LIFE CYCLE STUDY OF FLEX BANNER AND ITS IMPACT ON THE ENVIRONMENT

Supported by

Department of Materials Science and Engineering,
Indian Institute of Technology Delhi
Hauz Khas, New Delhi - 110016, India

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Project Co-ordinator
Prof. Anup K. Ghosh

Project Team
Mr. Jignesh S. Mahajan
Mr. Debjyoti Banerjee
Ms. Pooja Vardhini Natesan

Department of Materials Science and Engineering
Indian Institute of Technology Delhi
Hauz Khas, New Delhi- 110016, India

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FOREWORD

I am happy to write the foreword for the report "Life cycle study of Flex banner and its impact on the environment" by Department of Materials Science and Engineering, IIT Delhi under sponsorship by All India Laminated Fabric Manufacturers Association. The need for greener approach and environmental impact assessment in all walks of life has been advocated since long and this is crucial for sustainable development. The present report authored by Prof AK Ghosh and his team is a strong testament to the above imperative.

A Flex banner is a digitally printed ubiquitous communication medium. It is most widely used for outdoor advertising as it is flexible, durable, economical and, more importantly, recyclable. Flex banners are utilized not just for commercial advertising but, also to communicate information about various social schemes of the Government. There are hardly any viable alternatives with similar technological functionality. In this study, metallic boards and fabric/cloth banners have been compared with the Flex banners and have been found to be constrained by size restrictions, poor printability, weatherability etc. Large but, expensive, LED screens have also not dented the market for Flex banners. A Flex banner is a three-layered laminated structure wherein the polyester fabric is sandwiched between the films made of compounded PVC resin, CaCO3, plasticizers and additives. The polyester fabric imparts rigidity and durability while the PVC films provide flexibility and enable low cost digital printability of the Flex banners. Over the years, policy support by the Govt. of India has enabled the country to emerge as a major manufacturing hub both for domestic and export markets. Flex banners are printed and installed even by the small and medium businesses. After their usage, Flex banners carry an economic value as they can be reused as tarpaulin, roof covers, vehicle covers, food grain covers, bags, sitting mats etc. Importantly, they can be recycled wherein the constituents are suitably separated and utilized for various applications.

The major aim of the present study has been to provide a comprehensive model illustrating the environmental impact of the key ingredients that are present during the different stages (production, use, reuse and recycling) of the Flex banners with the help of life cycle assessment methodology. I am hopeful that this report will provide an effective learning experience and referenced resource for all the stakeholders.

Anil Wali, Ph.D.
Managing Director
Foundation for Innovation & Technology Transfer
Dean's Complex, IIT Delhi
Hauz Khas
New Delhi 110016

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EXECUTIVE SUMMARY

Communication plays a significant role in the society as it is the foundation of all the human relationships. Outdoor advertising has been effectively used for hundreds of years as a part of the marketing communication. The technological explosion in the digital era has made advertising much easier, cheaper and customized. A Flex banner is a digitally printed advertisement which is primarily kept along the sides of the roads so as to attract the people's attention and make a memorable impression. It can be considered as the most widely used medium for outdoor advertising as it is extremely flexible, cost effective, durable, recyclable and portable. The Government of India utilizes the Flex banners to communicate the various social schemes and regulatory announcements to a large audience in the urban and the rural areas. The commercial advertisements by the private companies help in the extensive marketing of their products/brands/services to the consumers.

According to the Technology Upgradation Fund Scheme (TUFS) launched by the Ministry of Textiles, Government of India, Flex banners have been placed under the category of Technical Textiles.[1] A Flex banner is commonly known as a "PVC banner" in India which is a misnomer as it is a three layer laminated structure wherein the polyester fabric is sandwiched between the films consisting of compounded calcium carbonate ($CaCO_3$), polyvinyl chloride (PVC) resin, plasticizers and additives. The polyester fabric imparts rigidity and durability while the PVC films provide flexibility and enable low cost digital printability of the Flex banners. The Government of India had imposed the Anti-Dumping Duty on the import of the Flex banners in 2010 so as to protect as well as promote the

local production.[2] This initiative enabled India to emerge as a major manufacturing hub for the domestic consumption and exports. In the Report "Single-Use Plastics : A Roadmap for Sustainability" published by the United Nations Environment Programme (UNEP) in 2018, the Flex banners have not been identified as single-use plastic materials.[3] Despite the abundant corporate campaigns insisting on warranties between 1 to 5 years for the usage of the Flex banners, their average lifespan in India is around one year.

Due to the numerous benefits offered by the Flex banners, they serve as the compelling medium for outdoor communication. There are no other commercially viable alternatives with similar technological functionality. In this study, metallic boards and fabric/cloth banners have been utilized for comparison with the Flex banners. They possess various constraints like size restrictions, poor printability, durability and weatherability which severely restrict their usage even at higher costs of fabrication. Large LED screens have not been able to replace the Flex banners for outdoor advertising purposes owing to the sophisticated installation and exorbitant costs of production and maintenance.

The common misconceptions that are associated with the Flex banners are:

- **Flex banners are flammable:** Lab trials as well as international research articles have clearly stated that PVC by itself is self-extinguishing when the source of the flame is removed. In the event of the ignition of PVC during an accidental fire, it mainly contributes in extinguishing rather than spreading the fire.
- **Flex banners generate dioxins:** Due to the self-extinguishing property, the Flex banners do not sustain burning which in turn eliminates the possibility of dioxin generation. Even during the production, the processing temperature of PVC does not exceed 200°C which is much below the threshold temperature.
- **Flex banners are non-recyclable:** Similar to most of the products made from PVC, the Flex banners are also reusable and recyclable which enables them to be used in multiple product life cycles without the degradation of the component materials.

Flex banners clearly belong to the category of B2B products which are printed and installed even by the small and medium business establishments. After their usage, they carry an economic value as they can be reused as tarpaulin, roof covers, truck covers, rickshaw covers, food grain covers, bags, sitting mats etc. They can also be recycled wherein the constituents are separated by means of a mechanical shredding process. The PVC compound can be utilized for flooring and manufacture of footwear, geotextiles etc. while the shredded polyester fabric can be used as soft fillers in the mattresses and pillows. The Government of India had recently issued the Guidelines encouraging the use of plastics including PVC for laying roads.[4] The Central Road Research Institute (CRRI) has been conducting research on the usage of the scrap of the Flex banners for bituminous road construction.[5]

Scope of the Study

The major aim of the present study is to provide a comprehensive model highlighting the environmental impact of the key ingredients that are present during the different stages (Production, Usage, Reuse and Recycling) of the Flex banners with the help of the life cycle assessment methodology.

CHAPTER 1
IMPORTANCE OF LIFE CYCLE ANALYSIS

1.1 Sustainability

Sustainability is the process of change wherein the exploitation of the natural resources, direction of the investments, orientation of the technological development and the institutional changes are in harmony (Figure 1). It results in the enhancement of both the current and the future potential to satisfy the human needs and aspirations. Sustainable management of the resources is crucial in the current scenario owing to their rapid depletion. The economic development and the conservation of the earth's natural systems need to be well balanced.

Figure 1. Pictorial Representation of Sustainability[6]

Joslyn Institute for Sustainable Communities, Nebraska, USA had developed an evidentiary model that depicts the domains (fields of human activity) of sustainability for the human society, bio/ecosystems, communities and Earth.[7] The five major domains are (Figure 2):

- Environmental (Natural and man-made)
- Socio-cultural (Human history, conditions and contexts)
- Technological (Appropriate and sustainable)
- Economics (Production of goods and services within a sustainable context and the financial resources to support the production, trade, operations and maintenance)
- Public Policy (Government or public rules/regulations that support or enhance the sustainable systems)

Figure 2. The Five Domains of Sustainability

1.2 Carbon Footprint

The main challenge in quantifying the emissions for obtaining the carbon footprint is the aggregation of the variable nature of the different materials released into the atmosphere. The simplest solution would be to add up the weights of the discharged materials. However, the amount of discharge of a particular compound may not always be equivalent to the quantity of discharge of another compound. Therefore, the discharges must be weighted on the basis of their properties before aggregation.

Generation of emissions during combustion

Compounds + Air → Unburnt hydrocarbons + Nitrogen oxide + Carbon monoxide + Carbon dioxide + Water + Other pollutants

Formation of Hydrocarbons

$R - H + {}^*O - O^* \rightarrow R^* + HO_2^*$

[Hydrocarbons + Oxygen → Alkyl radical + Peroxide radical]

$R^* + O_2 \rightarrow RO_2^*$

[Alkyl radical + Oxygen → Alkyl peroxide radical]

Formation of Nitrogen oxide

The generation of NO from atmospheric N_2 is governed by the Zeldovich mechanism.

$O + N_2 \rightarrow NO + N$

$N + O_2 \rightarrow NO + O$

$N + OH \rightarrow NO + H$

Formation of Hydrogen chloride

Saturated PVC → Unsaturated PVC + HCl (gas)

Formation of Carbon monoxide

$2C + O_2 \rightarrow 2CO$

Formation of Carbon dioxide

$C + O_2 \rightarrow CO_2$

Formation of Sulphur dioxide

$S + O_2 \rightarrow SO_2$

Carbon footprint is the amount of carbon dioxide released into the atmosphere as a result of the activities of a particular individual, organization or community (Figure 3). The standard ratios can be used for the conversion of the various gases into equivalent amounts of CO_2. These ratios are based on the Global Warming Potential (GWP) of each gas which describes its total warming impact relative to CO_2 over a set period of time (the time horizon is usually 100 years). According to the standard data, methane scores 25 over the time frame (meaning that 1 t of methane will cause the same amount of warming as that of 25 t of CO_2), nitrous oxide scores 298 while some of the super-potent greenhouse gases (GHG) score more than 10,000. The Annual Carbon Emission (ACE) calculator was developed by Catalyst Ltd. which helps in the measurement of the carbon emissions. It is comprised of different measurement options for each activity so as to fit with the mode of the data collection. A simple Microsoft Excel workbook is utilized to input the data on the energy usage, wastes, refrigerant loss (if

Figure 3. Correlation of the Carbon Footprint with the Emissions[8]

applicable) and travel (aircraft and taxi) in the appropriate month's sheet. The results are displayed as a graph of cumulative annual emissions which help to keep track of the carbon emissions of an activity/process. The provided charts have pre-set destinations for air and road transport which aid in the estimation of the distance travelled. Standard emission factors are used to convert the energy to emissions for the incorporation of the non-CO_2 gases (given in terms of CO_2 equivalent).

With the increasing sustainability claims throughout the globe, various environmental assessments viz., life cycle analysis (LCA), carbon footprint analysis, water footprint analysis, corporate social responsibility (CSR) report, volatile organic compounds (VOC) testing, environmental risk assessment etc. are being employed. LCA and carbon footprint analysis are the most commonly utilized assessments and they possess a number of similarities as well as differences. The inventory of the GHG emissions during the life cycle of a product and its impact on the climate change can be known from its carbon footprint (Figure 4). Therefore, it is a subset of the life cycle assessment.

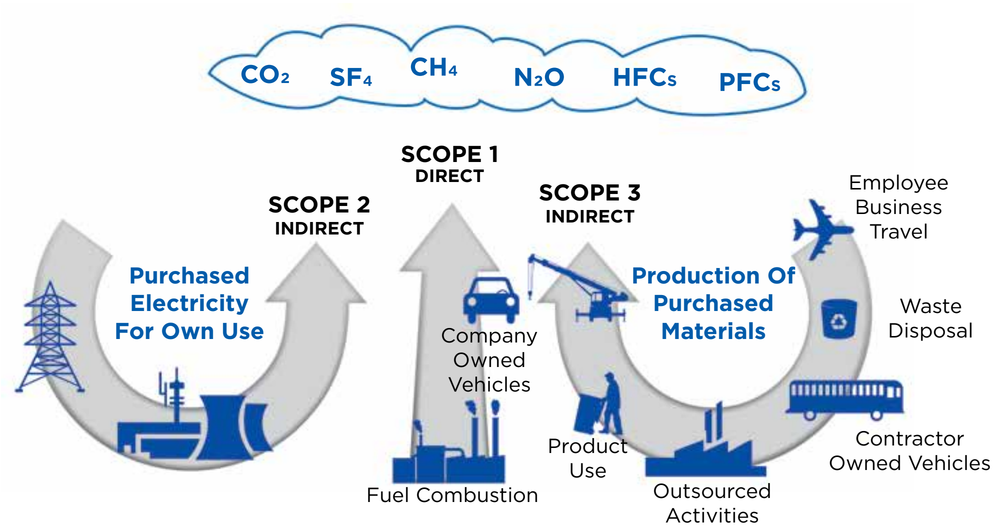


Figure 4. Carbon Footprint Analysis[9]

In addition to the GHG emissions, the LCA takes into account all other material and energy inputs and environmental releases so as to measure the potential environmental effects of a product, process or service during its life cycle. The spectrum of the categories of impact is broad which includes human health, ecosystem degradation, climate change and natural resource depletion. Hence, LCA is a multicriteria analysis that assesses the numerous factors affecting the environment while the carbon footprint is essentially a monocriterion analysis as it focuses only on the climate change. Both methods rely on the functional approaches for the impact assessment. A functional unit or the quantified performance of a studied product serves as the basis for these analyses and enables to draw a comparison between similar products. In the recent years, there has been an emergence of strong interest to assess the environmental effects associated with the commonly used products. The LCA is a comprehensive environmental and resource assessment of the consequences of all the processes involved from the birth to the death of the compounds viz., procurement of the raw materials, production of the compounds, usage and post-disposal with a possibility for recycle and reuse (Figure 5).

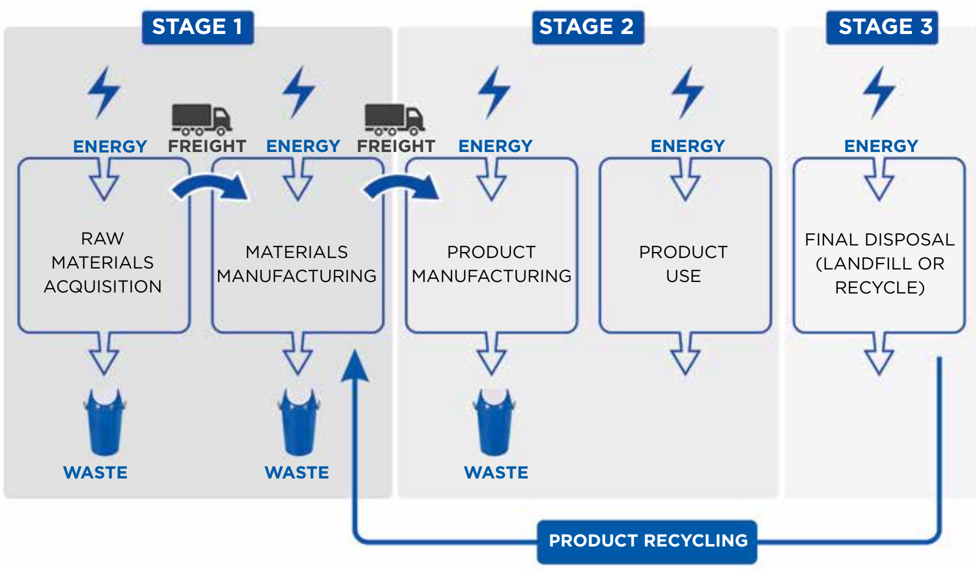


Figure 5. Different Stages of the Life Cycle Analysis[10]

1.3 Methodology

LCA involves the investigation of all the inputs (materials, energy, capital, equipment, man-hours) and outputs (product, by-products, wastes, emissions) (Figure 6). The two stages which are primarily involved in the life cycle analysis are the collection of the inventory of the inputs and outputs and assessment of their impact on the environment (Figure 7).

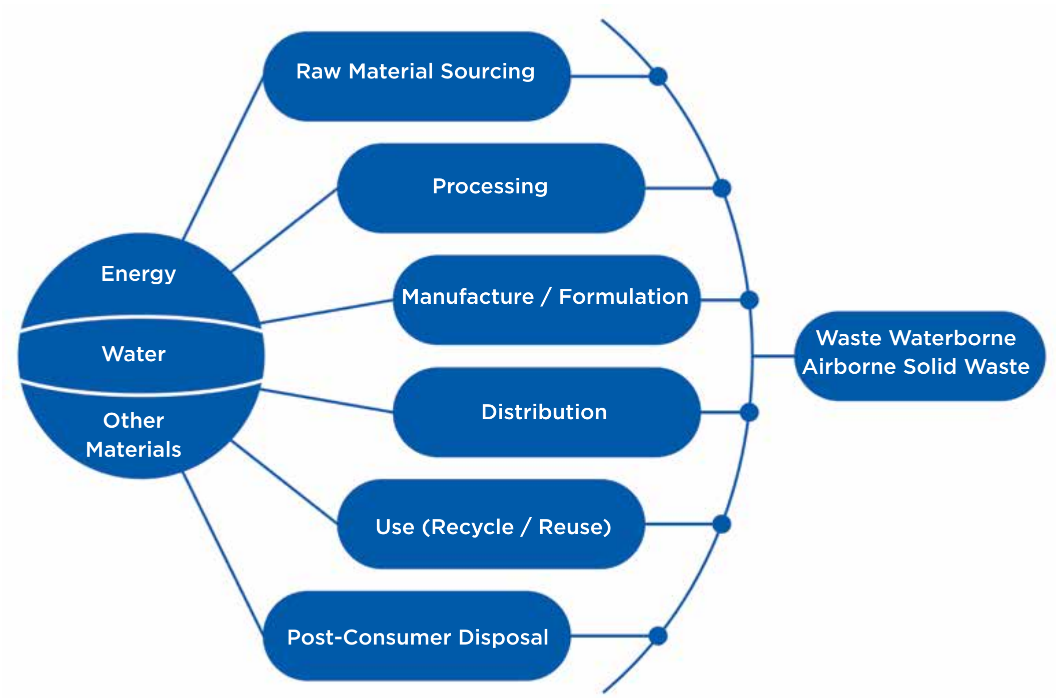


Figure 6. Various Inputs and Outputs Involved in the Life Cycle Analysis

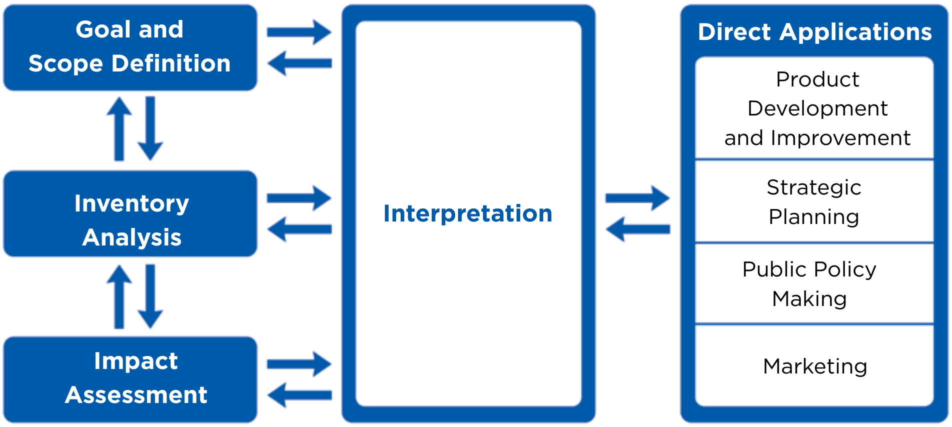


Figure 7. LCA Methodology

The societal impacts are the consequences of the social relations (interactions) weaved in the context of an activity (production, consumption or disposal) and the preventive or reinforcing actions taken by the stakeholders for their well-being (for example, enforcement of safety measures). Behaviours, socio-economic processes and capitals (human, social, cultural) are the causes for the societal impacts. Each stage (and their unit processes) in the life cycle of a product can be associated with the geographical locations where the processes are carried out (mines, factories, roads, rails, harbours, shops, offices, recycling firms, disposal sites). The stakeholders are those who are potentially impacted by the product's life cycle. The five major categories of the stakeholders are:

- Workers/employees
- Local communities
- Society (national and global)
- Consumers
- Value chain actors

Each category consists of a cluster of stakeholders who are expected to have shared interests due to their similar relationship with the investigated product systems. These categories provide a comprehensive basis for the articulation of the sub-categories (management, shareholders, suppliers, business partners) and addition of other categories (NGOs, public authorities, future generations).

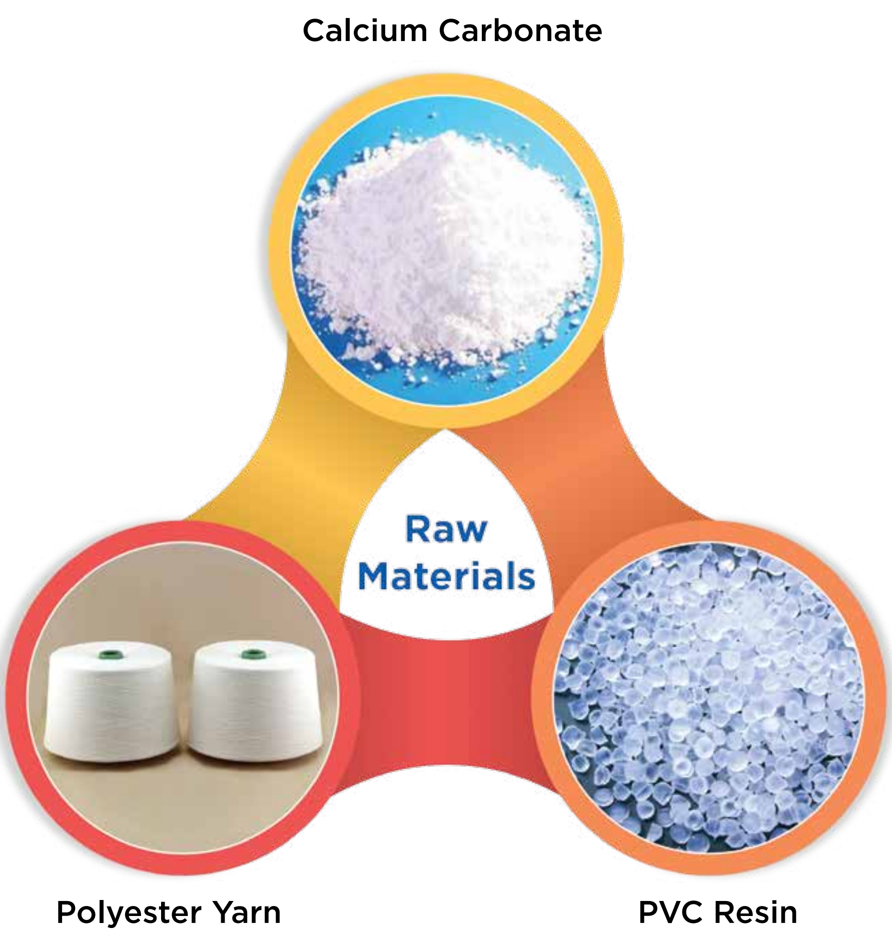
1.4 Benefits

As the citizens, companies and Governments are involved in a product's life cycle (from cradle to grave), all the relevant impacts on the economy, environment and society need to be taken into account while deciding the policies, management strategies, consumption and production patterns. The life cycle approach enables the product designers, service providers, Government agents and individuals to make the right choices for the long term with a consideration of the environmental media (air, water and land). The various advantages of LCA are as follows (Figure 8):

- **For the Industries:** Integration of the life cycle perspective in the overall management and sustainable product development by the Organization can give rise to several benefits in terms of the environment, occupational health and safety, risk and quality management. The brand value will be enhanced for the global players as well as the small suppliers.
- **For the Government:** The Governmental initiatives will strengthen the position of the industrial and service sectors in the regional and international markets and ensure that the economic development occurs while providing the overall environmental benefits to the society. Implementation of supportive programmes and life cycle approach and dissemination of the sustainability options by the Governments help in the global exposure of their social responsibility and proficient governance.
- **For the Consumers:** Life cycle approach facilitates the consumption to take place in a more sustainable manner by delivering better information about the purchase, transport systems and energy sources. It offers guidance to the consumers regarding the national and international strategies for the sustainable development. It also provides a platform for the multi-stakeholder discussions and improves the public involvement with the industries and Governments.

Figure 8. Benefits of LCA

CHAPTER 2
MAJOR CONSTITUENTS



Flex banners are highly preferred for low cost outdoor marketing of products/brands and promotion of events all over the world, including the developed economies viz., United States, European Union and Japan which have much stricter environmental policies and regulations. They are digitally printed with a wide range of rich colours to attract the attention of the people. They can be hung from an existing fixture, fixed to a wall or free standing. A Flex banner is manufactured by laminating the polyester fabric between two compounded PVC films as shown in Figure 9. The typical composition of a Flex banner is provided in Table 1. The most commonly used Flex banners are of 250 GSM of which the top PVC film contributes to 100-120 GSM, bottom PVC film is of 85-95 GSM and the polyester fabric is about 39-45 GSM.

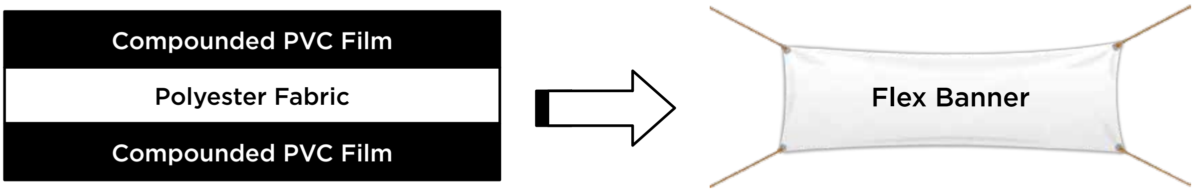


Figure 9. Structure of a Flex Banner

Table 1. Major Constituents of a Flex Banner

Materials	Composition (wt.%)
Calcium Carbonate	36
PVC Resin	33
Polyester Fabric	18
Plasticizers	9
Additives	4
Total	**100%**

2.1 Calcium Carbonate

Calcium carbonate constitutes to more than 4% of the Earth's crust and can be found all over the world. Its natural forms include chalk, limestone and marble which may be chemically identical but, they differ in many other aspects viz., purity, whiteness, thickness and homogeneity. They are produced by the sedimentation of the shellfish, corals and shells of the snails which were fossilized over millions of years ago. Chalk is a fine, microcrystalline material which is used as a writing tool. Limestone is a biogenic rock and is more compact than chalk. Marble is a coarse-crystalline, metamorphic rock which is formed when the chalk or limestone is recrystallized under high temperature and pressure. Large deposits of marble are found in North America and Europe for example, Carrara, Italy is the home of the pure white Statuario marble which was utilized for the creation of the sculptures by Michelangelo. Calcium carbonate is extracted by mining or quarrying and possesses an extraordinary value since it is exploited for many industrial applications. Pure calcium carbonate can be derived from marble while precipitated calcium carbonate (PCC) is obtained by passing carbon dioxide through calcium hydroxide solution. PCC has a very fine and controlled particle size with the diameter in the order of 2 μm and is particularly useful for the production of paper. Crushing and processing of limestone results in a powder called ground calcium carbonate (GCC) which is graded by size and is highly suitable for industrial and pharmaceutical applications. The study of calcium carbonate reveals several important lessons about the history of the Earth as the origin of its natural forms can be traced to shallow water. Large chalk deposits of the same age are found in many continents which led to the conclusion that there was shallow water world-wide wherein the shelled organisms thrived. This was also regarded as a proof for the Biblical flood. The protective shells and skeletons of the living organisms are made of calcium carbonate for example, eggshells are composed of approximately 95% of $CaCO_3$.

Calcium carbonate is one of the most versatile and extensively used materials in the everyday life of the humans (Figure 10). It is a widely exploited mineral in the paper, plastics, paints and coatings industries as a coating pigment owing to its special white colour and as a filler material. Its enhanced brightness and light scattering characteristics are highly valued hence, $CaCO_3$ is used as an inexpensive filler at the wet-end of the paper making machines for the fabrication of bright, smooth and opaque paper. It is also utilized as a filler during the production of adhesives and sealants. As an extender, calcium carbonate represents as much as 30% by weight in the paints. It is employed as an effective dietary calcium supplement, antacid, phosphate binder, base material for medicinal tablets, baking powder, toothpaste, dry dessert mixes, dough and wine. It is extremely indispensable in the construction industry as it serves as a building material in its own right (marble) and as an essential ingredient of cement. It contributes in the manufacture of mortar which is present in the bonding bricks, concrete blocks, stones, roofing shingles, rubber compounds and tiles. $CaCO_3$ decomposes into carbon dioxide and lime which is an important material for the production of steel, glass and paper. Calcium carbonate is an active ingredient of the agricultural lime and is used as a calcium supplement in the animal feed compounds. It is employed for the neutralization of the acidic conditions in both the soil and water because of its significant antacid properties. It highly benefits the environment as it can be used for flue gas desulphurization, drinking water and waste water treatment. Due to its natural buffer effect, it works as a pollution filter. The Greeks and Romans utilized $CaCO_3$ as fertilizers as it guarantees an adequate supply of calcium to the plants and stabilizes the pH of the soil. In Europe, more than 4.5 Mt of calcium carbonate is being supplied to this market every year. Industrial manufacturers rely on $CaCO_3$ as it has a multitude of characteristics which make it an ideal raw material for the fabrication of glasses, ceramics, chalk, cleaning products, dental care and cosmetics. Diverse requirements such as low iron oxide content for the production of high quality glasses, authorization for uses in foodstuffs, good buffering effect, low abrasion etc. can be met by an existing grade of calcium carbonate. The crystals of $CaCO_3$ are referred to as calcite which is generally considered as a rhombohedron. It is unique as its cleavage takes three distinct directions. There are more than 300 forms of calcite crystals which possess different colours, but are commonly white or transparent. Another important property of the calcite crystal is the double refraction i.e., when a ray of light travels through a medium, it gets split into two beams which travel with different speeds and are bent at two different angles of refraction. This phenomenon results in the formation of two images and is valuable for a number of optical applications.

Figure 10. Various Applications of $CaCO_3$

2.2 Polyvinyl Chloride

According to PlasticsEurope (Association of Plastics Manufacturers), Brussels, the global production of plastics has continued to rise and a total volume of about 280 Mt was attained in 2011 (2010: 265 Mt). The thermoplastics accounted for about 233 Mt while the remaining volume was divided among the elastomers, coatings, adhesives and sealants (Figure 11).

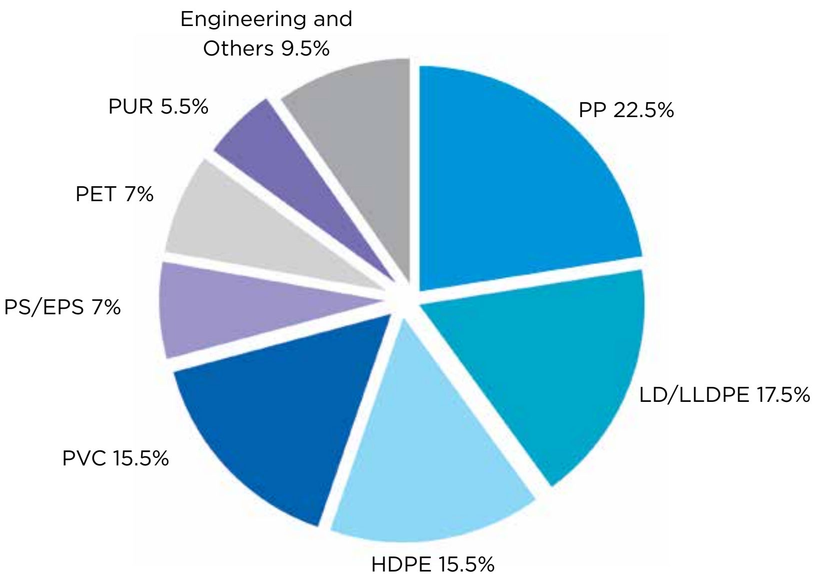


Figure 11. Global Consumption of Plastics in 2011[11]

PVC is one of the most important and abundant plastics which finds widespread use in the fields of construction, transportation, packaging, electrical/electronics and healthcare. 57% of the molecular weight of PVC is derived from common salt while the hydrocarbon feed stocks contribute to the remaining 43%. More than 50 Pt of salt is dissolved in the seas and over 200 Gt of salt is available underground. Ethylene acquired from the oils equates to 0.3% of the annual oil usage but, increasingly ethylene obtained from the sugar crops is being used for the PVC production. Northeast Asia accounts for over 50% of the global supply of PVC with China being the prime player in the global vinyl market owing to its enormous demand, capacity and output. The demand for PVC emerged in China during the 1990s which accelerated rapidly and made China as the world's largest PVC importer. The tremendous growth in the demand resulted in massive investments in vinyls enabling the country to move towards self-sufficiency. There continued to be an upward trend in the PVC demand thus, exceeding the capacity in the recent years. As it is a highly competitive market, there are many PVC manufacturers in the world. Shin-Etsu Chemical (Japan) possessed the highest production capacity of 3850 kt in 2016 which was followed by Formosa Plastics (Taiwan) with a production capacity of 3300 kt (Figure 12).

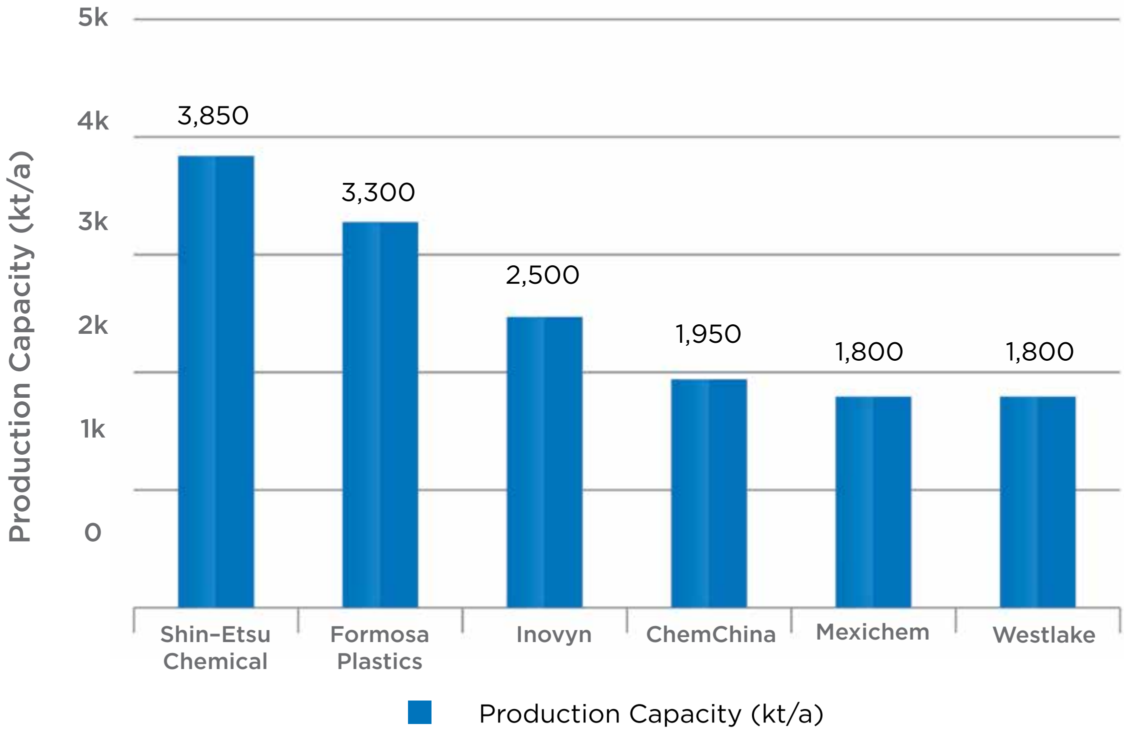


Figure 12. Leading Manufacturers of PVC in 2016[12]

The global consumption of PVC was about 5.5 kg per capita in 2016. The Asia-Pacific region had the maximum contribution in the global consumer market with China (12 kg per capita) and India (2.5 kg per capita) holding the largest shares (Figures 13 and 14).

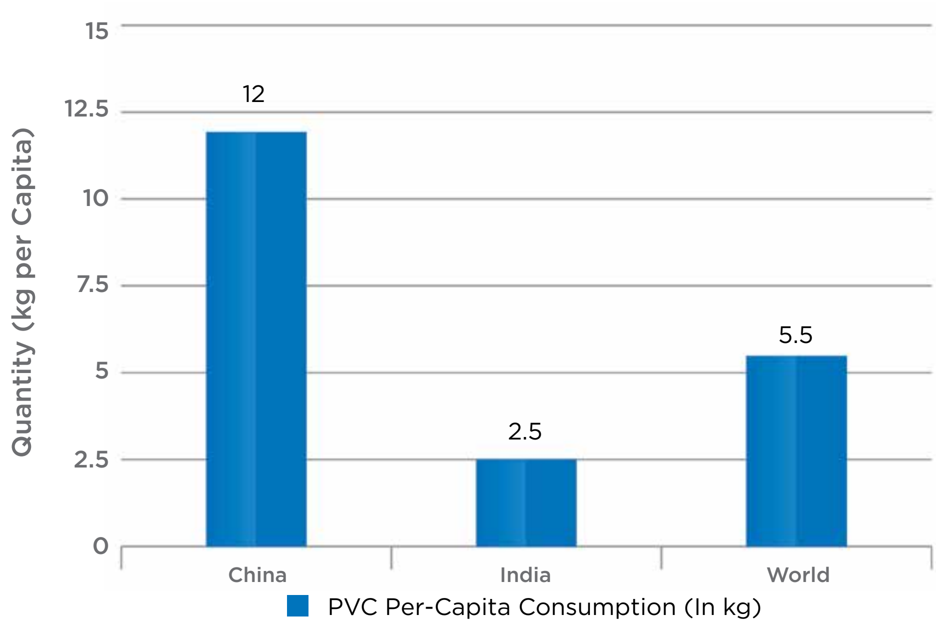


Figure 13. Per Capita Consumption of PVC in 2016[12]

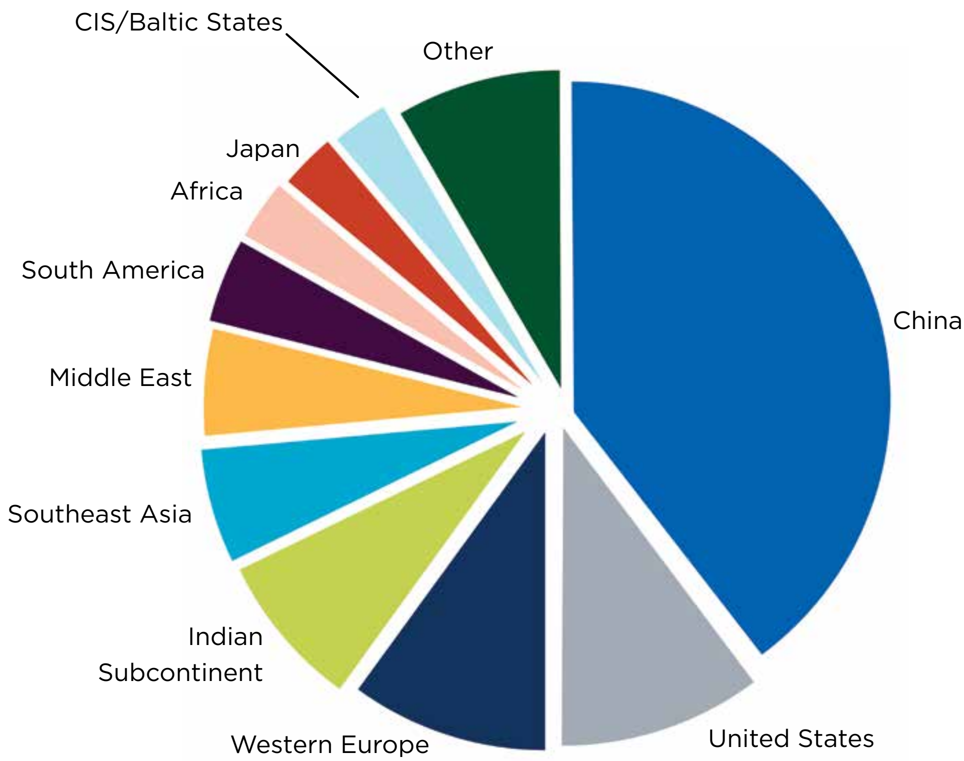


Figure 14. Global Consumption of PVC in 2016[13]

According to the industry estimates, there had been a remarkable growth in the Indian PVC market by about 10% (2.7 Mt) during 2015-2016. The imports had rapidly increased by 16% (1.6 Mt) which surpassed the domestic production. In India, nearly 74% of PVC was consumed for the fabrication of pipes and fittings (Figure 15). This is in stark contrast as this sector accounted for only 43% of the global PVC consumption (Figure 16). India's per capita PVC consumption is around 2.5 kg which is much lower when compared to the United States (11.8 kg) and China (12 kg). The PVC capacity of India has been presented in Table 2.

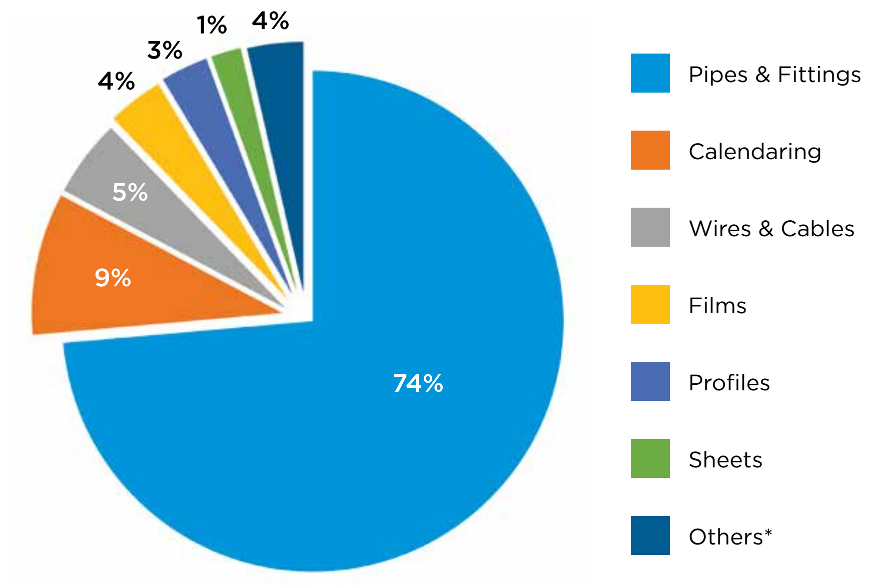


Figure 15. Indian PVC Demand Split in the 2015-2016 Fiscal Year[14]

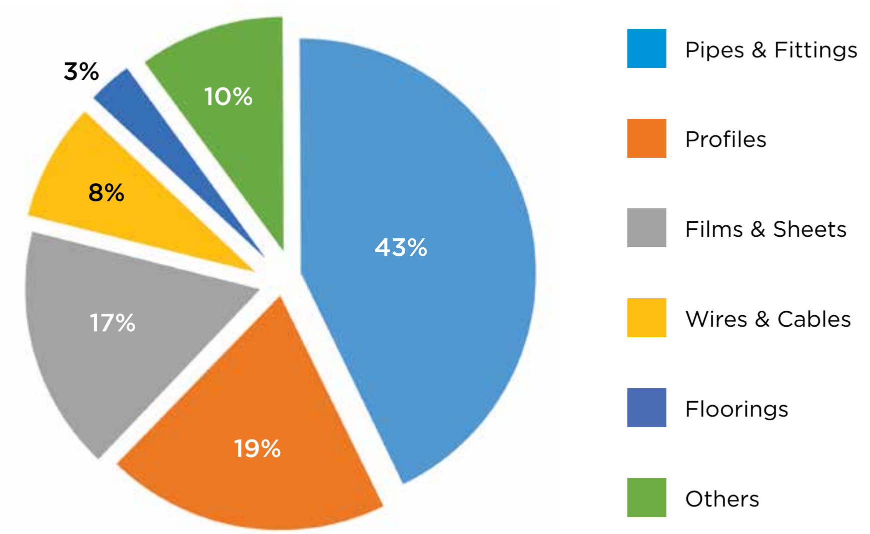


Figure 16. Global PVC Demand Split during the 2015-2016 Fiscal Year [14]

Table 2. Indian PVC Capacity in 2016[15]

Company	Location	Capacity ('000 Tonnes)
Reliance Industries	Hazira, Gujarat Dahej, Gujarat Vadodara, Gujarat	360 315* 80
Chemplast Sanmar	Cuddalore, Tamil Nadu	270*
Finolex Industries	Ratnagiri, Maharashtra	260
DCW	Sahupuram, Tamil Nadu	90
DC	Kota, Rajasthan	70**

*After debottlenecking
**PVC produced by calcium carbide route

PVC is an extremely durable construction material and possesses a wide range of colours. PVC pipes are flexible and can be used for construction, transportation lines, sewage, fittings etc. It can also be formed into sheets/films (transparent, opaque or coloured) which cater to the needs of a variety of industrial sectors for example, automobile and stationery. PVC cables are commonly used for several electrical applications. PVC is extensively employed for the fabrication of blood collection bags, drug collection bags, syringes, needle covers etc. Synthetic leather can be produced from PVC which is utilized for the manufacture of hand bags, car seat covers etc. PVC is also being exploited for attractive flooring and other decorative purposes (Figure 17).

Figure 17. Wide Range of Applications of PVC

PVC is a linear and strong polymer wherein the monomers are mainly arranged in the head-to-tail configuration i.e., there are chlorides on alternating carbon centres. There is some degree of syndiotacticity in the chain which influences the properties of the material for example, crystallinity of the polymer. About 57% of the mass of PVC is chlorine and the presence of these chloride groups imparts properties that are different from the structurally similar polyethylene. Vinyl chloride monomer (VCM) or chloroethene ($H_2C=CHCl$) is a colourless organochloride gas with a sweet odour. It is among the largest produced petrochemicals in the world (about 13 Mt per annum). The United States is currently the prime VCM manufacturing region because of its low production cost of chlorine and ethylene raw materials. In the past, VCM was utilized as a refrigerant. It can be formed in the environment when the organisms in the soil break down the chlorinated chemicals hence, it is a common contaminant found in the landfills. VCM is an industrially important chemical as it is the starting material for the synthesis of PVC through several polymerization techniques viz., suspension polymerization (80%), emulsion polymerization (12%) and bulk polymerization (8%) (Figure 18).

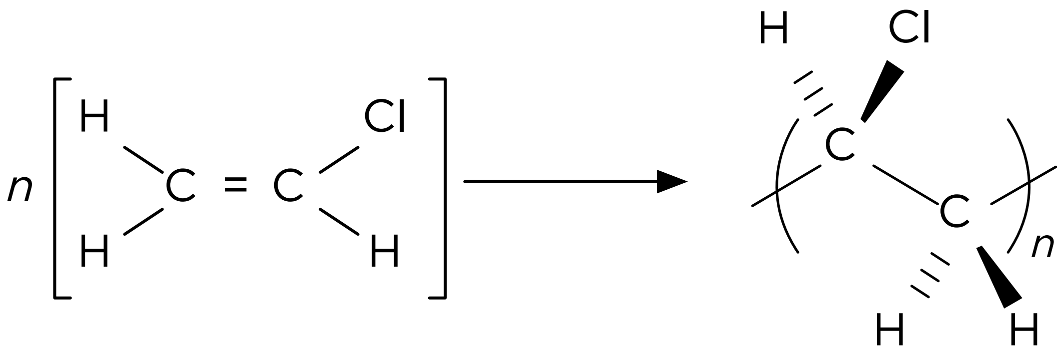


Figure 18. Polymerization Reaction of PVC

Suspension polymerization yields particles with an average diameter of 100-180 μm whereas smaller particles with an average size of 0.2 μm are obtained during emulsion polymerization. VCM, water, polymerization initiator and other additives are introduced into the reactor and pressurized. They are continuously stirred to ensure that the particle size of the PVC resin is uniform. Water is regularly added to the reaction mixture so as to maintain the suspension. As this reaction is exothermic, cooling is required. PVC is denser than VCM due to the significant reduction in the volume during the reaction. The polymerization initiators typically include dioctanoyl peroxide and dicetyl peroxy dicarbonate which possess fragile O-O bonds. Hence, these compounds break down in order to start the radical chain reaction. A combination of two different initiators is used to maintain a uniform rate of polymerization. The polymerization reaction then continues to take place with the help of the precipitated, solvent-swollen particles. The weight average molecular weight of the commercial polymers lies in the range of 100,000-200,000 Da while the number average molecular weight is about 45,000-64,000 Da. Once the reaction completes, the resulting PVC slurry is degassed and stripped to eliminate the excess VCM which is recycled. The polymer is then passed through a centrifuge for the removal of water. The slurry is further dried in a hot air bed and the resulting powder is sieved before storage or pelletizing. Normally, the resulting PVC has a VCM content of less than 1 ppm. The other processes like micro-suspension polymerization and emulsion polymerization produce PVC with smaller particle size and slightly different properties (Figure 19).

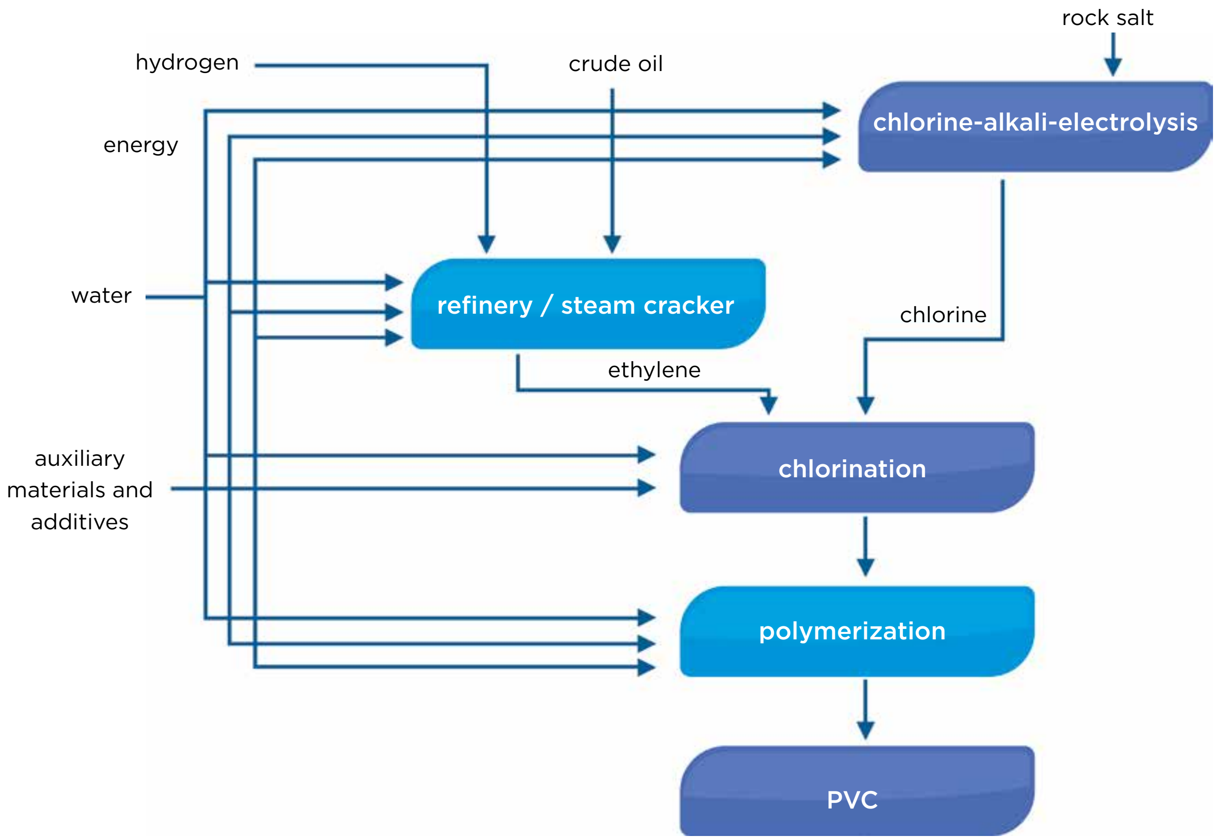


Figure 19. Flow Chart for the Production of PVC

2.3 Polyester Fabric

Polyester is a man-made, synthetic and long chain polymer and is chemically composed of an ester (85% by weight) which is an organic salt formed due to the chemical reaction between an alcohol and an acid. Polyester is a medium weight fibre with a density of 1.39 g/cm^3 and consists of polyethylene terephthalate polymers. It is heavier than nylon but, lighter than cotton. It is chemically inert to most of the chemicals, hydrophobic and possesses good strength and fungus resistance. In 1998, the share of the polyesters accounted for 34.1% of the overall fibre market whereas in the recent years, it accounts to almost half of all the fibres consumed by the mills globally. This share is expected to increase to 57.4% by 2020. There will be a significant reduction in the consumption of the cotton fibres (39.2% in 1998 to 25.5% by 2020). The share of the cellulosic fibres will increase from 4.7% in 1998 to 6.2% in 2020. Its current share is around 5.8%. Owing to the improved functionality of the polyester, wool and acrylic will also lose their shares from 3% and 5.6% to 1.1% and 1.7% respectively during the period of 1998 to 2020. In India, cotton dominates the fibre market with a share of over 50% while the share of the polyesters is more than 40%. According to Wazir Advisors, the trend is expected to change over the next five years. By 2020, the share of the polyester fibres in the total mill consumption will be around 46% while that of cotton will be 43%. This is also expected to escalate to 53% by 2030 and cotton's share will drop to 32% (Figures 20 and 21).[12]

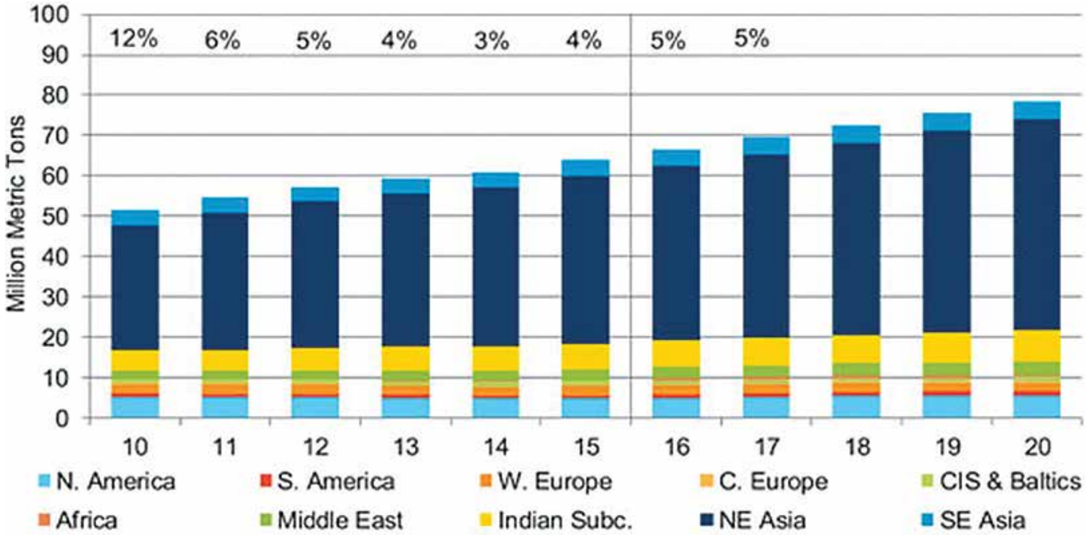


Figure 20. Region-Wise Polyester Demand in 2016[16]

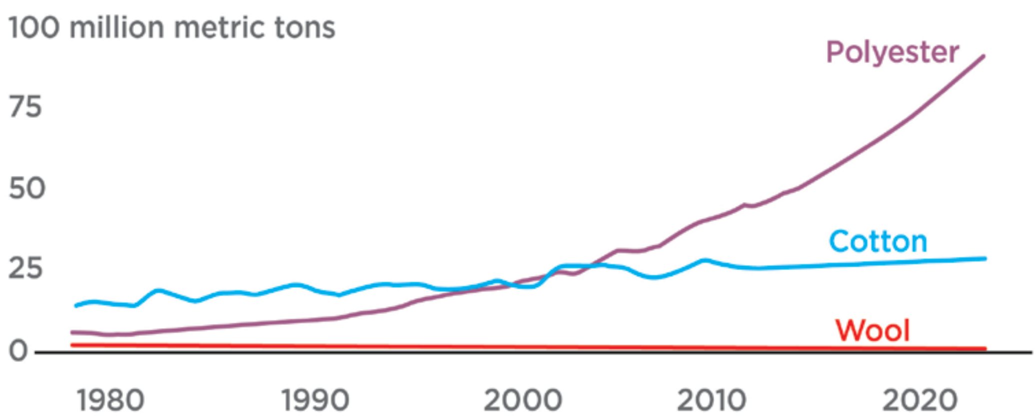


Figure 21. World Fibre Production[17]

Polyester is produced by heating terephthalic acid with excess of ethylene glycol in an atmosphere of nitrogen initially at the atmospheric pressure. A catalyst like hydrochloric acid can be used to speed up the reaction. There are two major steps in the synthesis of polyesters. The first step is the ester interchange (EI) in the dimethyl terephthalate (DMT) route or direct esterification (DE) in the purified terephthalic acid (PTA) route. Both produce a mixture of ethylene glycol esters of terephthalic acids. The second step is polycondensation which is common for both the routes. The resulting low molecular weight ethylene glycol terephthalate is heated for 30 minutes at 280°C and atmospheric pressure and then for 10 hours under vacuum. The excess of the ethylene glycol is distilled off and the ester polymerizes to form a new product which is hard, white and possesses high molecular weight of 8000-10,000 Da and melting point of 256°C. The polymer which is in the form of a ribbon is extruded in order to obtain chips. They are dried to remove the moisture and are fed into the hopper of the extruder machine. The polymer melts and gets extruded under high pressure through the spinnerets. Each spinneret consists of 24 or more holes/openings from which the yarns/filaments are drawn. A lubricant or an antistatic agent is applied on the filaments so that the individual fibres remain separate and do not agglomerate. The undrawn yarn is then wound onto the cylinders and is taken to the drawing zone wherein the draw twist machines extract it to about four times of its original length. Staple fibres are produced from a bunch of filaments and are passed through a crimping machine. The crimps are stabilized by heating in ovens, cut into specified lengths, baled and ready for dispatch (Figure 22).

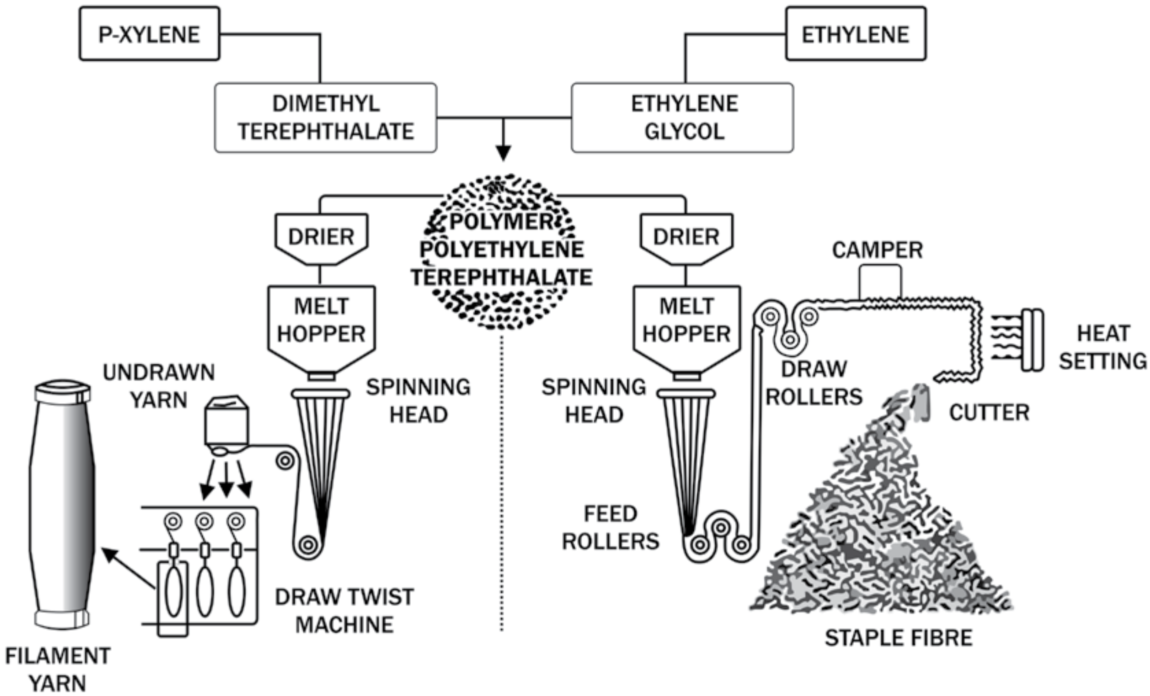


Figure 22. Fabrication of the Polyester Fibres[18]

CHAPTER 3
PRODUCTION PROCESS

The different steps involved in the production of the Flex banners are schematically shown in Figure 23.

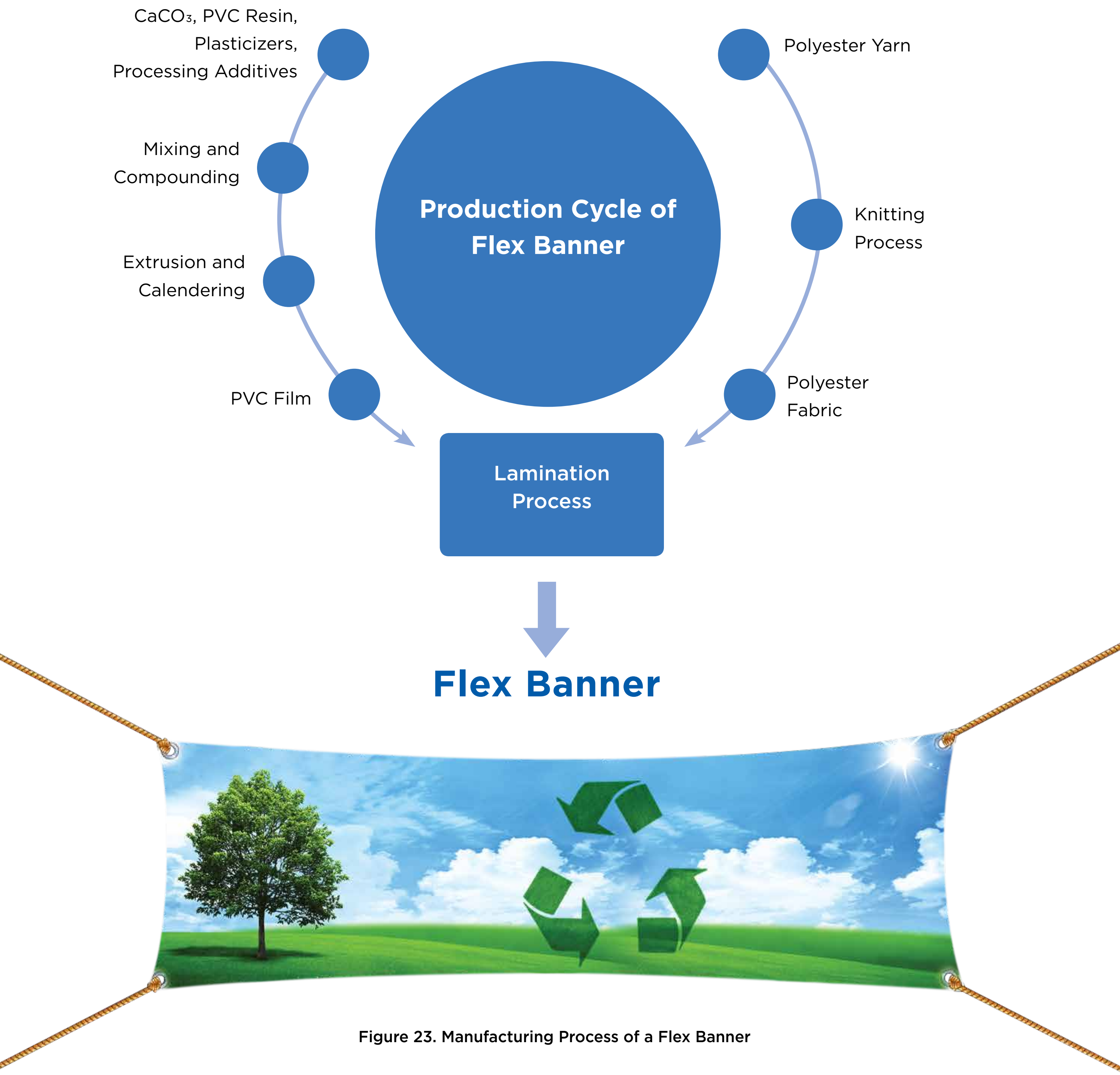


Figure 23. Manufacturing Process of a Flex Banner

3.1 Fabrication of the PVC Films

The sequence of the various processes associated with the manufacture of the compound PVC films is illustrated in Figure 24.

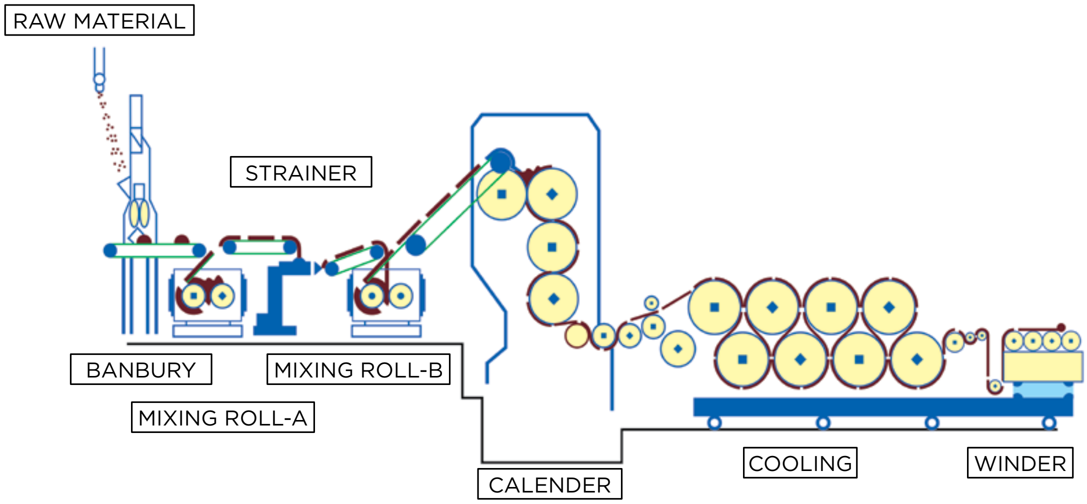


Figure 24. Production of the PVC Films[19]

The basic raw materials viz., $CaCO_3$, PVC resin, additives and plasticizers are uniformly blended with the help of high speed mixers so as to improve the processing quality. For further homogenization, the compound is fed into the Banbury mixer wherein it is subjected to high pressure and temperature. The Banbury mixer is a tangential mixing machine which has two slightly spiralled counter rotating rotors for proper mastication (Figure 25).

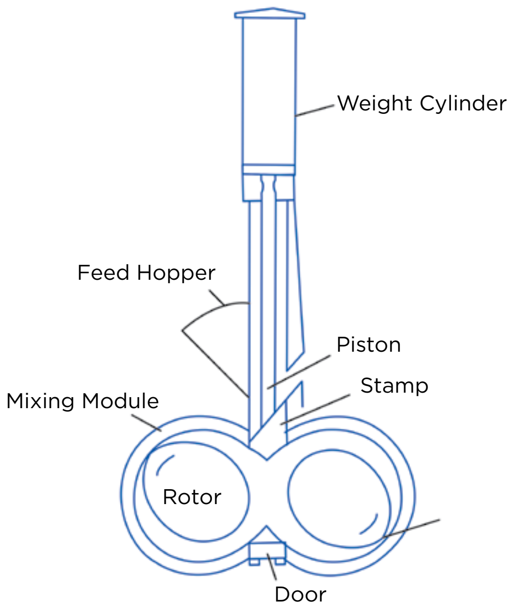


Figure 25. Banbury Mixer[20]

A rolling/reduction mill consists of rolls, gear box, motor, bearings, speed control devices and hydraulic systems. The basic configuration of a rolling mill is the two-high non-reversing wherein the rolls turn in only one direction. The two-high reversing mill has rolls that can rotate in both the directions so that the workpiece can be fed from either direction (Figure 26). The heated lump discharged from the Banbury mixer is placed in the nip formed between the rolls and the compound is mixed by cutting it off the rolls and re-feeding it into the nip. The compound gets thoroughly blended in the roll mill at high shear resulting in complete homogenization and degassing. The material is then pressed between the two rolls to yield a thick sheet whose thickness depends on the gap between the rolls.

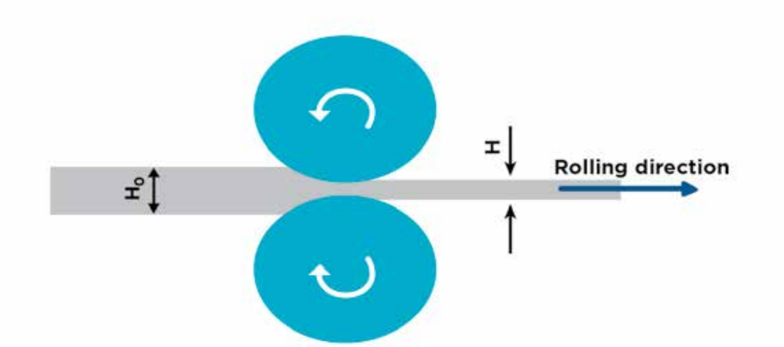


Figure 26. Two-High Rolling Mill[21]

The material (in the form of a strip) is transported from the roll mill to the strainer extruder for further mixing and segregation of the impurities (Figure 27). It enters into the hopper and comes in contact with a rotating screw which pushes the material into the barrel towards the head of the extruder. The barrel is heated using the heating elements, the head is periodically cleaned and the sieves are changed accordingly.

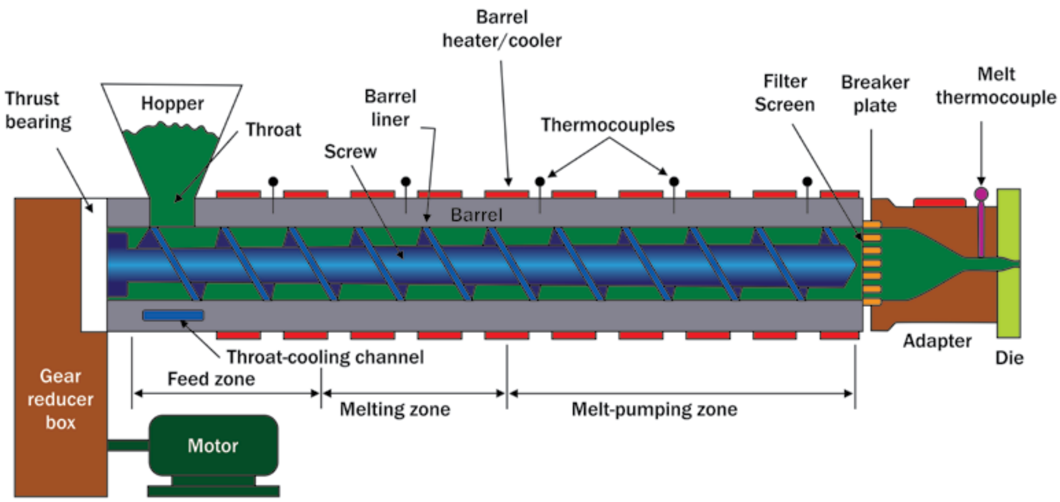


Figure 27. Extrusion Process[22]

The five main components of an extruder are screw, extruder drive, barrel, feed hopper and die (tubing/ flat film). The helical screw is the most important part of an extruder which is employed for the transport, heating, melting and mixing of the plastics. The extruder drive is an electric motor that supplies power to rotate the screw. The stability and quality of the products are highly dependent on the design of the screw. The outer barrel is responsible for the heating and cooling functions. The feed hopper holds the plastic pellets and ensures that they flow steadily into the barrel through the feed throat. The die is placed at the end of the extruder which determines the shape of the product. An additional roll mill is provided for better mixing thereby, improving the quality of the film. The well mixed compound of PVC and calcium carbonate (feed stock) are transported to the calendering machine through a conveyor. Calendering is the process of compression of a thermoplastic material between two or more steel rolls at a particular temperature and pressure in order to fabricate sheets/films of required thickness and width (Figure 28). The temperature and the speed of the rolls influence the properties of the produced film. The film is then embossed, cooled using a series of cooling rolls and wound at an ambient temperature in the winding unit. The calendering process is unique in its ability to manufacture very thin films possessing high quality, enhanced lustre, smooth surface, reduced air porosity and a large width of 4-6 m (Figure 29).

Figure 28. Calendering Machine

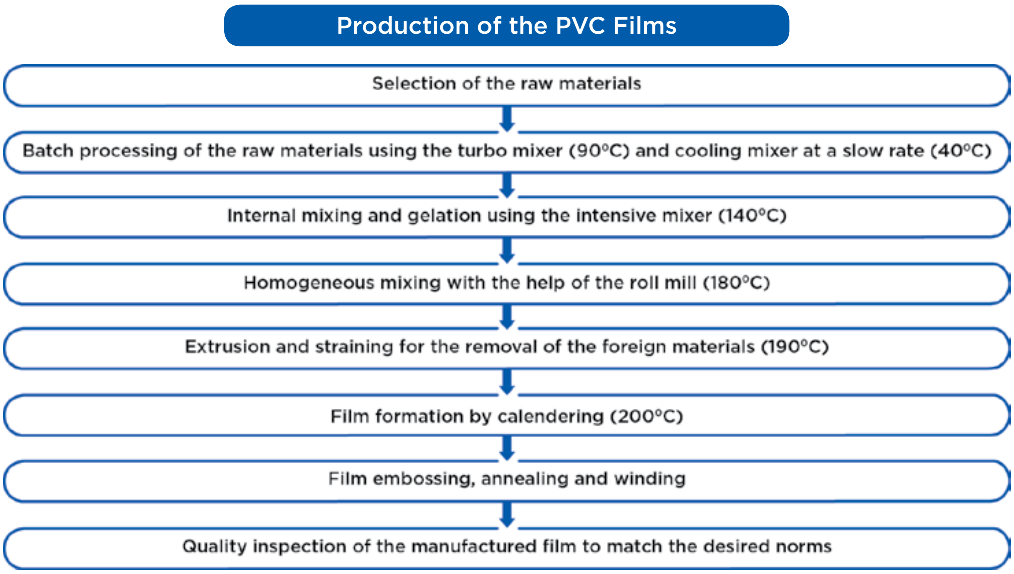


Figure 29. Sheet Fabrication Technique

3.2 Production of the Polyester Fabric

Knitting is the process used for the manufacture of the polyester fabric in the form of a series of intermeshed loops from the industrial or fully drawn yarns (Figures 30 and 31). The knitted fabrics are more stretchable than the woven fabrics. The fabric is made of weft and warp yarns of 150-200 D and stitching yarns of 70 D. The loops (building blocks) are formed from each yarn and are present along the length of the fabric. The parallel warp yarns are supplied in the form of sheets that are extracted from a single or multiple warp beams. The stitching yarns are fed to the needles using guide bars which swing laterally.

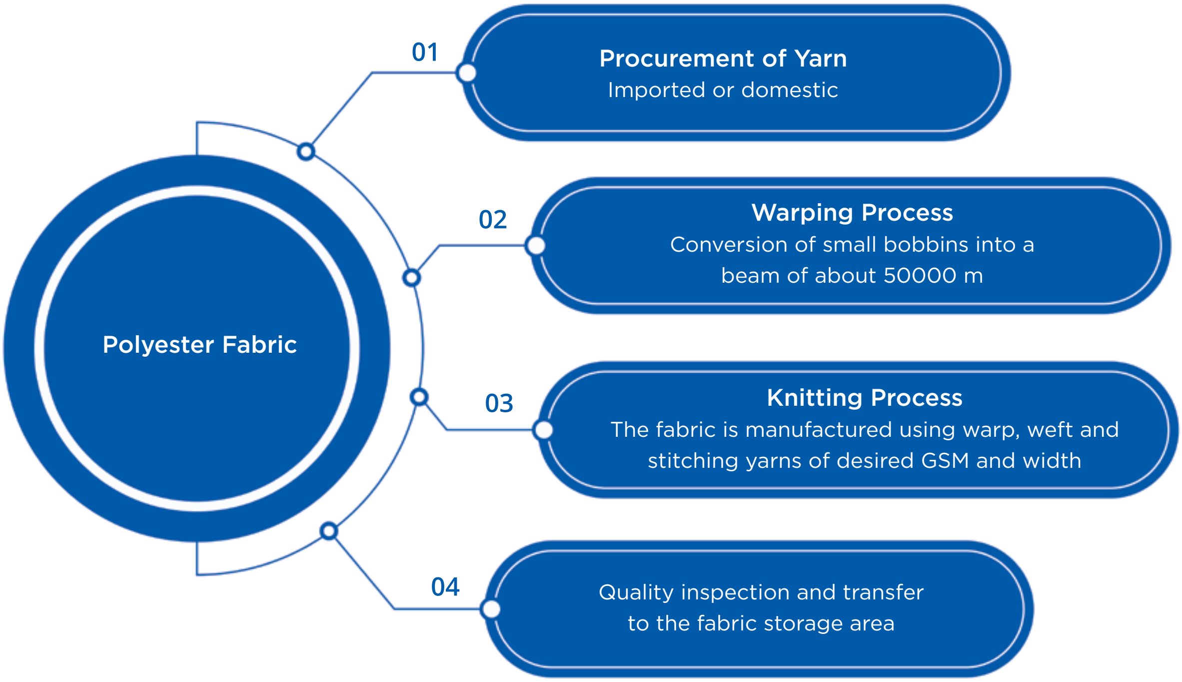


Figure 30. Production of the Polyester Fabric

Figure 31. Knitting of the Polyester Fabric

3.3 Lamination

The polyester fabric is sandwiched between the two compounded PVC films by the thermal fusion process (Figure 32). The composite material hence obtained is the Flex banner which possesses improved strength, stability, insulation, appearance, surface and other important properties.

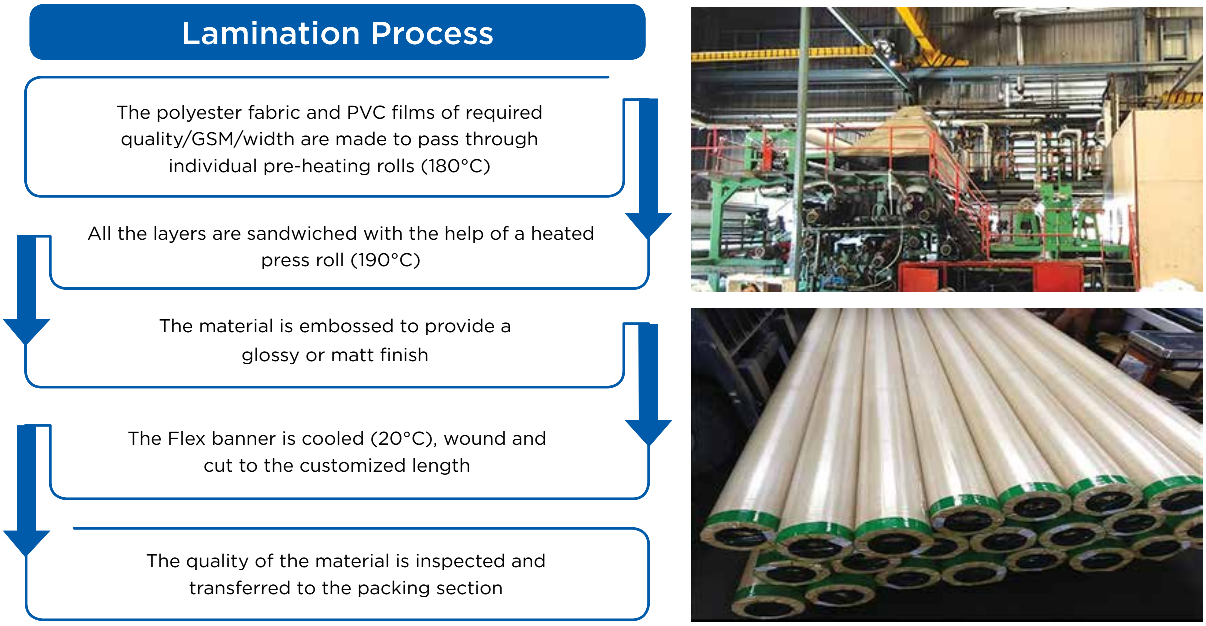


Figure 32. Lamination Process

CHAPTER 4

REUSE AND RECYCLING TECHNOLOGIES

4.1 Reuse

Flex banner advertisements have now become common in the urban and rural areas. As PVC is one of the major ingredients of the Flex banners, they are usually perceived as a threat to the environment. It is a common myth that the Flex banners cause severe problems in the urban areas due to their abundant usage. As they are non-biodegradable, adoption of innovative and eco-friendly strategies that encourage the reuse of the Flex banners is extremely important in the current scenario (Figure 33). These sustainable alternative solutions remarkably contribute to the waste reduction, complete exploitation of the existing material for social and economic benefits and environmental protection.

Figure 33. Reuse of the Flex Banners

Many of the reputed NGOs like Goonj have been using the Flex banners to cover the leaky roofs of schools (Figure 34), tin roofs of shanties (Figure 35) and as sitting mats at the flood relief centres so as to provide protection from the rain and cold weather. Such covers are long lasting, easily cleanable and significantly reduce the impact of the monsoons. Tarpaulin covers made from the Flex banners have been extensively utilized during various disaster relief operations in the villages of Uttarakhand, Nepal etc.

Figure 34. Usage of the Flex Banners to Cover the Leaky Roof of a School[23]

Figure 35. Utilization of the Flex Banners to Cover the Tin-Roofed Shanties[24]

The disposed Flex banners can be used for the protection of the buildings and crops from moisture, especially in the areas where there is an absence of direct sunlight. Hence, covers made from the Flex banners are prevalent in Assam, Bihar, Uttarakhand, Odisha etc. Numerous Vocational Training Centres were set up at Bihar after the flood in 2008 for the utilization of the local resources like bamboo and renovation of the abandoned structures under the Cloth For Work (CFW) initiative of Goonj. Covers made from the Flex banners were used as roofs and also to protect the walls of these centres. Over the years, such centres have provided livelihood for hundreds of unskilled first time worker women from the neighbouring villages and slums thus, making them economically independent and self-reliant. The Stitching Centre at Keshopur, Madhepura has trained about 750 girls and women which has encouraged them to purchase sewing machines and set up their own businesses for the sale of hand bags, pouches, wallets etc. (Figure 36).

Figure 36. Products made from the Discarded Flex Banners[24]

At many of the Chehak Centres (informal tuition centres that complement the formal Government school education) which were started by Goonj, expensive tarpaulin was replaced by the used Flex banners and those savings were used for other vital needs. The Chehak Centres at Saharsa and Purnia districts of Bihar are currently operational with over 200 children which are owned by the parents while Goonj provides the necessary material support. Goonj's cloth sanitary napkins ("MY Pads") and pouches made from the Flex banners are being distributed in several states viz., Maharashtra, Uttarakhand, Bihar, West Bengal, Madhya Pradesh and also in many slums of Delhi and NCR. They are especially beneficial for the women in the far flung villages who spend the entire day at work and do not have a place to store the used cloth pads so that they can be washed and reused later. The introduction of these leak-proof and cost effective pouches is a sustainable technique to ensure the reuse of the cloth pads (Figure 37). Long strips of the used Flex banners can be joined together to make sitting mats as depicted in Figure 38.

Figure 37. Fabrication of Pouches from the Disposed Flex Banners[23]

Figure 38. Production of Sitting Mats from the Used Flex Banners[23]

4.2 Recycle

Recycling is a crucial method in the field of environmental management wherein the discarded materials are separated from the wastes and reprocessed to acceptable standards so as to re-enter the economy as usable products hence, giving re-birth to a new product life cycle. The materials which are considered as unwanted and environmentally hazardous can become an economic and environmental boom through recycling. It is a cost effective process which can be carried out by utilizing lesser energy than manufacturing from the virgin materials. This approach of recovery of materials diminishes the threat to the environment and also facilitates the conversion of wastes to value added products. It helps in the conservation of the valuable resources and postpones the consumption of the virgin goods. Recycling avoids the environmental damage associated with the extraction and processing of the primary resources. The new understanding of the impacts of the landfills and incineration on the ground water and atmosphere has necessitated the implementation of stringent regulations on the waste disposal which would result in a substantial reduction in the greenhouse gas emissions. Recycling has considerable economic merits as it aids in the creation of more employment opportunities and generation of income (Figure 39).

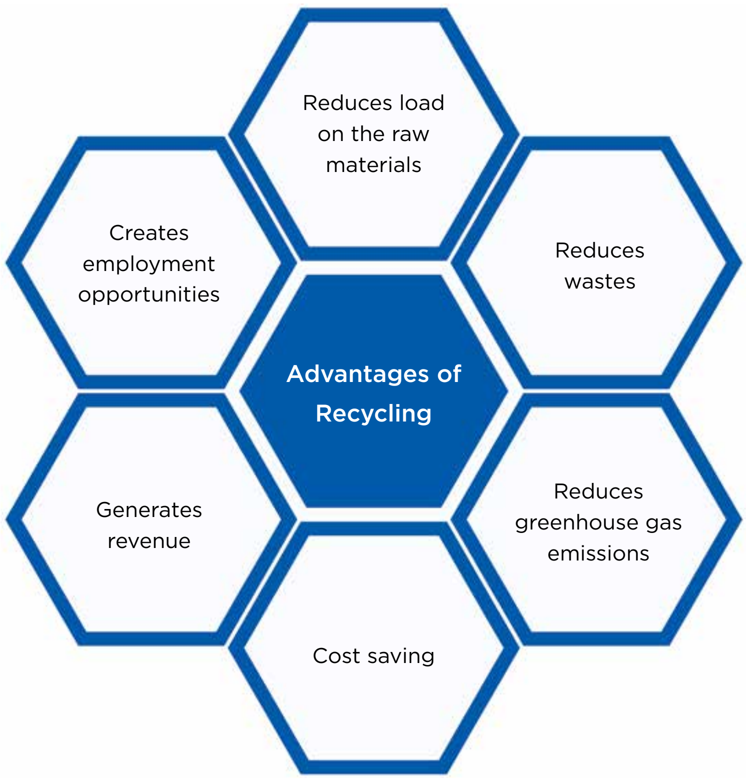


Figure 39. Advantages of Recycling

The used Flex banners are generally collected in all the major cities by the local rag pickers and sold to the segregation and reprocessing units. Therefore, they do not reach the masses and cannot be seen in the dump yards. With the recent technological advancements, it is commercially viable to segregate the components of the Flex banners namely, the PVC compound and polyester fabric. This is achieved by a mechanical shredding process after which the shredded mass is separated without heating or reprocessing (Figure 40). These materials are further utilized to manufacture new products with distinct life cycles viz., footwear, geotextiles, canal lining, flooring, PVC sheets for construction and agricultural applications, ropes, pipes, fillers in mattresses/pillows etc. (Figures 41 and 42). The Flex banner scrap can also be utilized for the construction of roads.

Figure 40. (a) Mechanical Shredding Machine, (b) Shredded PVC Compounded with $CaCO_3$ Granules

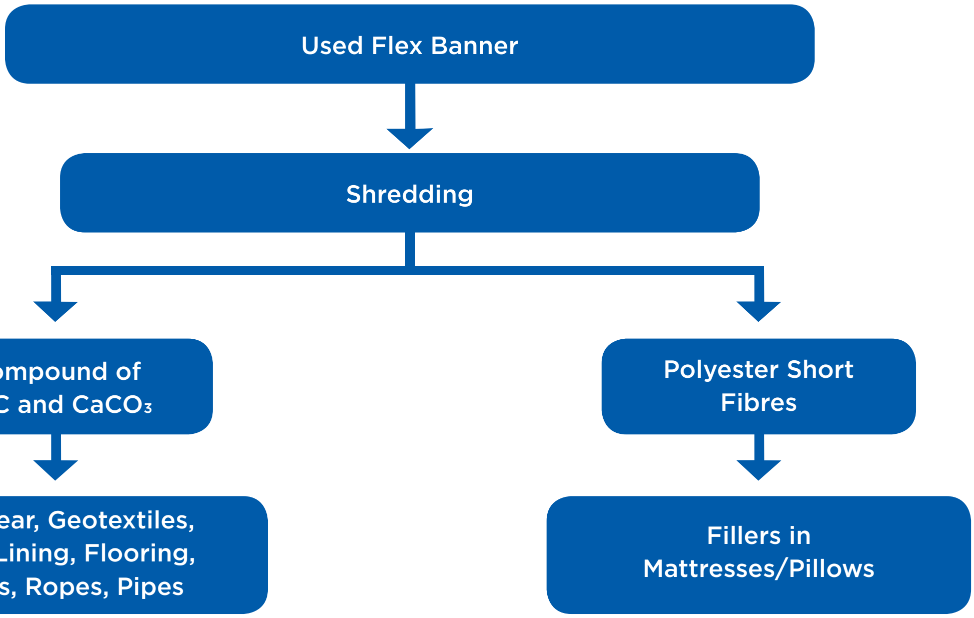


Figure 41. Recycling of the Flex Banners

Figure 42. Fabrication of High Strength Ropes from the By-Products of the Flex Banners

The students of CMR Institute of Technology, Bengaluru have fabricated daily use products viz., bags, raincoats, covers, ropes, envelopes, slippers etc. by recycling the Flex banners (Figure 43). With the help of Greenhood Technologies Pvt. Ltd., they have a patented mechanism which utilizes the polymeric material placed between the Flex banner layers and sealed with the help of marginal heat which will form bonds with the other polymer wastes. These products are extremely sturdy, cost effective, water-resistant and capable of carrying heavy loads. They possess high tensile strength and can be used in the packaging industry, construction, agriculture etc.

Figure 43. Purse made from the Recycled Flex Banners[25]

CHAPTER 5
LIFE CYCLE ANALYSIS

The comparison of the Flex banners with the fabric and metallic banners is provided in Table 3.

Table 3. Comparison between the Advertising Hoardings made from Different Materials

S. No.	Flex	Fabric	Metallic
1	Durable and maintenance free	Low durability and sometimes maintenance is required	The structure is durable. Maintenance is extremely critical as regular painting is needed to prevent corrosion.
2	Water-proof	Not water-proof	Water-proof but requires regular maintenance to avoid corrosion
3	Easy installation	Installation is tricky	Installation process is difficult. The erection should be done with all the precautionary measures to prevent accidents
4	Can last upto 5 years without fading	Life depends upon the quality/GSM of the fabric	Long life if installed properly. The structure and foundation need to be properly designed.
5	UV protection lasts for 3-5 years	No UV protection	Needs to be painted regularly
6	Bright vibrant colours and excellent photography	Vibrant colours and good photography. Poor image quality than the vinyl banners.	Vibrant colours, but generally painted
7	Stain and mildew resistant	Not resistant	Not resistant
8	Can be completely opaque and both sides can be used at the same time	Used from one side only	Preferred to be used from one side only
9	Banner sizes can be customized	Customizable	The joints should be checked periodically to ensure its safety
10	It has creative flexibility and can be used even at difficult locations	Can be installed at defined locations	Can be installed in the places that are defined for metallic structures
11	During heavy wind/storm, it may fall on the ground, but not fatal	Not fatal	Metallic hoarding can be fatal in case of storms/heavy winds
12	Electrically inert and no electrical shock in case of any accidents	Electrical insulator	Very good conductor of electricity and can be fatal
13	Easy to handle and carry	Easy handling and portable	Not easy to handle and carry
14	Cost effective and best value for money	Cost is not as attractive as that of the vinyl banners	Expensive
15	100% recyclable and can be converted into value added products	Recycling is difficult	100% recyclable
16	Existing banner printing machine can print easily	Very few machines are available and existing printing machines are not cost effective	It can be done through painting/ screen printing. Difficult, expensive and outdated process.
17	Key raw materials: Calcium carbonate, PVC resin and Polyester fabric	Polyester (Synthetic)	Iron/Steel/Aluminium (Natural resources)
18	Does not burn and retards fires	Fire resistant	No effect of fire
19	Light weight	Light weight	Heavy

Hence, the inherent advantages of the Flex banners include low cost, environmental friendly, durable, completely recyclable, convenient installation, endures adverse weather conditions, available in multiple sizes, ease of printing and maintenance. In India, the total domestic requirement was satisfied with the help of the imports from China till 2008. Later, few production units were set up by the Indian industrialists. In order to control the imports and support the Indian manufacturers, the Government of India had imposed the Anti-Dumping Duty on the Flex banners from China. The estimated market size of the Flex banner industry in India is about ₹1200 crores (100,000 t). Now, there are around 17 manufacturing units in India. The industry grew at a rate of 5-7% per annum however, there has been a stagnancy in the growth during the last two years.

Life cycle analysis is an extensive environmental management tool which is used for evaluating the effects of a process or a product on the environment. It offers a quantitative assessment of the consumption and disposal of materials by the system. Energy conservation and efficient energy usage are pivotal factors which should be taken into account during any fabrication process. The main goal must be to reduce the amount of energy required to provide the products/services through the implementation of new and creative technologies. Embodied energy is the sum of all the energies desired to yield a product or service. It is highly useful to calculate how successful/effective a product or service produces or saves energy (Figure 44).

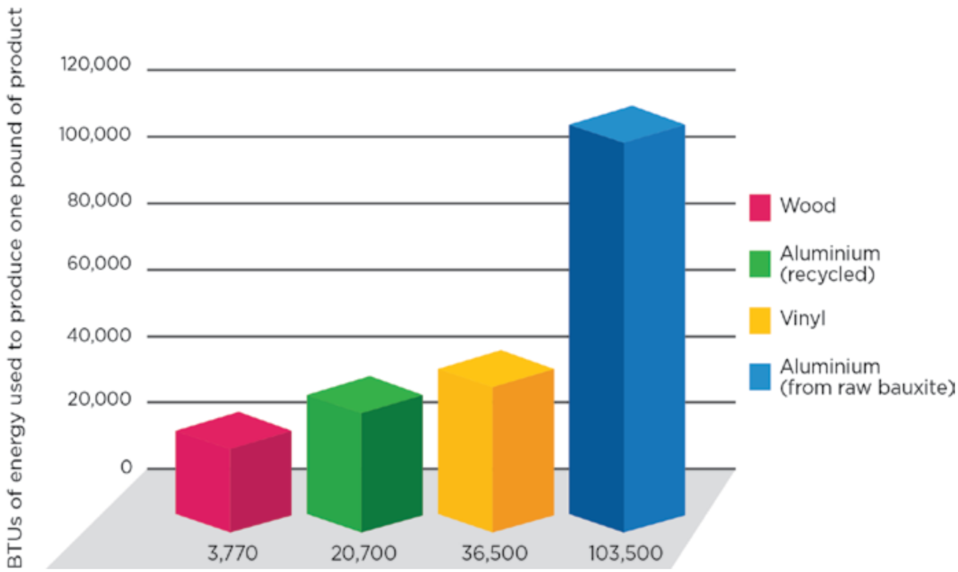


Figure 44. Embodied Energy in 1 Pound of Different Products[26]

Polyester yarn is utilized for the production of the knitted fabric. The power consumed for manufacturing 1 t of fabric lies in the range of 500-550 kW and the cost is around ₹3.25-4.25 per kg. The production capacity per person for a particular day is approximately 225-275 kg of Flex banner. Water is used for cooling purposes which is recycled with the help of cooling towers and chillers. No chemical treatment is utilized while recycling the Flex banners. The various resources which are necessary for the fabrication of the Flex banners and the associated costs have been presented in Tables 4-6.

Table 4. Resource Requirement for the Production of 1 kg of Flex Banner

Polyester cock, husk and limestone used for heating purposes	500 Cal/kg of Flex banner
Grinding and separation	0.3 kW
Downstream power consumption	0.3 kW
Energy required for the production of 1 kg of Polyester fabric	0.6 kW
Energy required for the production of 1 kg of Flex banner	0.8 kW
Water consumption for the production of 1 kg of Flex banner	Recyclable
Emissions during the production of 1 kg of Flex banner	No harmful emissions

Table 5. Requirement of Fuel for the Transportation of 1 kg of Flex Banner

Types of Transportation	Average Distance (km)	Average Fuel Consumption	Average Fuel Consumption for 15 t (l)	Average Fuel Requirement (l/kg)
From the factory to the dealer	800	4-5 km/l	160-200	0.12
From the dealer to the printer	100		20-25	0.002
From the printer to the site	50		10-12	0.001
Total Fuel Requirement				**0.123 l/kg**

Table 6. Cost Analysis

Various Costs	Amount in ₹ (per kg of Flex Banner)
Average manpower	3.25-3.75
PVC films	55-65
Polyester fabric	130-150
Grinding and separation	2-2.25
Downstream power consumption	2-2.6
Domestic selling price	100-125

The average lifetime of a Flex banner ranges from 6 months to 7 years, depending on the thickness and other technical parameters (Table 7). The State Bank of India (SBI) which is a leading nationalized bank had recently released a tender regarding the procurement of the Flex banners for their advertising needs wherein 5 year guarantee has been expected from the manufacturers.[27]

Table 7. Usage Time of the Flex Banners

Upto 30 days	2%
Upto 6 months	8%
Upto 1 year	80%
Above 1 year	10%

CONCLUSIONS

Life Cycle

- Extraction of raw materials
- Design and Production
- Packaging and Distribution
- Use and Maintenance
- Disposal
- Reuse/Recycle

Major Components

- Calcium carbonate
- PVC resin
- Polyester fabric
- Plasticizers, Additives

Advantages

- Flexible
- Cost effective
- Durable
- Recyclable
- Portable
- Eco-friendly

Reuse

- Roof cover
- Food grain cover
- Truck cover
- Rickshaw cover
- Tarpaulin
- Bags
- Sitting mats

Recycle

- Footwear
- Geotextiles
- Canal lining
- Flooring
- Sheets
- Ropes
- Pipes
- Fillers in mattresses/pillows

The major components of the Flex banners are calcium carbonate, PVC resin, plasticizers and additives. According to the Report published by the Indian Centre for Plastics in the Environment (ICPE) in 2009, PVC contributes to less than 0.5% of the municipal solid waste.[28] The PVC waste generated from the Flex banners is nearly negligible i.e., it is only 0.005% of the total PVC consumption in India, assuming zero reuse and recycling of the Flex banners. As the wastes produced during each step of the synthesis are reusable, it can be regarded as a zero solid waste generation process. It is also an eco-friendly process as there are no harmful emissions while manufacturing the Flex banners. They do not burn due to the self-extinguishing property thus, eliminating the possibility of the generation of dioxins. Flex banners have not been identified as single-use plastic materials by the UNEP. They belong to the category of B2B products and possess a high post-usage economic value. They are typically used for about 1 year and can then be reused as truck covers, food grain covers, rickshaw covers, bags, sitting mats etc. They can also be recycled and utilized for several applications such as footwear, geotextiles, flooring etc. Hence, the Flex banners serve as an ideal medium for the outdoor advertising purposes.

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AUTHORS

Prof. Anup K. Ghosh is the Head of the Department of Materials Science and Engineering (formerly Centre for Polymer Science and Engineering), Indian Institute of Technology Delhi, India. He had obtained his M.Tech. Degree in Chemical Engineering from Indian Institute of Technology Kanpur, India (1982) and Ph.D. in Chemical Engineering from SUNY Buffalo, USA (1986). With over 1500 citations and 10 patents to his credit, he is regarded as a global leader in Polymer Processing and Rheology. He has over 29 years of research experience and has significantly contributed in the areas of Reactive Processing of Polymer Blends and Alloys and Microcellular Processing of Polymers. He is a fellow of the National Academy of Sciences, India and had held the prestigious Reliance Chair Professor at Indian Institute of Technology Delhi during 2006-2011. He has supervised 25 Ph.D. Scholars and over 90 M.Tech. students. He is an Associate Editor of the Journal of Packaging Technology and Research and is a member of the Editorial Board of the Journal of Plastics Film and Sheeting and International Journal of Plastics Technology. He has been elected as the International Representative of the Polymer Processing Society (PPS), Asian Workshop in Polymer Processing (AWPP) and Fellow of the Indian Plastics Institute (IPI).

Mr. Jignesh S. Mahajan is pursuing his Ph.D. in Materials Science and Engineering at University of Delaware, USA. He had received his B.Tech. Degree in Fibres and Textile Processing Technology from Institute of Chemical Technology (formerly UDCT), Mumbai, India with the Gold Medal in 2016. He had completed his M.Tech. Degree in Polymer Science and Technology at Indian Institute of Technology Delhi, India in 2018 with the 1st Rank. He had worked on a collaborative project with the Reliance Industries Ltd., Mumbai, India for his Master's Thesis. He has worked on various research areas such as Electrospinning, Nanofibres, Polymer Rheology, Nanocomposites, Biocomposites, Nanocellulose and Lignocellulosic Fibres.

Mr. Debjyoti Banerjee is pursuing his Ph.D. in Fibre and Polymer Science at North Carolina State University, USA. He had completed his B.Tech. Degree in Chemical Engineering from Jadhavpur University, Kolkata, India in 2015. He had obtained his M.Tech. Degree in Polymer Science and Technology from Indian Institute of Technology Delhi, India with the 1st Rank in 2017. He has worked on Foam Processing of Polymers and Lignocellulosic Fibres.

Ms. Pooja Vardhini Natesan is currently a Ph.D. Scholar at the Department of Materials Science and Engineering, Indian Institute of Technology Delhi, India. She had obtained her Bachelor's Degree in Materials Science and Engineering from College of Engineering Guindy, Anna University, India in 2016. She had pursued the final semester of her Bachelor's at the University of Aveiro, Portugal under the fully funded Erasmus Mundus Svaagata Exchange Programme. Ms. Pooja had completed the Erasmus Mundus FAME (Functionalized Advanced Materials Engineering) Double Master Programme (First year at University of Augsburg, Germany and Second year at Grenoble Institute of Technology, France) in 2018 with complete financial assistance. She had pursued her Master Dissertation at KTH Royal Institute of Technology, Sweden. She was also a participant of the PolyNano Summer School at the Technical University of Denmark. The areas of her research interest include Nanotechnology, Biomaterials and Lab-on-a-Chip Devices.

Department of Materials Science and Engineering

Indian Institute of Technology Delhi

Hauz Khas, New Delhi - 110016, India