg) for six weeks

Source: Reprinted from “Bari ML, Simol HA, Khandoker N, Begum R, Sultana UN. Potential human health risks of tannery waste-contaminated poultry feed. Journal of Health and Pollution. 2015 Dec;5(9):68-77.”

Metal	Broiler Chicken		Deshi Chicken		Free-ranging Chicken		
	Exposure rate (minimum avg) mg/kg/day	Exposure rate (maximum avg) mg/kg/day	Exposure rate (minimum avg) mg/kg/day	Exposure rate (maximum avg) mg/kg/day	Exposure rate (minimum avg) mg/kg/day	Exposure rate (maximum avg) mg/kg/day	*Permitted Maximum Tolerable Daily Intake by FAO/WHO
Cr	0.006	0.023	0.004	0.012	0.003	0.041	11 mg/kg/day
Cd	0.0003	0.0009	0.0003	0.0005	0.0004	0.0007	0.005 mg/kg/day
Pb	0.015	0.022	0.012	0.021	0.037	0.042	0.005 mg/kg/day

*PMTDI: Permitted Maximum Tolerable Daily Intake a: tolerable intake suggested by the FAO/WHO, #Lenntech (2011), *JOINT FAO/WHO Food Standards Program, Codex Committee on Contaminants in Food, 2011

Table 5 - Minimum and Maximum Average Daily Exposure Value per kg/day Due to Ingestion of Contaminated Poultry [22]
Source: Reprinted from "Bari ML, Simol HA, Khandoker N, Begum R, Sultana UN. Potential human health risks of tannery waste-contaminated poultry feed. Journal of Health and Pollution. 2015 Dec;5(9):68-77."

One part of SCW is mixed with 9 – fold amount of other ingredients to decrease the protein percentage and heavy metal content. But still, prolonged feeding of such feed may result in accumulation of heavy metals in parts of the poultry. Also, the free ranging chickens in the tannery area showed higher contents of heavy metals compared to other types of poultry studied. This might be because they might have been consuming raw waste, water and other discharge in the tannery area. From the studies, it has been proved that the buildup of heavy metals in various edibles of poultry is likely if the feed consists of heavy metals.

This could produce harmful effects not only to the animals but also to the humans consuming them. It has been widely reported that ingestion of heavy metals, which are non- biodegradable, causes numerous serious health disorders in human beings. [23] Long term exposure of Cadmium - a heavy metal which is a mutation and cancer-causing element which causes lethal problems at lower concentrations – through water or air leads to accumulation of Cd in the kidneys.

From the table, we can see that the exposure value of Cr and Cd of free ranging chicken was higher than other poultry but lower than permissible limit. But we can see that the Pd is a major factor to the health risk in chicken and the humans consuming them.

Cd and Pb which are non-essential nutrients causes harmful effects on human and livestock, may accumulate in the body especially in the liver, kidney and even in muscle. Accumulation of Cd has been observed in the ovaries and uteri of dairy cows which may also have a negative impact on reproduction. The effect of Pb is more severe in children and at high concentrations can result in

death due to lead poisoning. Other effects of Pb include never disorders, anemia, neurological damage reduced IQ etc.

2.4 Environmental regulations involving leather industry:

- **THE CLEAN AIR ACT:**

In order to control air pollution on a national level, the US government designed a federal law called the Clean Air Act In 1963. It is one of the earliest and most dominant environmental laws and one of the most widespread and thorough laws based on air quality in the world. It is governed by the US Environmental Protection Agency (EPA) in synchronization with local, tribal and state governments.

The Clean Air Act (CAA) control air pollution. After many amendments, the law was revised and passed with overwhelming support on November 15, 1990, by President George H. W. Bush. It was revised and passed to curb problems such as acid rain, ozone depletion, and toxic air pollution. For stationary sources, it also created a national permit program and also improved enforcement authority. Leather industries generate Hazardous Air Pollutants (HAP) such as volatile organic compounds in organic solvents.

The series of laws passed and amended are,

- 1955 – During this year, Air Pollution Control Act was passed by the Congress in United States.
- 1963 - With $95 million dollars for pollution control programs at state, local and federal level, the Congress passed the Clean Air Act.
- 1967 - In order to authorize planning grants to state air pollution control agencies, Congress passed the Air Quality Act.
- 1970 – Congress passed major amendments to the clean air act, which improved and reinforced the air quality standards in US.
- 1977 - Additional protection for air quality was added by Congress in class 1 national parks wilderness areas.
- 1990 – Additional amendments to improve and enforce the standards for SOx and NOx emissions to control acid rain.

Final Amendments [24] in 1990 to the Clean Air Act of 1970:

- Programs were authorized for air deposition and control.
- Authorized controls for 189 toxic pollutants and created permit program requirements.
- Expanded and modified provisions concerning enforcement authority.

This Act requires the states to establish and develop State Implementation Plans or SIP to show how they will achieve the desired air quality standards by 1977. Hence, even though it's a federal

law governing entire country, most of the work is done by the states in order to carry out the Act. If the state wants to take over obedience or compliance with the CAA, it has to write and submit an SIP to the EPA for their approval. An SIP is a collection of standards and regulations, a state will utilize in order to clean up polluted areas. Each plan must be approved by EPA. If one SIP is not acceptable, EPA can retain the CAA enforcement in that state. But the US government assists every state by providing expert studies, scientific research, designs, engineering designs and money to support the program.

The US government does allow the state regulations to be stricter than the federal regulations except California because of its history with smog pollution in some of the metropolitan areas. Many states or the concerned citizens belonging to that state have established their own set of programs to help improve pollution clean-up strategies. For example,

- California's Clean Air project
- Georgia's clean air campaign
- Illinois citizens for Clean Air and Water – Coalition of farms and citizens to reduce the hazardous effect of large livestock production methods.
- New York's Clean Air NY
- Oklahoma's Breathe Easy
- Oregon's Indoor Clean Air Act
- Texas' Drive Clean Across Texas
- Virginia's Clean Cities

CAA Resources: 40 CFR Parts 50 to 99

- **CLEAN WATER ACT:**

The CLEAN WATER ACT (CWA) is one of the primary federal laws issued by the US government concerning water pollution. The main objective of this law is to maintain and restore the national water's chemical, physical and biological integrity. It also recognizes the responsibilities of the states to address pollution and giving assistance to states who are doing so which also involves funding for publicly owned treatment works for the wastewater treatment improvement [25].

The basis of the CWA was passed during 1948, called the Water pollution control act. This act was reorganized and expanded in 1972 with new amendments. The common name of this Act became Clean Water Act.

The U.S. Environmental Protection Agency (EPA) along with state governments, initially administered these regulations and laws, though some provisions were controlled by U.S. Army Corps of Engineers like dredging and filling.

CWA Resource - 40 CFR Parts 100 to 129 and 400 to 503 (Part 425 provides the effluent guidelines and standards for leather tanning and finishing.)

The CWA introduced a permit system for regulating the point sources of pollution called the National Pollutant Discharge Elimination System (NPDES). The point sources include,

- Industrial facilities [including shipping activities, mining, manufacturing, and gas extraction]
- Agricultural facilities like animal feedlots.
- Municipal government (sewage treatment plants) and other government facilities (military base).

The 1972 CWA established a new requirement for technology-based standards for point source discharges. EPA, based on the performance of the pollution control technologies which disregards the discharge of the pollutants in a particular receiving water body, crafts these standards for discharge categories.

The framework of the CWA includes the states establishing new Water Quality Standards (WQS) for them [26]. WQS are risk-based requirements which set site specific standards or allowable pollutant levels for individual water bodies (lakes, rivers etc.). EPA is required to issue standards for the state if the state fails to issue WQS.

- **COMPREHENSIVE ENVIRONMENTAL RESPONSE, COMPENSATION, AND LIABILITY ACT (CERCLA OR SUPERFUND)**

Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) or the Superfund law of United States was established and enacted by Congress on December 11, 1980 [27]. This law established the federal superfund program which was governed by the EPA. By CERCLA, the EPA gets authorization to respond directly to discharge of hazardous substance which could impact or endanger public health, welfare, or the environment.

There are almost 40000 superfund sites in the country and over 1600 sites among them are listed in the National Priority List (NPL). NPL sites are considered to be highly contaminated that requires long term enquiry and corrective actions [28].

EPA uses Hazard ranking system (HRS) to analyze site score varying from 0 - 100 depending on the amount of hazardous substance released in the site. A score of 28.5 on NPL will render the site eligible for long term remedy.

The primary objective of this law is to decrease the risks to human health and environment through a mish mash of cleanup, engineered controls like caps and site restrictions like the use-restriction

on ground waters. Secondary objective is to return the site to its productive use whether as a business, recreation, or a natural ecosystem. The most important part of this act related to leather manufacturers is the hazardous substance release reporting requirement.

CERCLA permits two types of response reactions,

- **Removal actions –** They are short-term responses taken to address the releases or threatened releases that requires immediate attention or response. They are classified as emergency, critical and non-critical. These removal actions are usually used to address local risks like abandoned hazardous drums or contaminated surface soils which will cause potential harmful effect on human health or the environment.

- **Remedial action –** Remedial actions are long term, larger and expensive actions that looks forward to permanently and significantly reduce the risks associated with the release or threat of release of hazardous substance. These actions might include the preventing the migration of the pollutants after release, combination of eliminating, treating or offsetting the toxic substance. All the actions could only be funded when they are listed in the NPL. But these remedial actions, caused by the responsible parties under consent decrees, may be performed at both NPL and non NPL sites, which are commonly called Superfund Alternative Sites according to the published EPA guidance and policy documents.

- **THE EMERGENCY PLANNING AND COMMUNITY RIGHT-TO-KNOW ACT:**

The Emergency Planning and Community Right-To-Know Act (EPCRA) was created by The Superfund Amendments and Reauthorization Act of 1986. Congress passed EPCRA in November in order to American community to "deal safely and effectively with the many hazardous substances that are used throughout our society" [29]. The main purpose of this act is divided into two.

- Supporting and encouraging emergency planning in order to respond better to chemical accidents.
- Providing information to the local government and public regarding the likely chemical hazards in their communities.

In order to enable the smooth cooperation between industry, absorbed citizens, public-interest organizations, and government at all levels, the Act institutes a local level forum called the Local Emergency Planning Committee (LEPC). The State Emergency Response Commission (SERC) governs the LEPCs in each state.

The primary responsibilities that the LEPCs and SERCs are charged with are,

- To write the emergency plans in order to safeguard public from chemical accidents.
- Create procedures to prevent and if needed, evacuate the public in emergency cases.
- To provide information to the local government and the public regarding the possible chemical hazards in their communities.
- Help and provide support in preparing the public report on the yearly release of toxin chemical into water, air and soil. [30]

The EPA provides a description of the 4 groups of chemicals that needs to be reported under The Emergency Planning and Community Right-To-Know Act.

- **Extremely Hazardous substance:** This list contains about 300 chemicals and due to their high toxic properties, they were chosen to provide a primary focus for chemical emergency planning. These chemicals might be an immediate concern to the community if they had been released at a certain amount.
- **Hazardous substance:** These substances are listed under the prior “Superfund hazardous waste cleanup regulations” (“Section 103(a) of the Comprehensive Environmental Resource and Conservation Liability Act—Superfund”). This register / list consists of almost 720 substances. Immediate reporting must be done in case of release of these substance as they could cause serious health hazards to the community upon release.
- **Hazardous chemicals:** These chemicals are not on any lists, but they are defined as chemicals which represent physical or health hazard by the Occupational Safety and Health Administration
- **Toxic chemicals:** There are around 320 chemicals which were selected by the Congress mostly due to their long-term toxicity. The release of toxic chemicals into the air, water, or land must be reported annually in order to be entered into the national database.

EPCRA resource: 40 CFR Parts 350 to 372

- **SAFE DRINKING WATER ACT:**

The Safe Drinking Water Act (SDWA) is the foremost federal law in US which was passed with the intention of ensuring safe drinking water for public. For all the states, localities and water suppliers, EPA is required to set some standards for the quality of drinking water. The SDWA applies to all public water systems in US. The Act does not include private wells (In 2020, private wells serve 13% of US household). According to a study in 2020, children raised in household having unregulated wells had an increased danger of raised blood lead compared to the wells that were regulated by the EPA [31]. The federal drinking standards are organized into 6 groups:

- **Microorganisms:** EPA has issued some standards for microorganisms like *Giardia lamblia, Cryptosporidium*, coliform bacteria, *Legionella*, and enteric viruses. Plate count and turbidity are two microorganisms related tests to show water quality by EPA.
- **Disinfectants:** Standards for, monochloramine and chlorine dioxide, chlorine [32].

- **Disinfection byproducts:** Standards for chlorite, bromate, halo acetic acid and trihalomethanes.
- **Organic chemicals:** EPA has issued standards for more than 50 chemicals that includes benzene, dioxin, PCBs, styrene, toluene, vinyl chloride and several pesticides.
- **Inorganic chemicals:** Standards has been issued by EPA for antimony, arsenic, asbestos, barium, beryllium, cadmium, chromium, copper, cyanide, fluoride, lead, mercury, nitrate, nitrite, selenium and thallium.

EPA requires the SDWA to identify and list the contaminants which needs to be regulated. Every five years, the Agency must publish the list called the Contaminant Candidate List (CCL). Now EPA has to take a decision whether to regulate at least five contaminants listed.
EPA has developed 4 CCLs as of 2017,

- CCL 1: in 1998, 50 chemical and 10 microbiological contaminants were listed. But in 2003, EPA made a determination that no regulation is required on nine of these contaminants in the list.
- CCL2: In 2005, the remaining 51 contaminants were considered again, and EPA determined that 11 of them required no regulation.
- CCL3: Based on the recommendations from the National Research Council and National Drinking Water Advisory Council, EPA revised the listing. It reviewed 7500 chemicals and microbial contaminants and the list was narrowed to 600 for further evaluation, 104 chemicals, and 12 microbial contaminants had also been registered in 2009. During 2016, 4 of the contaminants in the list were determined to require no regulation.
- CCL4: EPA considered the contaminants in the CCL3 where the determination was not yet made and also requested public opinion on additional contaminants. Totally 94 chemical groups and 12 microbial contaminants were registered in 2016.

The National Primary Drinking Water Regulations (NPDWR) in the future will have standards governing non- transient non-community water systems (office buildings, schools, factories, hospitals etc.) because of long term exposure of a population which is stable.

SDWA Resources: 40 CFR Parts 141 to 148

- **TOXIC SUBSTANCES CONTROL ACT:**

In 1976, the Toxic Substances Control Act (TSCA) was passed by the 94th US Congress and administered by the EPA. The three main objectives if TSCA is to assess and regulate new commercial chemicals before they arrive in the market, to regulate the already existing chemicals in 1976 that posed a risk to the environment and public health, for example PCBs, Lead etc. [33].

TSCA does not identify and separate the chemicals into toxic and non-toxic category. Rather, it prevents the manufacture or the import of the chemicals that are not listed in the TSCA inventory. The Act provides EPA the power to attain information and require producers to test the products. It required the EPA to create a list of the existing chemicals and industries, which provided EPA the ability to regulate the production of new chemicals and its use. Generally, manufacturers have to send or submit pre manufacturing notification to EPA before the manufacturing or the importing of the new chemicals for commerce.

Many Academies, non-government organizations, scientists and also some government agencies have criticized TSCA for not able to successfully regulate the safe use of chemicals that affect public health and the environment. They argue that “the inability to function as intended results from a series of legal, organizational, and political challenges" [34].

Some state governments have established “comprehensive regulatory programs” for more strict control over toxic chemicals as a response to the Congress’ failure on not modernizing TSCA. In states such as Michigan, Connecticut, California, many chemical laws were implemented in order to favor tighter regulations to protect vulnerable populations and the environment from dangerous chemical exposure.

The demand for the sustainable products can improve innovation and also increase investment in new products that will gradually replace the toxic chemicals. Green chemistry is a creative way to deal with chemicals before they become hazardous with a motive of making chemical and products, “benign by design” [35]. According to Safer Chemicals, 18 states have passed 71 chemical laws since 2003. Similarly, in order to increase the innovation and reduce the hazardous substance to human health, California government implemented the California Green Chemistry Initiative (CGCI). The CGNI responds to people’s demand – consumers and environmental groups which demand greener products.

TSCA Resources: 40 CFR Parts 702 to 799

2.5 Effects of these regulations:

- **CLEAN AIR ACT:**

According to a study in 2017, Clean Air Act of 1970 has resulted in 10 % decrease in pollution in all the countries that exceeded the threshold for pollution set by the Act in 3 years since the regulations came into effect. In the same study, it says that this regulation-induced decrease in pollution has helped a lot of workers to work more and earn 1 percent more in their annual earnings. Because the air quality across the US increased, it is estimated that 205,000 premature deaths were prevented along with millions of complications related to raspatory. This resulted in an economic saving of $50 trillion compared to the amount invested in the Clean Air Act standard – $523 billion.
Automobiles, trains, boat engines have become 90% more cleaner for pollutants such as carbon monoxide, nitrogen oxides, hydrocarbons etc. [36] Also, the allowable VOC emissions, carbon monoxide, nitrogen oxides and lead from cars, has been decreased by 90% which resulted in decrease in the national pollutant emission despite an increase of yearly total driven miles by 400%. Since 1980, Quarter of the ground ozone level has been cut and mercury emission have been reduced by 80%.

[37] A 2018 study showed that, between 1980 and 2008, Clean Air Act contributed to 60% decrease in the pollution emission by the manufacturing industries.
According to EPA, the 1990 CAA amendments has prevented or will prevent-

	Year 2010 (cases prevented)	Year 2020 (cases prevented)
Adult Mortality - particles	160,000	230,000
Infant Mortality - particles	230	280
Mortality - ozone	4,300	71,000
Chronic Bronchitis	54,000	75,000
Heart Disease - Acute Myocardial Infarction	130,000	200,000
Asthma Exacerbation	1,700,000	2,400,000
Emergency Room Visits	86,000	120,000
School Loss Days	3,200,000	5,400,000
Lost Work Days	13,000,000	17,000,000

Table 6 - Health benefits of the Clean Air Act programs that reduce levels of fine particles and ozone. [24]
Source: Reprinted from "Clean Air Act of 1963." *Wikipedia*, Wikimedia Foundation, 23 Feb. 2021, en.wikipedia.org/wiki/Clean_Air_Act_of_1963.

- **CLEAN WATER ACT:**

According to a 2018 study, which is the first comprehensive study of water pollution over the past decades conducted by researchers at UC Berkeley and Iowa State University, the Clean Water Act of 1972 has propelled several substantial improvements in U.S. water quality [38]. This team evaluated data from 50 million water quality measurements, which had been collected at 240,000 monitoring sites in U.S. between 1962 and 2001.

Majority of the 25 water pollution measures showed improvement that includes the dissolved oxygen concentration increase and decrease in fecal coliform bacteria. Between 1972 and 2001, the share of rivers safe for fishing increased by 12%.

Clean Water Act (CWA) is considered to have a strong rationale. Many rivers before 1972 were so polluted to the point that they would catch fire. Despite this, there are many controversies surrounding CWA. One of the controversies is that the benefit of the CWA act does not outweigh the cost of enacting it.

Despite good improvements in the quality of water, almost all of 20 recent economic analyses estimate that the economic benefit does not outweigh the total cost. This is contrary to the Clean Air Act in which the economic benefit greatly exceeds the cost associated with enacting the act. This analysis sis performed because adding up the cost and benefit - both monetary and non-monetary – of a particular policy is one of the ways to estimate its efficiency and effectiveness.

The entire cost associated with an environmental policy such as CWA will include direct expense, such as the $650 billion spent due to grants in municipalities, indirect investments that include such as cost t companies in order to improve wastewater treatment. The benefits here can include decrease in the travel to find a good fishing spot or a swimming spot, increase in pricing of waterfront house.

The researchers carried out their own cost-benefit analysis of CWA municipal grants and combined with 19 analyses conducted by EPA and other hydrologists. It was found that, on average, the calculate economic benefit were less than half of the entire cost.

But it is stated that many of these studies count very little or no benefit of restoring and cleaning of the lakes, rivers, for human health because it is assumed that if they consume the water, it goes through a separate purification process. Also, drinking water treatment plans test for hundreds of different chemicals and the United States industry produces over 70,000 chemicals. Hence there is a possibility that existing studies do not calculate or measure, that have relevant consequences for human well-being.

- **TOXIC SUBSTANCES CONTROL ACT:**

The TSCA (Toxic Substance Control Act) granted the responsibility to EPA to make sure that chemical in manufactured products is safe. But over time, the TSCA was deemed to be a failure. Firstly, TSCA overlooked more than 60,000 chemicals which were already in use prior to 1976, from any new kind of testing. Secondly, even though all the new chemicals are required by TSCA to be approved by the EPA, many companies were only compelled to submit the toxicity data that had been already generated. EPA would have no other option than to judge the chemical based on the limited information provided to them.[39] EPA only placed legal limits on the manufacturing and production of only certain chemicals called the Toxic Five – Asbestos, Dioxin, Perchlorinated biphenyls, Hexavalent chromium, Chlorofluoroalkanes. This is because EPA had to present the proof that the chemical causes “unreasonable risk” to both the public health and the environment.

The “Frank R. Lautenberg Chemical Safety for the 21st Century Act” plans to tackle most of these problems. This Act finally provides the authority to EPA to prohibit old or new chemicals that pose danger to public health and environment. EPA can require now, increased toxicity testing prior to approval of the chemical, ban chemicals or limit their usage based on scientific evidence based on public and environmental well-being without bearing in mind, the economic impact to the company. Moreover, animal welfare and health has been increased because of the latest requirements to improve, lower, and totally replace the vertebral animal testing.

- **SAFE DRINKING WATER ACT:**

Because of SDWA and the other regulations imposed by the EPA, the drinking water quality has increased tremendously and steadily in United States for the past 40 years. Before the Act, large parts of US. suffered a lot without proper drinking water for many years leading to several diseases caused from the chemical from the wastes from industries, sewage, untreated wells etc. In March 2010, EPA finished a 6-year long review of the NPDWR in order to identify technological changes, and other factors that provide a health or technical basis for supporting revisions that would strengthen the public health systems.[40]

The effectiveness of SDWA is also proved by recent research, further added regulated contaminants, and transparency requirements. The EPA is now trying and evaluating the risks of particular health concerns related to drinking water, including microbial contaminants, radon, arsenic, water from ground sources etc. According to the data gathered since 1971 by the collaboration of EPA and Centre for Disease Control and Prevention (CDC) in order to study and minimize the waterborne disease outbreaks in Unites States, the incidence of outbreaks since 1974 were the highest during the early 1980s and the incidence of outbreaks have gradually decreased since then. Hence even with the challenges of water born outbreaks, the quality of drinking water has gradually improved thanks to SWDA and EPA regulations, which also includes Total Coliform Rule (1989) and Surface Water Treatment Rule (1989).

3. Natural leather Industry Trend Analysis:

3.1 Red Meat Consumption Per capita:

Animal hides are a by-product of meat industry and these hides are processed separately after the animal is killed for meat and its skin removed. Most of the animal hides are taken from animals with red meat like cows, sheep, pigs, goats etc. The most common raw material for leather is the hide of cow. To identify the trend of natural leather industry over the years, it is important to study the source of the leather hide first and its current situation in United States.

The amount of cow hide produced is directly proportional to the number of cows or other animals killed for consumption in the food industry. Cow meat is the most consumed red meat and also the highest contributor to the leather industry. Most leather produced and which are sold in the United States are made from mostly cattle or calves. Hence there is a significant relation between the use of cow hides and beef consumption. Hence cow has been taken as the base for our analysis. It is important to take into account, the annual consumption of meat by United States in order to identify the trend of the leather produced annually. The Figure 6 below explains (loss adjusted) average availability of red meat, per capita from 1970 to 2016. The per capita loss adjusted food availability is calculated by taking the available food for consumption by humans per capita and accounting for some spoilage, restaurant wastes, losses in stores etc.

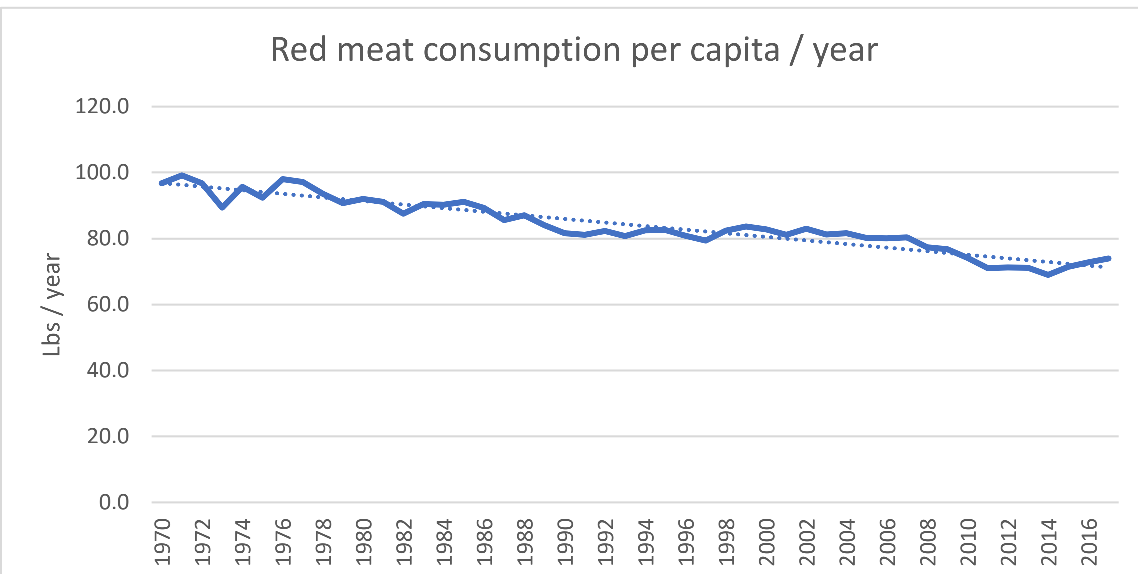


Figure 6. Average amount of red meat availability for consumption per capita per year in US. The dotted line represents overall trend. Source : IBIS world

The data in figure 6 is taken from 1970 to 2016. The solid line in the graph represents the average meat consumption per capita per year accounting for spoilage. The dotted line represents the trend of the graph. From the graph, it can be seen that the trend of annual red meat consumption by an individual is gradually decreasing overall along the years from 99 lbs./year during 1970 to 74 lbs./year at the end of 2016. Hence it is evident that per capita red meat consumption by Americans have decreased gradually over the years for various reasons.

One of the reasons that could have been a result of this decline would be increase in the consumption of poultry. The Figure 7 below represents the average availability of poultry for consumption per capita from 1970 to 2016. As we can identify from the below graph, there is a gradual but significant increase in the consumption of poultry per capita every year from 1970 to 2016. Although there is no significant evidence showing the reason for declining red meat consumption could be increase in poultry consumption, it can be safely concluded that it could be one of the many reasons for the declining trend.

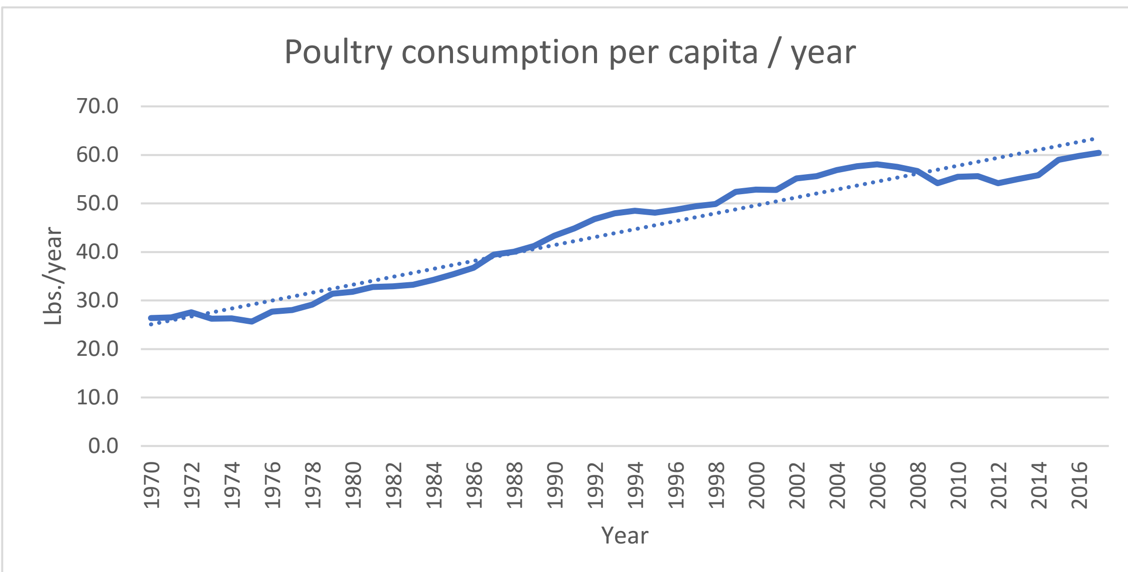


Figure 7 - Average amount of poultry availability for consumption per capita per year in US. The dotted line represents overall trend. Source: IBIS world

But the increasing population of United States over the years also must be taken into account. The population of US. has greatly increased from 205,052,000 during 1970 to 332,915,073 during 2021. So, if we consider the total consumption of red meat per year,

(Annual consumption = Annual population * annual consumption per capita)

then the amount of meat consumption will also drastically increase irrespective of decrease in the individual meat consumption. As mentioned already, the amount of cow hide produced is directly proportional to the number of cows or other animals killed for consumption in the food industry. Hence, it can be concluded that the amount of leather produced in the US. is abundant and is still increasing over the years.

3.2 Annual Revenue trend of leather industry:

In this section, the annual revenue trend of natural leather tanning and finishing, and leather goods and manufacturing industries from 2003 to 2026 is estimated. The industry revenue is the entire sales of goods and services (except sales tax); subsidies on production; capital work done by rental or lease; other income operating outside the firm (commision income, rent, leasing, hiring income etc.). The figure 8 representing the revenue trend is shown below.

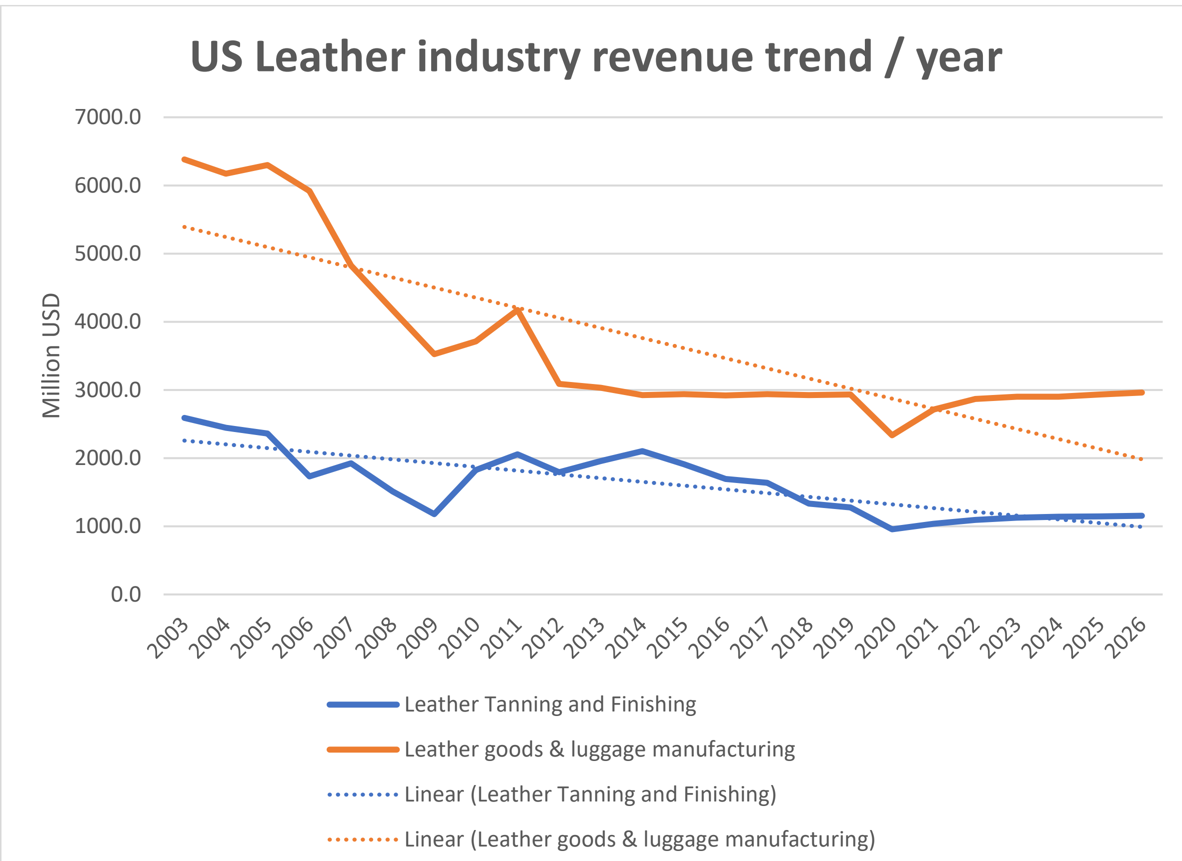


Figure 8 - U.S. leather industry annual trend data. The dotted lines represent the overall trend.

Source : IBIS world

The blue solid line and the yellow solid line represents the change and the estimated change in the revenue of leather tanning & finishing and leather goods& manufacturing industry respectively from 2003 to 2026. From the figure 8, it can be seen that the annual revenue of the leather industry is gradually decreasing at a considerable rate over the years.

3.3 Interpretation:

From calculating the total annual consumption from figure 6, it can be seen that the total annual consumption of meat in Unites States is increasing despite the decrease in consumption per capita.

This is due to the result of rapid increase in the population of U.S. in the last 40 years. Hence, it can be concluded that since there is abundant of meat produced to satisfy the growing population, then the quantity of cow hides produced will also be very high. The most predictable outcome would be that the revenue of leather industry must have increased considering the huge amount of hide production.

But from figure 9, the result seems to contradict our concluding statement. The revenue of both leather goods & manufacturing and leather tanning & finishing has been declining gradually along the years. Hence, the most important question that could solve this argument is “Why is the revenue declining despite abundant hide production?” and “What happened to the processed hides?”.

One of the many reasons which could be the factor affecting the decreasing revenue trend would be the passing of environmental laws and regulations. Many leather tanneries have shut down over the years since they were not able to follow the heavy environmental regulations imposed on tanneries. Following the environmental guidelines had sometimes result in less or no profit for many small-scale businesses. Hence, they were not able to operate or run a fully functional tannery for a long time while following many standards. Some of the tanneries were also shut down after the guidelines were passed because of the lack of revenue and resources to develop the company such as machinery, manpower, new chemicals etc.

Hence, we attempted to find what happened to the hides that were processed in abundance from slaughterhouses. In order to balance the declining revenue due to decreasing number of tanneries over the years, United States started to export leather hides to other countries and import foreign leather goods to sell domestically.

3.4 Alternative ways attempted to achieve revenue target:

3.4.1 Export of leather hides / skin:

One of the many reasons for the constant increase in the production of leather hides in United States is International export. Some of the companies being unable to follow the environmental regulations and guidelines imposed by the US government on tanneries, started to export the leather hides to foreign countries. The international trade is estimated to exceed almost 80 billion USD annually. There is a high level of exporting from United States to countries such as China, Brazil, India, etc. United States is the largest supplier of animal hides in the global leather manufacturing industry. Over 96 % of the population of the world is outside U.S. In the same manner, world's users of U.S. hides are located overseas. Being the largest supplier of hides, export seems to have been so important for Unites States' prosperity. Hence it is essential for the U.S. hides and skin exporters to obtain access to the foreign markets. The export trend of leather to foreign countries is shown in the figure 9 below.

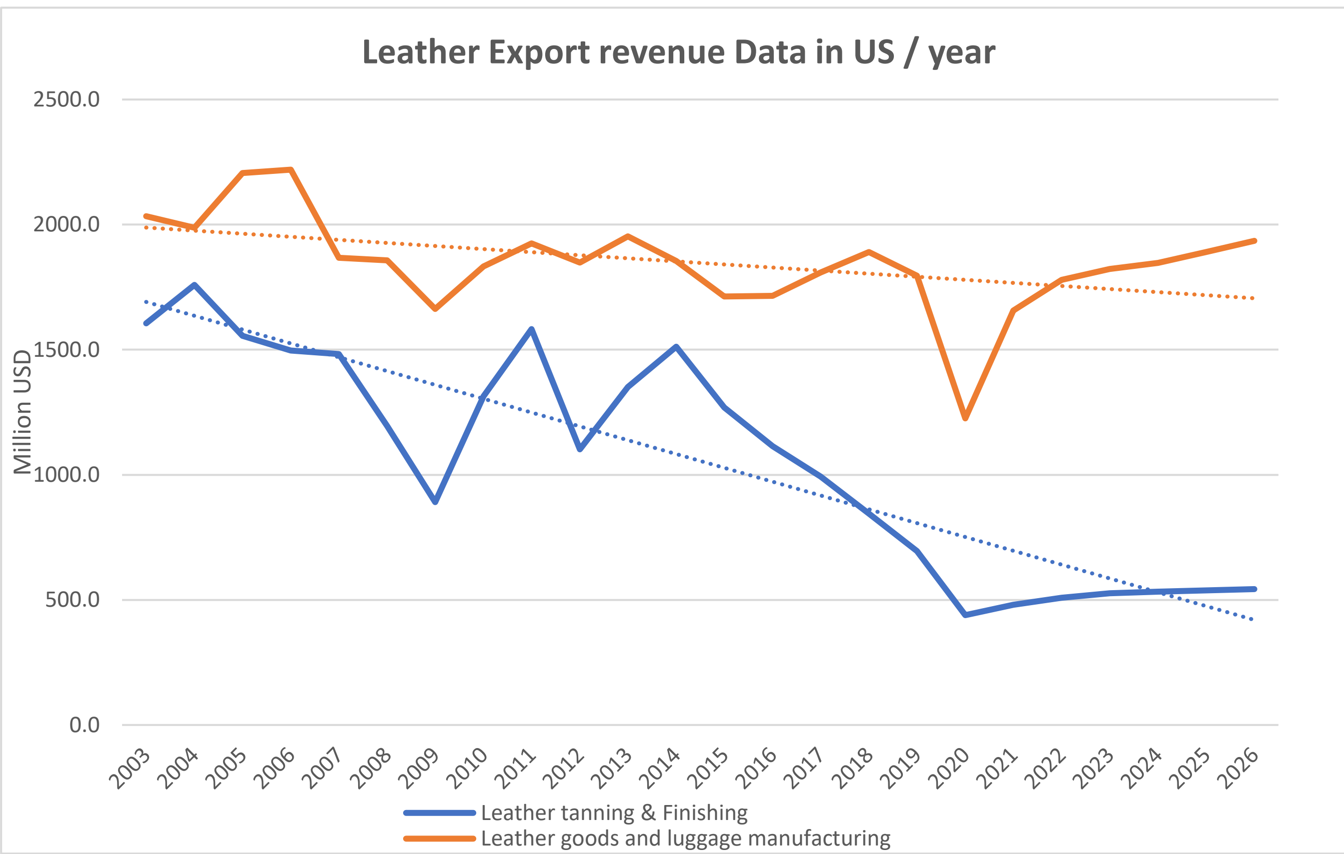


Figure 9 – Leather export revenue data in United States. The dotted lines represent the overall trend. Source - Modified from IBIS world

In the above figure, the blue solid line and the yellow solid line represents the change and the estimated change in the export revenue of leather tanning & finishing and leather goods & manufacturing industry respectively from 2003 to 2026. As we can see, the export revenue of goods and luggage manufacturing has been gradually but consistently decreasing over the years. Whereas there is significant decrease in the export revenue of tanning and finishing industry.

3.4.2 Importing Leather Products into US:

Another probable way of stabilizing the total leather industry revenue of United States is importing foreign leather products into US. The leather hides are exported to foreign countries and the finished products are sent to US by foreign markets and sold in US. The revenue of imports is shown in the figure 10 below.

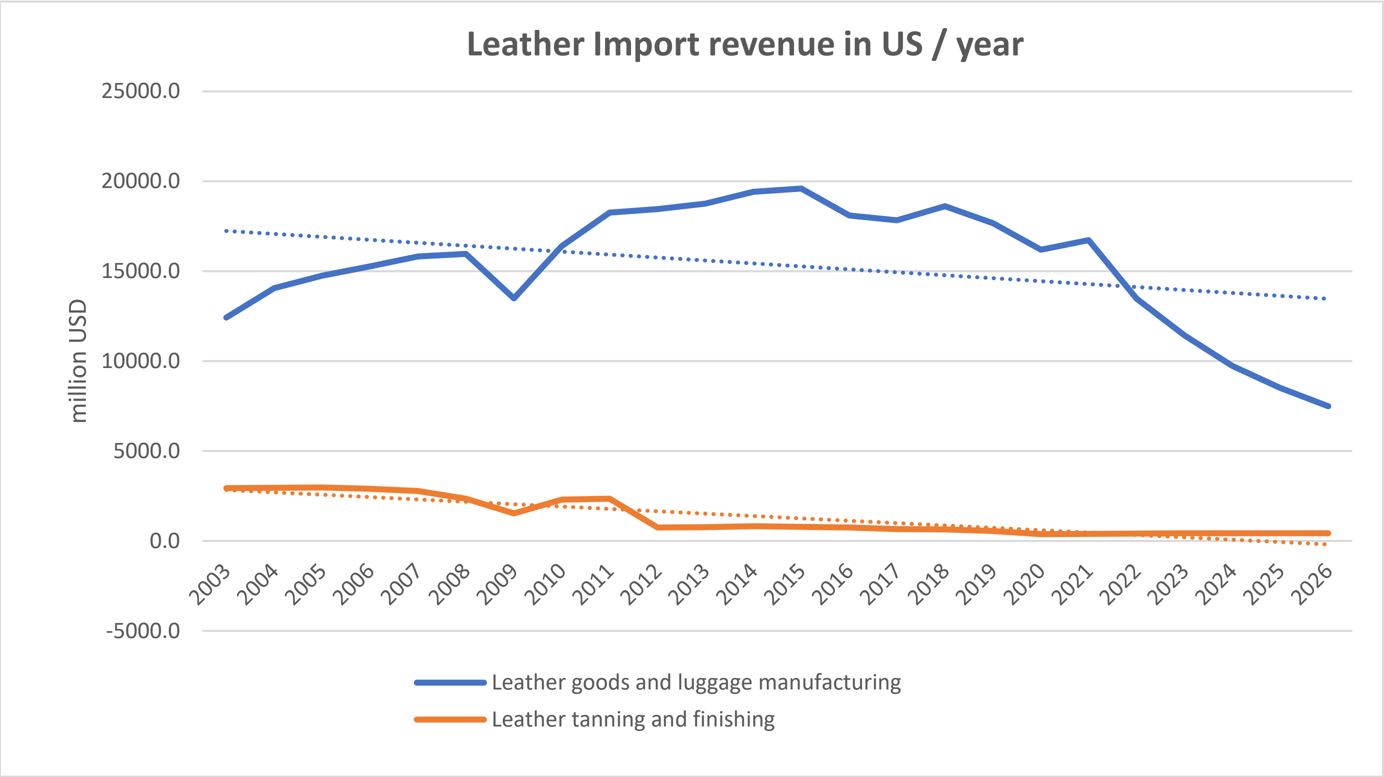


Figure 10 – Import revenue in United States. The dotted lines represent the overall trend. Source – IBIS world

In the above figure, the blue solid line and the yellow solid line represents the change and the estimated change in the import revenue of leather tanning & finishing and leather goods& manufacturing industry respectively from 2003 to 2026. As we can see, the export revenue of goods and luggage manufacturing has been significantly decreasing over the years. Whereas there is constant but steady decrease in the export revenue of tanning and finishing industry.

3.5 Reason for the decline in export and import revenue:

The probable reason why there is a decline in both import and export revenue is discussed in this section. One of the most probable reason would be the tariffs imposed by U.S. government on foreign countries and the retaliatory tariffs on U.S.

A tariff is nothing but the taxes that are imposed by a country on the services and goods imported from another country. Taxes are usually imposed by governments to raise revenue, exert leverage over a foreign country and protect domestic industries. Since most of the consumer products are manufactured outside United States, President Trump's administration felt that it was impacting the economy of the country and the job security of citizens in U.S. [41]. Hence, as an attempt to increase the output of manufacturing and produce more jobs for citizens, President Donald Trump enforced a series of taxes on imported goods since the year 2018.

The United States apparel and footwear import value stood at $129 billion during 2018, with almost 40% clothing and 73% of footwear imports from China. For all goods, the average import duty was 1.8%. But, the latest trump tariff saw an increased 25% tariff onto the existing tariffs for imports from China. Additionally, further tariffs have been planned for Europe, specially targeting leather handbags with more than $20 value, because of a dispute over aircraft subsidies.

The United States Hide, skin and Leather Association (USHSLA) has raised concerns over this potential tariff and its further impact on the leather , hide and skin industry. They claimed that US exports over 95% of total domestic production transported to key markets like the EU, who sell the finished products back to the United States. An additional tariff of 5% per month could be added to US imports for Mexico until it reaches 25% in response to immigration issues. Mexico is considered as the significant apparel and footwear manufacturing hub to be retailed in the United States. Mexico is the 7th largest supplier of footwear and the 8th largest supplier of apparel to the United States. It currently exports $691 million of men's and women's blue jean from Mexico which is almost 35% of the total imports.

Now due to these United States tariffs on the foreign imported products and raw materials, many businesses in United States which buy imports and sell it domestically are facing economic problems and are almost forced to close their companies. Businesses of all sizes have watched their input costs increase due to the tariffs [42]. To maintain the already slim profit margin, many of these businesses are forced to increase the prices of their product. But not all businesses can simply offset the tariff cost through price increase since their customer would be price sensitive and can easily shift or take their business to foreign competitor. All these companies have started to take other cost-cutting measures like laying off employees and forgoing expansion. There are also countless farmers and exporters who saw their markets dry up eventually as trading partners imposed retaliatory tariffs. More than 200 companies, due to Trump tariffs and also aggregated

with Republicans Fighting tariffs, have suffered a lot of damage. Even though the victims and their story differ, the catalyst remains the same throughout.

So now due to these tariffs, not only the business in US, but also the foreign leather hide / skin buyers are facing some economical situations. They are forced to pay more taxes now to sell their finished products in US. Since United States is one of the leading importing countries in the world, it is not very convenient for the foreign countries to change their market suddenly when considering a profit margin. Hence the economy of the other countries is affected, and the foreign companies are forced to take measures to stabilize their revenue by reducing wage fee, manpower, increase the price of their products. But many price sensitive customers will easily shift to other foreign competitors if the feel that the prices of the domestically produced leather products are increasing. Some foreign leather companies have been forced to shut down due to insufficient profit and steady decline in revenue. Hence the tariffs not only economically affected U.S. but also many foreign countries in the world.

Another issue faced due to the imposing of tariffs by the US government is the retaliatory taxes by its competitors. The highest buyer of leather raw materials in the global market is China. Now due to the tariffs, China is forced to buy the raw materials at a higher cost. In October 2019, the Trump Administration increased the tariff rate on 250$ billion worth of Chinese products from 25% to 30%. To protect its own economy, Chinese government imposed a 10 percent tariff on the imported goods from U.S. which also includes the leather hides. This move has seriously affected the revenue of many companies in U.S. which are exporting leather products other countries. They are forced to pay more taxes for exporting their raw materials to foreign countries.

Customer Confidence Index:

Customer demand is another factor that is related to the decline in the revenue. The Customer Confidence Index (CCI) measures the customer outlook on current and future financial conditions. An increase in the customer confidence leads to higher investment and greater consumer spending, as consumers feel comfortable with their financial situation. The confidence index from 2012 to 2025 is shown below in figure 11.

Although COVID 19 played a huge part for the steep decline in the graph during 2020, the market doesn't seem to have estimated to recover even after 5 years. This can be a clear evidence to show that the customer demand for domestic leather products is slowly decreasing over the years.

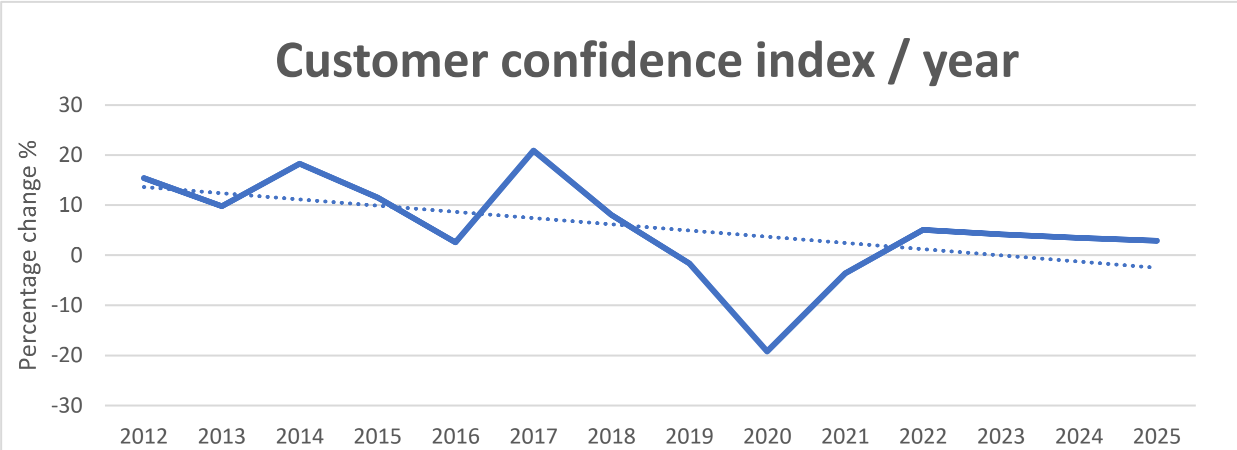


Figure 11 – Customer confidence index chart data. The dotted lines represent the overall trend. Source - IBIS world

4. Synthetic Leather – an overview

4.1 Introduction:

Synthetic leather, also known as Faux leather, is a type of leather which is a petroleum-based alternative to real / animal leather. It is a leather which is synthetically manufactured. It does not involve any natural elements in the manufacturing process; hence it is completely man made. It is represented in many names such as artificial leather, faux leather, synthetic leather, imitation leather etc. All these names indicate that it is not a pure leather, but a substitute for it.[43]

Faux leather usually feels cold and unnaturally even compared to genuine leather. Synthetic leather when pressed upon, doesn't wrinkle or stretch much as real leather but it simply depresses and retains its original position. Faux leather usually smells like plastic because of the chemicals used in the production.

4.2 History:

Over the years, many alternatives to natural leather were invented. In 1845, A German chemist, Christian Friedrich Schönbein invented Nitrocellulose. This nitrocellulose was then turned into collodion (pyroxylin) by French scientist Louis-Nicolas Menard during 1846. This pyroxylin or collodion was initially incorporated in the dressing of wounds acting as a protective covering. It was later used in fabrics.

In 1910 DuPont Fabrikoid company created Fabrikoid which was a pyroxylin infused cotton fabric. DuPont company patented it in 1915. Fabrikoid was very durable and water resistant and was used in many accessories like automobile seat covers, upholstery etc. During early 1920's,

Naugahyde was used in most of woman handbags. It is fabric which was coated with leather fibers and rubber. It became very popular during 1930s and by the end of 1940s Naugahyde was used by the US armed forces for war equipment. Naugahyde remained as one of the dominant leather brands of synthetic leather until competitors emerging during the 20th century superseded Naugahyde's dominance in the market.

Major revolutionary invention was the use of polyurethane and poly vinyl chloride infused leather products during the 1960s. These leather types were considered the most durable and flexible leather that most resembled the natural leather products. It can almost perfectly replicate the appearance and also the durability of natural leather at a considerably low cost and the production is far less labor intensive. Taking into account, both ethical considerations and practical considerations, the consistent demand for synthetic leather substitutes has increased at end of the 20th century.

Many leather companies are still trying rigorously to achieve a more economical and environmentally friendly substitute to natural leather compared to the existing synthetic leather types.

Leather can be classified into various types based on different characteristics. Here we stress on the types of leather based on the type of raw material is manufactured with. Leather can be classified mainly into Natural leather / Real leather and synthetic leather.

4.3 Types of synthetic leather:

Synthetic leather usually goes through a lot of steps during the manufacturing process before the end product is ready. There are many types of processes by which synthetic leather is prepared. Hence, they are also of different types based on the type of raw materials used for the manufacture [44].

- **Plastic Leather:**

One of the most commonly manufactured synthetic leather is plastic leather. In this process, the fabric is covered with a neat coat of plastic. The commonly used materials for plastic leather are polyurethane and polyvinyl chloride. These plastics are readily and cheaply available in the market and hence synthetic leather is much cheaper than genuine leather. Plastic leather is as durable as genuine leather, and it does not fade.

The Polyvinyl chloride (PVC) based leather is a product of adding plastic material and dye to vinyl, which provides the fabric a much more real leather look. Also, vinyl-based synthetic leather is not generally used for clothing even though it is more flexible than polyurethane because it is not breathable. PU based faux leather is created by coating natural fabrics such as cotton / wool

with a polymer-based substance, then further treating it for a real leather like appearance. This type of faux leather is more breathable than vinyl-based leather, and it is used more for clothing and items that will meet the skin.

- **Poromeric Leather:**

The term poromeric was coined by DuPont. The foremost poromeric leather was Corfam introduced by DuPont in 1963. Poromeric leather preparation is like plastic leather. The only difference between them is, poromeric leather is a combination of different synthetic fibers in order to select one that feels similar to the genuine leather. In this process, a polyurethane layer is coated on a polyester fabric. The end product has a glossy texture and is porous. This leather fabric is breathable and can hence be used for products like boots, gloves etc.

- **Leatherette**:

Leatherette is another type of leather which involves the use of both plastic and fabric. But in this case, the fabric can either be natural or synthetic. The material is very strong and requires very little maintenance. It was widely used in book bindings, cases for cameras etc. It is being used in cars today.

Leatherette is not suitable for clothing since it does not allow the sweat to escape from the fabric. Another reason for Leatherette being not suitable for clothing is it can melt easily upon contact with fire. It requires very less maintenance and it does not crack or fade easily. Hence it is widely used in automobiles.

4.4 Manufacturing process:

Faux leather is manufactured in a series of steps. Most of the faux leather in today’s market is composed of a base textile coated with a plastic material. The following steps involved in the production of faux leather are explained below [45],

- **Obtaining the Base Material:**

The most common base material used by many faux leather companies are usually polyester or cotton. This polyester or cotton base material that are used in Faux leather are porous and sometimes rough. This means that they must have to be manufactured specially. Some companies manufacture their own base materials but most of the time they are bought from third party manufacturers / production facilities.

- **Formulating the plastic:**

In order for the plastic substances to bind well with the plastic material, the manufacturers have to formulate the plastic substance used. Poly vinyl chloride is made by the combination of salt constituents and petroleum constituents. Chlorine is produced by manufacturers by exposing the salt to electrolysis and this is mixed with ethylene which can be derived from petroleum. The end product is nothing but ethylene dichloride. The ethylene dichloride, at high temperatures can be converted into vinyl chloride monomer, which is further transformed to polymer with poly vinyl chloride resin. Manufacturers also add plasticizers to bind the final product to the base fabric in order to make the plastic more flexible.

- **Binding the materials:**

To the underlying base textiles, faux leather manufacturers bind the polyurethane or polyvinyl chloride. There are a lot of processes to do this, but it is mostly performed by melting the plastic and covering it on the base textile material. The general manufacturing process of PU and PVC leather is represented in the figure below,

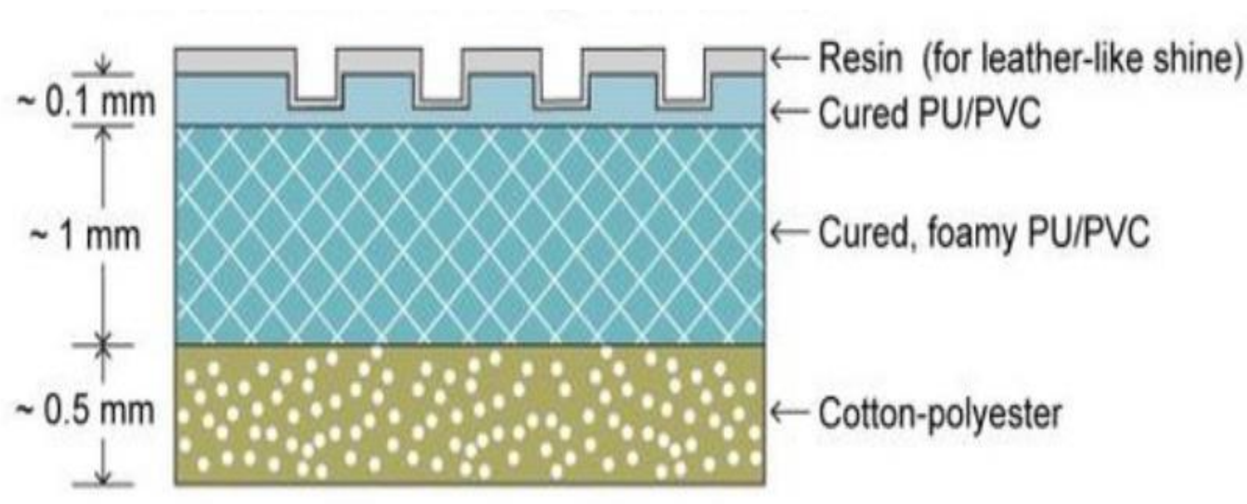
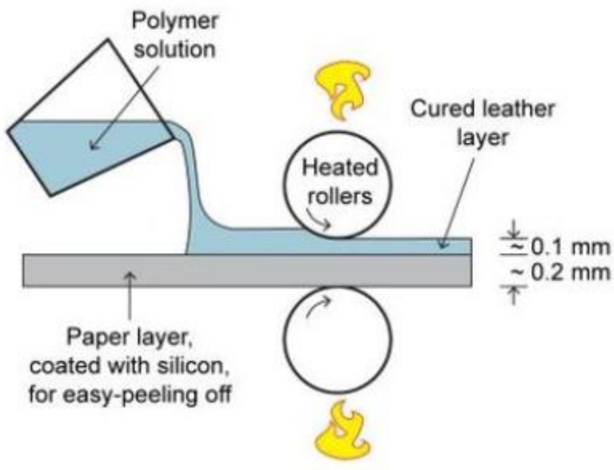
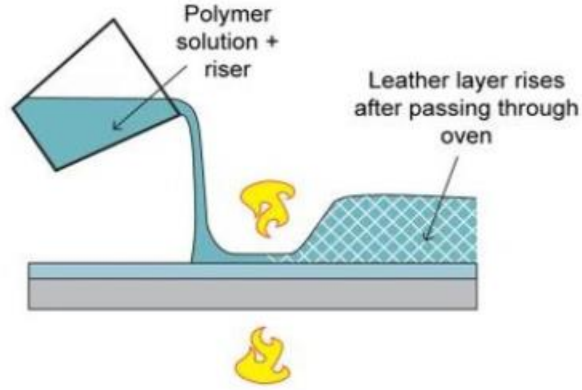


Figure 12 – Cross sectional view of synthetic leather

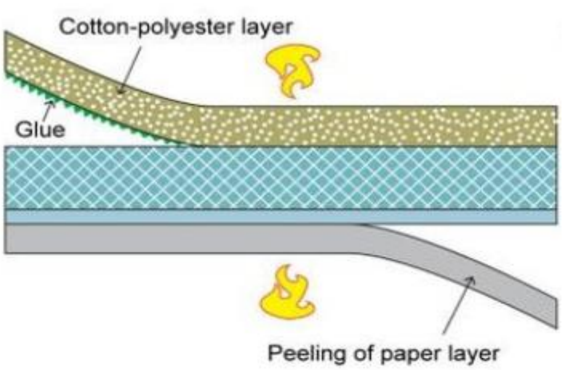
Source: Reprinted from **"**Gurera D, Bhushan B. Fabrication of bioinspired superliquiphobic synthetic leather with self-cleaning and low adhesion. Colloids and Surfaces A: Physicochemical and Engineering Aspects. 2018 May 20;545:130-7."



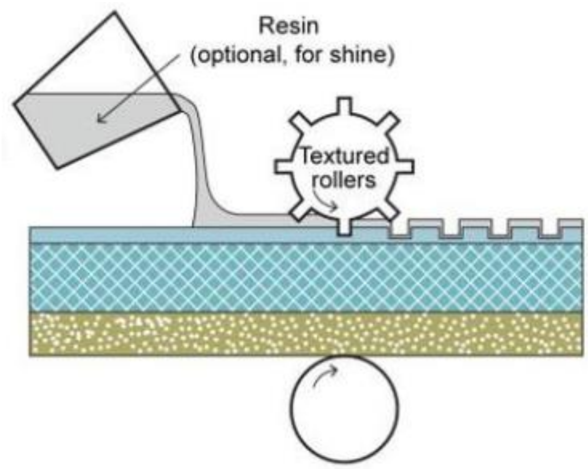
13 (a)



13 (b)



13 (c)



13 (d) (orientation flipped)

Figure 13 – Manufacturing process of plastic based synthetic leather
(a) Pouring of first, thin polymer layer
(b) Pouring of second, foamy and thick polymer layer
(c) Pasting of strengthening cotton-polyester layer
(d) Addition of leather like grooves and shine

Source: Reprinted from "Gurera D, Bhushan B. Fabrication of bioinspired superliquiphobic synthetic leather with self-cleaning and low adhesion. Colloids and Surfaces A: Physicochemical and Engineering Aspects. 2018 May 20;545:130-7."

The entire process consists of four steps,

- In the first step, the polymer solution is poured or laid on a layer of paper which has already been coated with silicon which will be easy to peel off at the end of the process. The poured layer of polymer solution is passed through heated rollers and this creates a thin layer of cured leather layer on top of the paper. The polymer solution consists of 55% PVC/PU polymer, 40% plasticizer, 1% stabilizer and balance fillers [46].

- In the second step, this solution of polymer is mixed with a riser and is poured onto the previous layer of cured polymer. The layer is then passed through a heated oven where the new layer of polymer becomes foamy and thick.

- In the third step, the cotton / polyester layer which is the base material is poured onto the second layer and simultaneously the paper layer below the first layer is peeled off when it is passed through an oven.

- The fourth layer is used to produce leather like grooves on the top layer and also to produce a shiny layer with a texture. This is done by pouring a resin layer on the third layer and passed through textured rollers. This final step is only to provide a natural leather feel and looks, hence it is optional.

4.5 Pros and cons of synthetic leather:

Pros:

- Faux leather is less expensive than natural leather and is easily affordable.
- It can be finished with a variety to textures as per requirements and can be polished to have a gloss and matt finish. Hence it is very versatile.
- Faux leather is staining resistant, and it does not wear or crack easily.
- It does not easily fade, and the color does not diminish easily.
- It is more easily manufactured compared to natural leather and the manufacturing time is less.
- Faux leather is water and UV resistant.
- It requires very less maintenance.

Cons:

- Some of the faux leather types, especially polyvinyl chloride leather is not breathable and comfortable.
- Faux leather is not as hypoallergenic as real leather.
- Plastic based faux leather, which is commonly used is not biodegradable
- Faux leather is durable and flexible but is also vulnerable to tear or puncture.
- Since it is non-biodegradable, it results in the accumulation of more environmental wastes.

5. Future Trends in leather industry:

Both Animal leather and faux leather manufacturing industries have been working meticulously over the years to make their product more sustainable and less harmful to the environment. Considering the development of the leather industry, there has always been a dispute on which type of leather is better. But we can find some of the development in both sides and recognize the effort. Hence, we will look further into the futuristic advances and current development in both natural and artificial leather industry in the coming sections.

5.1 Biotechnological trends in natural leather industry:

The leather processing industry has been continuously changing by the global environmental regulations. Tanning and Pre-tanning processes are responsible for the 80% to 90% of the total pollution in the industry [47]. These processes generate toxic gases like hydrogen sulfide and also toxic wastes like lime and chrome sludge. In the areas of leather making, the use of enzyme-based products is currently being researched. Some of the emerging and future biotechnological advances in the leather making process are discussed in this section.

- **Developments in the past decade:**

In the last 2 decades, biotechnology's growth has results in substantial improvements in both the production and the application of bio-products in various leather processing steps. One of the examples is the dung extraction from hides during the soaking process [48]. The recombinant DNA technology's evolution and advances in protein engineering has led the pathway to the development of broad range of proteases for the usage in de-hairing, soaking and liming process. In recent research, it was shown that the hair can be loosened by neutral protein dispase without any damage to the collagen fibers [49].

Many attempts to develop alkaline protease have been made especially from *Aspergillus tamarii* and *Alcaligenes faecalis* that can loosen up hair with no chemical assistance. Some recent studies show that certain bacterial culture possess keratinolytic activity, which can be useful for depilation.

Some of the lime-free enzyme-based fiber opening methods involve the use of strong alkali, lyotropic agents, bating enzymes and *Lactobacillus* based enzymes [50][51][52].

Further research into degreasing enzyme's efficiency reveals that 'enzyme pickling' with acid lipases and proteases increases degreasing effectiveness, while the neutral lipases increase the degreasing effectiveness at neutral pH [53]. A combination of enzymes not only might be essential to the breakdown of grease but also might help to release the broken-down products from the skin.

- **Non-lime enzyme assisted de-hairing for cow hides:**

A dehairing process which is enzyme assisted has been developed that utilizes 85 percent less sodium sulfide compared to conventional lime-sulfide dehairing process [54]. By employing commercially available enzyme formulation based on bacterial alkaline protease, loosening of hair was attempted. The dehairing process hence requiring no lime, can eliminate lime sludges, and the complete hair removal can be done in an uncommon pH (8.0) compared to the pH of the process that required lime (pH 12.0). Using a commercially available enzyme formulation, studies on the optimization of concentration of enzyme, sodium sulfide were done. The results showed that 0.5 % sodium sulfide concentration and 1% enzyme concentration is required for complete hair removal. Recently, for dehairing bovine hides, a mixture of proteolytic enzymes derived from *Streptomyces griseus* along with surfactant and carbonate buffer was used [55]. Even though this process loosens the hair considerably, full removal can be achieved after re-liming using a sharpening agent.

- **Biocatalytic fiber opening :**

For cow hides, goat and sheep skins, in an attempt to decrease the pollution from Beamhouse operations, an enzyme – based fiber opening process was developed [56]. Lime based swelling eliminates proteoglycans through osmotic forces, which results in wrinkle formation and area reduction. Substrate specific enzymes like α-amylase will disintegrate or break proteoglycans, that opens the fiber matrix and causes swelling. The samples which were subjected to enzyme based and lime-based fiber opening followed by the chrome tanning process, showed alike and comparable degree of fiber opening under the microscope [57]. When compared with the conventional leather processing, the reduction in effluent loads of total solids and COD for the experimental leather processing is 20 percent and 45 percent, respectively. The total dry sludge is decreased to 12 kg per 1000 kg of processed raw hides, which was 152 kg of dry sludge previously. This could be considered as one of the most groundbreaking accomplishments in solid-waste management and total solid reduction. Biocatalytic leather processing made more economically viable by commercially available enzymes. Since the biocatalytic process utilizes enzymes for both fiber opening and dehairing process, the resulting increase in the area of leather provides a revenue of 70$ USD per metric ton of raw hides processed.

- **Bio driven 3-step tanning technique:**

A 3-step enzyme driven tanning process which is applicable to hides and skins has been developed that includes, enzyme-based fiber opening, enzymatic dehairing, pickle free chrome tanning at pH 4.0 to pH 8.0 [58]. Additionally, instead of chromium, an approach that employs plant-based polyphenol compounds for tanning process at pH 8.0 has been suggested for 3-step tanning process. Similar or comparable bulk and physical properties were shown for processed leather compared to that of the conventional tanning process. The chemical consumption and chemical discharge of the three-step tanning process were reduced by 98% and 88% respectively. The decrease in COD emission loads is 50% - 84% and decrease in total solids is 74%-84% for the bio catalyzed 3-step tanning process when compared to conventional leather tanning process[59]. Also, this process provides more economic benefits especially in terms of reduced power consumption, reduction of water and increased area yield.

- **Biotechnology : Other future trends:**

The leather manufacturing process worldwide, remains as a chemical processing of biological matrix skin. Convention leather tanning process follows generally the “do-undo” methodologies like curing and soaking (hydration and dehydration), pickling & basification (acidification & de-pickling) and liming and deliming (swelling and de-swelling). This logic only results in ecological imbalances and process inefficiencies. There is a requirement to process leather by eliminating the do-undo process logic. One idea can be the use of a “do-only” logic where each process does not have to be reversed in the procedure [59]. By the use of particular bioproducts for a specific action instead of chemicals, this can be achieved. By acquiring the knowledge on which enzyme is required for a particular process, it is likely to acquire them and incorporate biological techniques for sufficient production in terms of both quantity and quality. An exemplar change in leather sector would involve the bioprocessing of hides/skin in the beamhouse, tanning and post-tanning processes, which would result in most efficient and cleaner leather processing. The field of biotechnology provides new ways to employ conventional or traditional by-products like silk, leather fibers etc. and provides sustainable industrial growth.

Processes or products	Probability of success[a]	References
Bioproducts (plant based) for ambient preservation of raw skins and hides	**	B
Complete replacement of sodium sulfide for de-hairing	****	[57]
Fiber opening without osmotic forces	****	[59]
Growth mark and wrinkle removal	***	[65]
Enzymes for de-fleshing	***	B
Smart enzymes for degreasing	***	[66]-[68]
Bio-crosslinkers as tanning agents (bio-tanning) for biodegradable leather	**	[69]
Enzymes at post-tanning for area yield and improved chemical uptake	***	[70]
Paradigm shift from chemical-based to complete bioprocess-based leather making	**	[56],[71]

Note : (a) Probability of success: (**** - most probable); (*** - probable); (** - least probable); (* - unlikely). Modified from [47]
B - New Millennium Indian Technology Leadership Initiative: Biotechnology for Leather project (launched by the Council of Scientific and Industrial Research, India).
Table 7 - List of biotechnologies that might have the potential for success in leather processing [47].

There has been investigation on other natural products for the control of microflora activity that are responsible in the degradation of the skin. Proteases and lead enzyme products can be used individually or combined for de-hairing and de-fleshing to remove the use sodium sulfide and lime. A further area where biotechnology can be used in the leather sector is the tanning process itself. It will be intriguing to discover if the biomolecules / enzymes could tan the skin and hides. The development of enzyme catalyzed crosslink to stabilize the collagen matrix would enable the leather production to become more sustainable and environmentally friendly [60].

5.2 Synthetic leather:

When it comes to Faux / artificial / synthetic leather, many industries are working on finding safer and sustainable alternatives for polyurethane and polyvinyl chloride. Plant based vegan leather has been a major comeback for the faux leather industries in the recent years as they were criticized for using plastics and also for depletion of fossil fuels. The recent developments based on plant based synthetic leather and engineered leather are taking over the leather fashion industry at a very elevated degree.

- **Silicone-based leather:**

Silicone leather is a coated fabric which is also very similar to polyurethane and polyvinyl chloride coated fabrics. But that is the only similarity between them. Silicone leather is more environmentally friendly and a suitable alternative to other traditional coated fabrics with a long list of benefits. Silicone leather is made from specially developed silicone material which has been refined for many years [61].

Silicone is categorized as an elemental polymer material which stands as a bridge between organic and inorganic material. Silicone's molecular chain consists of Si-O inorganic base unit, and its side chains connected through the silicone atoms and organic groups. Hence silicone is considered to possess both an organic material's elasticity and an inorganic material's stability.

Silicone material being used for baby pacifiers is very safe and it has an innate ability to withstand different weather conditions. The main characteristics of silicone leather are weather resistance, stain resistance, durable, safe, waterproof, chemical resistance, temperature resistance, sustainable and eco-friendly. Organic silicone leather is made by silicone combined with ultra-fine fibers and non-woven fabrics. It is then processed and prepared to be suitable for variety of industrial applications.

- **Mushroom Leather (Muskin & Mylo):**

Muskin is a material similar to leather which is made from the caps of a specific mushroom called Phellinus ellipsoideus. The caps once extracted, are treated similar to that of animal leather but with completely natural techniques. The natural techniques include the use of eco-friendly products such as eco-wax, which adds special additional characteristics to the leather [62].

This mushroom is not only extracted and engineered in an eco-friendly manner, but the use of this mushroom is also beneficial to the environment. This species of mushroom, native to the subtropical forests, feeds on the trunks of the trees causing them to rot gradually. MusKin is a helpful way to prevent the use of animals for leather and keep our environment safe and healthy. Mushroom leather is sustainable, non-toxic, waterproof, and very durable. Now, only 40 to 50 m^2 of Muskin could be produced in one month, hence it is more suitable for limited edition collectibles.

Mylo is also a type of mushroom leather which is made from mycelium. The underground root structure of mushrooms is called mycelium [63]. The vegetative part of a fungal or fungal bacterial colony which contains an area of branched filamentous hyphae is the mycelium. The mycelial fungus colonies happen in or on soils and other substrates. When a dikaryotic mycelium is formed by the combination of two compatible homokaryotic mycelia, the mycelium can form mushrooms.

The mushroom leather grows from the mycelial cells, that are processed and grown in optimal growth conditions to produce a strong , sustainable alternative material for animal leather. The mushrooms are basically fed with cellulose and they are grown carefully. This leather is strong, flexible and waterproof. It is uniquely customizable and can be incorporated with textures and other features directly into the material.

At first glance, Muskin and Mylo look very similar but they have different sources. Muskin is made from mushrooms and Mylo is made from underground root structure of mushrooms called mycelium.

- **Pineapple-based leather:**

Pineapple leather or Pinatex is a synthetic leather like material that is made from a combination of natural pineapple leaf fibers, petroleum-based resin and thermoplastic polyester. It is a non-woven textile material which is not made from animal hides. The leaf fibers come from Philippines. Around 10 percent of the agricultural exports of the country come from pineapples. The fruit is sold whereas the leaf is treated as waste. But in this case, it is treated as the main raw material for the leather. Almost 480 leaves are required to produce 1 m^2 of pineapple leather. Hence, with a huge supply of leaves, farmers benefit by producing minimum waster and having the ability to sell more crops for industrial consumption and gain some profit.[64]

The pineapple leather is made in a few steps. The first step involves the breaking down of the leaves of pineapple and extracting the long fibers. This process of removing fibers is called “decortication”. For the fibers to be turned into the Pinatex mesh, the sticky residue is required to be removed from the extracted fibers. This is done by degumming the fibers. After degumming the fibers, the long pineapple fibers are processed into non-woven mesh structure and are turned into a refined form which form the base of the material. The next process is the finishing process, which involves the use of petroleum-based resins, which makes the finished product to look more leather-like. This provides the leather with more color, texture, looks and a surface which is water and abrasion resistant.

- **Bio-fabricated leather:**

Bio fabricated leather is made from collagen grown from yeast in a lab compared to the conventional leather making process, where the leather is made from collagen-based hides which have been altered chemically through tanning process to remove almost everything except the collagen. Bio fabricated leather is the least publicly spoken yet the most interesting.

The company behind the making of this leather is called “Modern Meadow” and the name of their product is called “Zoa”. Zoa has been changing the game of innovation for years and has made a surprising uproar in the synthetic leather industry. The leather, Zoa is made up something that Modern Meadow calls “nature’s essential protein”, also known as collagen. Collagen is a protein

that is found on the skins of animals which supplies elasticity and suppleness and is also essential to desirable leather characteristics. The imitation leather or bio fabricated leather called Zoa is also made from collagen that was grown from yeast in a lab.

A more sustainable choice than the existing leather production system can be growing the animal collagen directly to make imitation leather. Conventional leather involves the nurturing and slaughtering of livestock animals. Also, Nurturing, raising and breeding these animals, like cows, requires a lot of resources in terms of land, water, and cattle feed. It also results in unintended impacts such as deforestation, contamination of surface and underground waters, and emissions of greenhouse gases (GHG). In comparison to global transportation which emits around 12% of all GHG, livestock agriculture is responsible for 14.5% of all GHG emissions.

Modern meadow is going forward and leading ahead in the leather manufacturing process, starting from collagen to produce leather. Modern Meadow can engineer the yeast genetically to grow collagen with different and desirable properties – ability to mimic the type of hide (e.g., cow hide / goat hide). Additionally, the bio fabricated leather is not limited to the size and shape of the animal unlike the conventional leather making process – it can be grown to any shape or size.

6. Conclusion:

In this report, the structure, composition and characteristics of natural leather and synthetic leather has been discussed. Also, the environmental regulations imposed on tanneries by the United States government has also been discussed. The regulations seemed to have impacted the natural leather industry when it comes to economy. Even though it has helped in solving most of the environmentally negative factors, it has not helped the industry in maintaining a stable profitable revenue over the years.

The annual revenue of the leather has been declining despite the increase in the total annual meat consumption in U.S. These environmental regulations can be concluded to have been a major factor in the decline of revenue trend. However, when we consider the fact that U.S government has used the export of animal leather hides to foreign countries and import finished foreign products, there should have been a positive outcome, but it was evident from our investigation that even the export of animal hides did not pave way to any profitable means.

U.S. leather companies which domestically produce leather products are forced to increase their product's selling price since it is very strenuous to abide by the regulations without a large expenditure or investment to produce changes in their company. The customers have started to now shift to imported products considering the fact that the domestically produced leather products are sold at a higher price.

Due to the trade wars between countries involving increase in tariffs, the companies in U.S. are facing more difficulties in exporting hides to other countries. The foreign countries, in order to retaliate the increase in import tariffs by the U.S. government, have increased the taxes for the hides / skin sold by the U.S. Hence the companies that are selling the hides must pay more tariffs than usual.

Overall, the leather industry is in a dire situation and there seems to be very less progress in developing technologies to stabilize the reducing income for leather industry in the country.
We have discussed about the rising synthetic leather alternatives and also its future trends to make it further safer to the environment. It is hence safe to suggest that synthetic leather, being the best suitable alternative could perhaps help eliminate the natural leather industry over the years, which would not only be more environmentally friendly but also economically friendly to U.S.

7. References:

[1] Sharphouse JH. Leather technician's handbook. Leather Producers' Association; 1983.

[2] Leafe MK, editor. Leather technologist’s pocketbook. Society of leather technologists and Chemists; 1999.

[3] *Advice on Leather Care, Leather Cleaning and More Brought to You by BLC, the Leather Experts*, www.all-about-leather.co.uk/.

[4] Heidemann E. Fundamentals of leather manufacture. Roether; 1993.

[5] TXTURE, et al. “Four Types of Tanning Methods: Chromium Tanning, Vegetable Tanning, and Smoke Tanning.” *TXTURE Boots*, 24 Mar. 2021, txtureboots.com/two-types-of-tanning-method-chromium-tanning-and-vegetable-tanning/.

[6] “GET THE FACTS.” *Leather Naturally - Benefits of Leather | Leather Naturally | Advantages of Leather*, www.leathernaturally.org/Education/Fact-Sheets/Benefits/Benefits-of-leather.

[7] Chen, Annie Taylor. “Leather Vs. Non-Leather Bags - The Pros And Cons.” *Petite & Minimal*, Annie Taylor Chen, 17 Dec. 2018, www.petiteandminimal.com/leather-vs-non-leather-bags-the-pros-and-cons/.

[8] -, Michael, et al. “Top Leather Producing Countries and Industries in Which It Used.” *CountriesToday.com*, 8 Apr. 2019, www.countriestoday.com/leather-producing/.

[9] Emission Factor Documentation for AP-42 Section 9.15

[10] 2016 Membership Directory, Leather Industries of America Inc.

[11] Rastogi SK, Kesavachandran C, Mahdi F, Pandey A. Occupational cancers in leather tanning industries: A short review. Indian journal of occupational and environmental medicine. 2007 Jan;11(1):3.

[12] Bonassi S, Merlo F, Puntoni R, Ferraris F, Bottura G. Epidemics of lung tumors in a Biella tannery. Epidemiologia e prevenzione. 1990 Sep 1;12(44):25-30.

[13] Rastogi, SK, et al. “Occupational Cancers in Leather Tanning Industries: A Short Review.” *Indian Journal of Occupational and Environmental Medicine*, vol. 11, no. 1, 2007, p. 3., doi:10.4103/0019-5278.32456.

[14] Montanaro F, Ceppi M, Demers PA, Puntoni R, Bonassi S. Mortality in a cohort of tannery workers. Occupational and environmental medicine. 1997 Aug 1;54(8):588-91.

[15] Sclove RE, Scammell ML, Holland B. Community-based research in the United States. Amherst, MA: The Loka Institute. 1998 Jul.

[16] Jasim Uddin Khan, "Local Tanners Eye Bright Prospect as US, EU Quitting Leather Processing," The Daily Star 20 Dec. 2007.

[17] Reuters, "Toxic Tanneries Drive Bangladesh Leather Exports: Report," 9 Oct. 2012.

[18] Doble M, Kumar A. Tannery effluent (Chap. 12). Biotreatment of industrial effluents. Butterworth-Heinemann. 2005:133-43.

[19] Sivaram, N.M., and Debabrata Barik. "Toxic Waste From Leather Industries." *Energy from Toxic Organic Waste for Heat and Power Generation*, Woodhead Publishing, 9 Nov. 2018, www.sciencedirect.com/science/article/pii/B9780081025284000055.

[20] Development Document for Effluent Limitations Guidelines and Standards for The Leather Tanning and Finishing Point Source Category, EPA-440/1-82-016, U. S. Environmental Protection Agency, Research Triangle Park, NC, November 1982.

[21] Kanagaraj J, Velappan KC, Babu NK, Sadulla S. Solid wastes generation in the leather industry and its utilization for cleaner environment-A review.

[22] Bari ML, Simol HA, Khandoker N, Begum R, Sultana UN. Potential human health risks of tannery waste-contaminated poultry feed. Journal of Health and Pollution. 2015 Dec;5(9):68-77.

[23] Abduljaleel SA, Othman MS. Metals concentrations in eggs of domestic avian and estimation of health risk from eggs consumption. J Biol Sci [Internet] 2011 Dec 10 [cited 2015 Oct 19];11(7):448–53.

[24] "Clean Air Act of 1963." *Wikipedia*, Wikimedia Foundation, 23 Feb. 2021, en.wikipedia.org/wiki/Clean_Air_Act_of_1963.

[25] *The Clean Water Act of 1977 - JSTOR*. www.jstor.org/stable/40912265.

[26] Water Quality: A Half Century of Progress. www.epaalumni.org/userdata/pdf/waterquality.pdf.

[27]“Summary of the Comprehensive Environmental Response, Compensation, and Liability Act (Superfund).” *EPA*, Environmental Protection Agency, 27 July 2020, www.epa.gov/laws-regulations/summary-comprehensive-environmental-response-compensation-and-liability-act.

[28] “Superfund.” *Wikipedia*, Wikimedia Foundation, 9 Mar. 2021, en.wikipedia.org/wiki/Superfund.

[29] “Emergency Planning and Community Right-to-Know Act (EPCRA).” *EPA*, Environmental Protection Agency, 11 Jan. 2021, www.epa.gov/epcra.

[30] *Mass.gov*, www.mass.gov/. Retrieved 22 April 2018.

[31] Gibson JM, Fisher M, Clonch A, MacDonald JM, Cook PJ. Children drinking private well water have higher blood lead than those with city water. Proceedings of the National Academy of Sciences. 2020 Jul 21;117(29):16898-907.

[32] “National Primary Drinking Water Regulations.” *EPA*, Environmental Protection Agency, 5 Jan. 2021, www.epa.gov/ground-water-and-drinking-water/national-primary-drinking-water-regulations.

[33] “Toxic Substances Control Act of 1976.” *Wikipedia*, Wikimedia Foundation, 2 Mar. 2021, en.wikipedia.org/wiki/Toxic_Substances_Control_Act_of_1976.

[34] Vogel SA, Roberts JA. Why the toxic substances control act needs an overhaul, and how to strengthen oversight of chemicals in the interim. Health affairs. 2011 May 1;30(5):898-905.

[35] California Green Chemistry Initiative. "California Green Chemistry Initiative Final Report" (PDF). Retrieved April 9, 2014.

[36] John Bachmann, David Calkins, Margo Oge. "Cleaning the Air, We Breathe: A Half Century of Progress." EPA Alumni Association. September 2017.

[37] "Environmental regulations drove steep declines in U.S. factory pollution". Berkeley News. August 9, 2018. Retrieved August 11, 2018.

[38] Kara Manke| October 8, 2018October 8, and Kara Manke. “Clean Water Act Dramatically Cut Pollution in U.S. Waterways.” *Berkeley News*, 8 Oct. 2018, news.berkeley.edu/2018/10/08/clean-water-act-dramatically-cut-pollution-in-u-s-waterways/.

[39] Peter Olins, et al. "New Toxic Substances Control Act: An End to the Wild West for Chemical Safety?" *Science in the News*, 25 Oct. 2016, sitn.hms.harvard.edu/flash/2016/new-toxic-substances-control-act-end-wild-west-chemical-safety/.

[40] Weinmeyer, Richard, et al. "The Safe Drinking Water Act of 1974 and Its Role in Providing Access to Safe Drinking Water in the United States." *Journal of Ethics | American Medical Association*, American Medical Association, 1 Oct. 2017, journalofethics.ama-assn.org/article/safe-drinking-water-act-1974-and-its-role-providing-access-safe-drinking-water-united-states/2017-10.

[41] "News Article." *How Trump Tariffs Are Affecting the Footwear and Apparel Sectors*, www.blcleathertech.com/news/how-trump-tariffs-are-affecting-the-footwear-and-apparel-sectors.

[42] Lincicome, Scott, et al. "Here Are 202 Companies Hurt by Trump's Tariffs." *Cato Institute*, 22 Jan. 2021, www.cato.org/commentary/here-are-202-companies-hurt-trumps-tariffs.

[43] Sewport. "What Is Faux Leather Fabric: Properties, How Its Made and Where." *Sewport*, Sewport, 6 Dec. 2019, sewport.com/fabrics-directory/faux-leather-fabric.

[44] "Types of Synthetic Leather You Ought to Know About." *Home Quicks*, 7 Feb. 2011, homequicks.com/synthetic-leather.

[45] Media, Grit. "What Is Faux Leather Made Out Of?" *Buffalo Jackson Trading Co.*, Buffalo Jackson Trading Co., 6 Oct. 2020, buffalojackson.com/blogs/insight/what-is-faux-leather-made-out-of.

[46] Gurera D, Bhushan B. Fabrication of bioinspired superliquiphobic synthetic leather with self-cleaning and low adhesion. Colloids and Surfaces A: Physicochemical and Engineering Aspects. 2018 May 20;545:130-7.

[47] Thanikaivelan P, Rao JR, Nair BU, Ramasami T. Progress and recent trends in biotechnological methods for leather processing. TRENDS in Biotechnology. 2004 Apr 1;22(4):181-8.

[48] Auer N, Covington AD, Evans CS, Natt M. Enzymatic removal of dung from hides. Journal of the Society of Leather Technologists and Chemists. 1999 Jul;83(4):215-19.

[49] Paul RG, Mohamed I, Davighi D, Covington AD, Addy VL. The use of neutral protease in enzymatic unhairing. Journal of the American Leather Chemists Association. 2001 May 1;96(5):180-5.

[50] Development of a leather processing method in narrow pH profile.
Part 2. Standardization of tanning process. J. Soc. Leather Technol. Chem. 2001; **85**: 106-115

[51] Thanikaivelan P, Rao JR, Nair BU, Ramasami T. Approach towards zero discharge tanning: Exploration of NaOH based opening up method. Journal of the American Leather Chemists Association. 2001 Jun 1;96(6):222-33.

[52] Schlosser L, Hein A, Keller W, Heidemann E. Utilisation of a Lactobacillus culture in the beamhouse. Journal of the Society of Leather Technologists and Chemists. 1986 Nov;70:163-8.

[53] Palop R, Marsal A, Cot J. Optimization of the aqueous degreasing process with enzymes and its influence on reducing the contaminant load. Journal of the society of leather technologists and chemists. 2000 Jul;84(4):170-6.

[54] Development of a leather processing method in narrow pH profile. Part 1. Standardization of unhairing process.
J. Soc. Leather Technol. Chem. 2000; **84**: 276-284

[55] Gehring AG, Dimaio GL, Marmer WN, Mazenko CE. Unhairing with proteolytic enzymes derived from Streptomyces griseus. The Journal of the American Leather Chemists Association. 2002;97(10):406-11.

[56] Thanikaivelan P, Rao JR, Nair BU, Ramasami T. Zero discharge tanning: a shift from chemical to biocatalytic leather processing. Environmental science & technology. 2002 Oct 1;36(19):4187-94.

[57] Saravanabhavan S, Aravindhan R, Thanikaivelan P, Rao JR, Nair BU. Green solution for tannery pollution: effect of enzyme based lime-free unhairing and fibre opening in combination with pickle-free chrome tanning. Green Chemistry. 2003;5(6):707-14.

[58] Aravindhan R, Saravanabhavan S, Rao JR, Nair BU, Thanikaivelan P, Chandrasekaran B. bio-driven lime and pickle free tanning paves way for greener garment leather production. Journal of the American Leather Chemists Association. 2004.

[59] Thanikaivelan P, Rao JR, Nair BU, Ramasami T. Biointervention makes leather processing greener: an integrated cleansing and tanning system. Environmental science & technology. 2003 Jun 1;37(11):2609-17.

[60] Marmer WN. Overview of the USDA hides and leather research program. Journal of the American Leather Chemists Association. 2001 Mar 1;96(3):88-93.

[61] "About Silicone Leather." *Fabric Funhouse*, fabricfunhouse.com/pages/about-silicone-leather.

[62] Stanton, Audrey. "These Leather Alternatives Are Changing The Future Of Sustainable Fashion." *The Good Trade*, The Good Trade, 28 May 2020, www.thegoodtrade.com/features/sustainable-vegan-leather-alternatives.

[63] Madonia, Daniele. "Mushroom Leather / Muskin - Everything about This Vegan Fabric." *DAN AND MÉZ - Sustainable Vegan Watches*, 2 Nov. 2020, danandmez.com/blog/mushroom-leather/.

[64] Liberty Leather Goods. "Pineapple Leather - Vegan Leather from Pineapple Fibers." *Liberty Leather Goods*, Liberty Leather Goods, www.libertyleathergoods.com/pineapple-leather/.

[65] Ricker, M., ed. (1999) What's new in leather chemicals.Leather201(Suppl., September), 6-20

[66] Bornscheuer UT, Bessler C, Srinivas R, Krishna SH. Optimizing lipases and related enzymes for efficient application. TRENDS in Biotechnology. 2002 Oct 1;20(10):433-7.

[67] Pandey A, Benjamin S, Soccol CR, Nigam P, Krieger N, Soccol VT. The realm of microbial lipases in biotechnology. Biotechnology and applied biochemistry. 1999 Apr;29(2):119-31.

[68] Jaquess PA, Elmore ME, Miguel NB, Brown E, Marmer B, May M. Advances In Stabilized Enzymes For Leather Processing. Discussion. The Journal of the American Leather Chemists Association. 1999;94(9):355-61.

[69] Marmer WN. Overview of the USDA hides and leather research program. Journal of the American Leather Chemists Association. 2001 Mar 1;96(3):88-93.

[70] Rasmussen L.Wet blue enzymes–new treatment for area gain. World Leather.2002;15(1):44-5.

[71] Saravanabhavan S, Thanikaivelan P, Rao JR, Nair BU, Ramasami T. Natural leathers from natural materials: progressing toward a new arena in leather processing. Environmental science & technology. 2004 Feb 1;38(3):871-9.