The ICAC Recorder

# Part-2: Value Addition to Linters

## 1. Introduction

Seed cotton harvested in the field undergoes the primary processing of separation of lint and seed in ginning factories. This process is the most important and significant operation that decides both the yield of lint and its quality. The cotton seed that gets separated in the process is an important genetic material having the potential to yield a fresh crop as well as several valuable by products, if processed in a scientific manner, sequentially.

The current availability of Cotton seed is estimated to be more than 50 million tonnes world-wide. The Global cotton seed sector is a vibrant industry projected to grow with a CAGR of 5.2% since 2019. It is envisaged that this thriving sector attracting newer investments and players is expected to touch US$ 1.0 Billion in the near future. With the introduction of genetically modified cotton in many countries, this industry has witnessed increased investments from the private sector in developing and releasing newer strains of cotton with active participation of the farming community.

The cotton seed that leaves a ginning factory is surrounded on its surface by a thick fuzz that could not be separated during ginning. The amount of fuzz residue on the seed is, however, decided by the type of ginning/mechanism employed for ginning viz. saw ginning or roller ginning. The fuzz, known as linters, is a mass of short fibres that adhere to the seed tenaciously even after ginning, and has a thicker secondary wall at the seed surface accounting for the resistance to removal during separation. If the cotton seed is processed in a scientific manner then the fibres could be separated and put to effective use. Scientific processing of cotton seed is a system of operations that enables separation and recovery of invaluable constituents viz. linters, seed hulls (outer cover of the kernel) and kernel, and also provides avenue for preparation of seed meal or de-oiled cake. (Figure-1). Each of these by products or constituents has tremendous scope for value addition and contributes effectively to the composite economy of cotton.

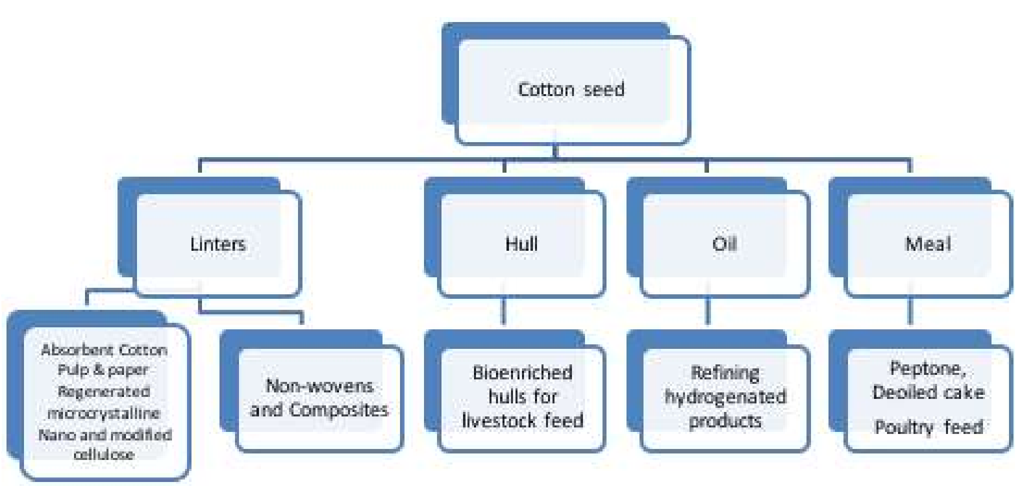
As already noted, the process of separating the fuzz from ginned seeds is known as de-linting. This process of removal of short fibres adhering to the seed can be effected in more than one way depending on the end use of the seed. Two processes, in vogue, commercially have gained importance 1. Acid delinting and 2. Mechanical delinting. Though, many other mechanisms such as flame treatment have evoked research interest in purifying seed to enhance its germination potential in the field,they have not gained popularity. While acid delinting is a process of treating ginned seeds with acids with the primary purpose of sowing the seed for the next crop, the fuzz is completely lost in the process. In mechanical delinting the fibres are not degraded unlike in acid delinting and is recovered for further use. This is usually accomplished by high speed rotating sharp screws or abrasive surfaces to cut or rub the fibres off the surface of the seed hull. This process heavily relies on the physical friction to remove the fuzz forcibly.

### (a) Advantages of Mechanical Delinting

Several beneficial traits have been identified during mechanical delinting of ginned seeds. The recovery and recyclability of the fuzz (linter) is the primary advantage apart from prevention of environmental pollution. However, the cost of delinting is found to be higher compared to acid delinting. In view of the emerging uses of linters enhancing its scope for value addition, several researchers have attempted to improve the functioning of mechanical delinter particularly its ease of operation {1,2,3}.

A typical yield of cotton linters is around 9% by weight of the seed. A study of yield of linters from different species of Cotton {4} revealed that, the linter content from *G. hirsutum* cotton is about 10.5%, whereas the native cottons from India belonging to *G. arboreum* & *G. herbaceum* yield linters varying from 4.3-5.9%. *G. barbadense* species produce naked seeds. Hybrid cotton seeds (intra-hirsutum and *hirsutum* x *barbadense*) have shown higher fuzz with linter content exceeding 10%. The linters collected after the first phase using delinting machines are called "First Cut Linters" and after second phase are called "Second Cut Linters". "Third Cut Linters" are often referred to as hull fibres. However a mixed version of linters, denoted as "mill runs" is used for production of pulp.

Figure-1. Scientific processing of cotton seed-constituents and possible value addition



### (b) Physical & Chemical Characteristics of Linters

The physical parameters of the linters recovered depended on the phase of collection from the delinting machine.

Table-1 describes in detail the characteristics of the linters.

| Parameters | Value |
|---|---|
| *Fibre length<br>1st Cut (mm)<br>2nd Cut (mm)<br>3rd Cut (mm) | <br>2.5-6.0<br>2.0-3.0<br>Less than 2.0 |
| Colour (depending on cut) | Clear, clear to brown, brown |
| **Cellulose<br>Holo cellulose<br>Alpha cellulose | Higher than 80% up to 85 %<br>80%<br>78% |
| Water/moisture content (%) | 6.0-8.0 |
| Extractables (%)<br>Fat & waxes (%)<br>Pectin (%) | 5.0-6.0<br>2.0<br>1.0 |
| Proteins (%) | 2.0 |
| Ash (%) | 2.0 |
| Insoluble lignin(%) | 0.7 |
| Foreign matter (%) | 1.0 |
| Seed hulls | 11.0 |

Note: The constituents do not necessarily add up to 100% as they are measured on different samples. *The ensemble contains a large proportion of short fibres (fibres less than the average length). **The cellulose linter has low viscosity and therefore low degree of polymerization.

### (c) Comparison of Attributes of Lint, Noil & Linters

| Parameters | Lint | Noil | Linters |
|---|---|---|---|
| Length (mm) | 20-38 | 15-19 | Less than 6 |
| Micronaire/maturity | 3-6.5 (depending on length) | Less than lint | Less than noil |
| Strength (g/tex) | 16-34 | Weaker than lint | Weaker than noil |
| Short fibre content (%) | 4-5 (increases with decrease in length) | Increases to 10% | Shortest fibres |
| Amenability to cleaning | Depends on maturity & length, generally poor | Better than lint | Better than lint and noil |
| DP (chainLength) | 1800-3200 | 1200-1500 | 600-800 |
| Cellulose content (%) | 80-85 | 85-95 | Above 98 |
| Specific surface area | Lowest | Higher than lint | Very high surface Area |
| Affinity to chemical reagents | Poor | Increases commensurate to lowering DP | Very high affinity |
| Adhesion of Micro-organisms | Poor | Increases with Surface area | High adhesion |
| Value addition | Heavily dependent on length, fineness strength and structure | Quality of cellulose primarily, fibre parameters secondary role | Mainly on the quality and quantity, purity of cellulose |

The comparison here is among three types of celluloses.

1. Lint (Primary processed – fibre extracted from seed cotton,
2. Noil (compressed bale opened, reprocessed, individualized) and
3. Linter (ginned seed, reprocessed by saws to remove fuzz).

While the primary processed material has a form dependency, the reprocessed material relies on internal organization and quantity of the constituent cellulose.

### (d) Primary Processing of Linters – Bleaching

The foreign matter present in linters is removed by bleaching, currently by using peroxide. The bleached linter is one of the purest forms of alpha cellulose (more than 99%) {5}. Due to their purity and whiteness and lower DP (around 600-800), this cellulose forms the basis for a large number of special and niche products.

## 2. Availability and Market Prospects of Cotton Linters

Globally, the availability of cotton linters depends on the production of cotton in general, barring the *G. barbadense* species. A rough estimate of linters is projected to be approximately 18% of the cotton production in that year. The current level of production potential for linters globally is around (prospectively could be) 5-5.2 million tonnes. However, it is reported that the global availability would not be more than 1.0 million tonnes {6}. In India, the extraction of cotton linters is about 90,000-100,000 tonnes, contributing only to less than 10% of the world production. The price of cotton linters depends on the foreign matter content, whether it is first cut or mill run, and its cellulose content. The price varies with that of cotton internationally. The price in India, fluctuates with the availability in the market, governmental regulations, and export. The price in recent years varies between US$ 1000 to US$ 1500 per tonne again depending on the quality of bleaching. The marketable commodity in export arena is in the form of a bale.

In India, cotton linters are always in short supply and as a result it becomes unaffordable to small processors. This situation is essentially due to absence of scientific processing of cotton seed in large quantities. However it is reported that out of the available quantity, internationally, a very small fraction of the linters (say about 10%) is used for value addition, offering scope for its enhanced utilization, posing no threat to the availability of the raw material.

Market research analysis and prospective growth rate predictions in global cotton linter sector are routinely carried out by market analysis experts, although all such information is not available in public domain {7}. However, Asia Pacific region is expected to hold the largest share in global bleached linter cellulose market. The factors supporting Asia pacific is the availability of cotton. India and China are prominent cotton lint manufacturers with cost effectiveness. Owing to improved socio economic aspects in the region, use of cotton linters in pharmaceutical, food, and personal care products are expanding, there by contributing to the growth of the bleached linter cellulose market.

The linter market is segmented into high grade and technical grade {8}. The technical grade market constituted the major chunk of the overall industry in 2018. Technical grade linter is used in pulp & paper, personal care, paints, packaging etc. The market size in 2018 was around US$ 1.0 billion and in 2025, it is expected to be about US$ 1.3 billion with a CAGR of around 4%.

Bleached linter market, due to presence of several small and medium scale manufacturers, remains fragmented. However, this is the product that is used as raw material for viscose, acetate, carboxymethyl cellulose etc., for their manufacture. This industry is always on the look-out for cheaper raw material from plant biomass of natural fibres in general, that could prove to be cheaper substitute for linter. This can limit the prospective potential of bleached linter market in the near immediate future.

## 3. Diversified Value Added Products from Cotton Linters

As already noted, being the purest form of cellulose, linter contains only cellulose up to 98-99%, in which alpha cellulose constitutes more than 80%, with negligible lignin, and other non-cellulosic components. Linters are employed traditionally and in modern times with improved technology, for manufacture of several products with diverse application in wide-ranging fields. A panoramic view of the products that could be manufactured from bleached linters is summarized in Figure-2.

In the sections below, it is intended to summarize the research carried out in some of the above areas, delineating salient findings and applications .

### (a) Absorbent Cotton

Absorbent cotton is one of the value added products, manufactured with minimal processing once the bleached cotton linters are available. Also referred to as "surgical Cotton", this product becomes highly absorbing and is soft on skin. The ease with which surgical cotton is made both by using comber noil as well as linters (depending on the availability in a region) has made it very popular among small scale manufacturers.

Linters from the first cut consisting of longer fibres, if in a compressed bale form, are opened, scoured, and bleached. In the wet state, the bleached fibres are opened, got rid of water and dried. The dried fibres are again opened, carded and made into a roll. The absorbent cotton is then converted into wipes, pads or wound dressing cloth/gauze depending on the need.

### (b) Pulp and Paper

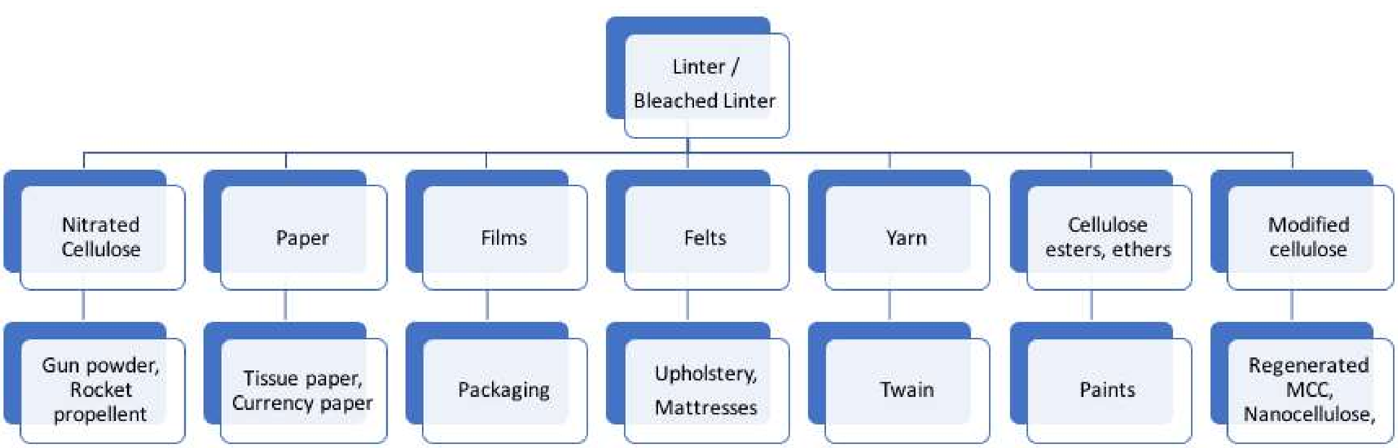
Bleached cotton linter is made into pulp and the pulp then is used to prepare various kinds of high grade paper products such as, technical paper, security paper, insulating paper, filter paper, art paper, and also high quality printing paper.

The originally brown coloured linter cellulose, is bleached with 12% sodium hypochlorite {9}. The bleached linter pulp has a whiteness index of 67.5%, bright ness of 64%, and yellowness reduced to a single digit, 6%. Several pulping methods have been used to produce pulp with better qualities and with least load on the environment. Organo-solv pulping {10}, has been attempted to prepare quality pulp on Egyptian cotton linters, that possessed good length but simultaneously higher impurities.

Conventionally, cotton linters are used in small quantities or in a mix with wood pulp. This is due to poor inter fibre bonding and low tensile and burst strength. The above deficiencies are ably overcome by introducing addition or substitution reactions to modify and make the material amenable to pulping.

Chemically modified celluloses showed good inter fibre bonding and thus removed inherent shortfall in linters. Hydroxy-ethyl cellulose and carboxy methyl cellulose (CMC) improved inter fibre bonding by 85% and also exhibited significant tenacity improvements when they were mixed in proportion with a cationic cellulose. Several attempts have been made {11}, to improve paper quality by introducing additional treatments to the bleached pulp. Addition of 0.25 to 2.0% of potassium permanganate solution improved the paper characteristics. When comber noil and linters are mixed in a blend as 80/20 and pulp prepared; the quality of pulp and that of paper

Figure-2. A panoramic view of value added products from linters



products did not show any reduction thus paving the way for some cost saving {12}.

An innovation that has been brought about in paper making is by additives in the pulp mixture to effect special properties to paper. Electrical Insulated paper {13} has been prepared by the addition of hydrophobic fibres such as polyester to pulp to prepare paper of low density, high porosity, and high dieletric resistance. The dielectric constant has been shown to improve further if lead sulphate is added to the pulp. A very recent study {14}, has clearly demonstrated that addition of micro-fibrillated cellulose extracted from cotton linters up to 10% to unbleached Kraft pulp/paper improved the tensile strength by 11-18%, burst factor by 11-13%, and enhanced the Z directional tensile strength.

## (c) Regenerated Cellulose

Another well developed route to add value to linters is to convert them into regenerated cellulose in various forms such as staple fibre, continuous filament yarn, films etc. Over the years, regenerated cellulose manufacturing process has undergone several changes. Cotton linter as an effective raw material has significantly contributed to these developments in no small measure.

Traditionally, cellulosic fibres (comber noil or linters) after purification and bleaching are treated with carbon-disulfide (CS2) solution to dissolve cellulose and by using an appropriate extrusion mechanism, regenerated cellulose fibres/filaments are prepared. An alternate route has been to prepare Cuprammonium Rayon {15} by dissolving cotton linters in a solution of cuprammonium hydroxide and ammoniacal copper sulphate and the dissolved cellulose is treated with sulfuric acid and extruded as regenerated cellulose. These conventional celluloses referred to as "Rayon" had problems with toxic releases and other environmental issues. An improved process of preparing regenerated cellulose known as "LYOCELL" process {16} is to dissolve cellulose in NMMO solution prior to regeneration. The over-all process involves dissolution- spinning-deformation- cooling- relaxation- coagulation- washing and finishing. There were several positive characters in LYOCELL such as environment friendliness, efficiency, high crystallinity, long crystallites, high strength and modulus in comparison to conventional Rayon. One of the demerits of this process has been fibrillation of cellulose.

In order to counter the fibrillation problems in LYOCELL cellulose, an attempt was made {17} to prepare a dope of cotton linters and wood pulp prior to dissolution. This dope could, not only significantly reduce the cost of raw material but also could to a large extent reduce fibrillation. Another way to reduce fibrillation has been noted {18}, in spun regenerated fibres prepared from high molecular weight cotton linters (derived from high molecular weight cotton) treated with NMMO via LYOCELL process.

A large number of research reports concentrated on enhancing the solubility of cellulose prior to regeneration to improve the properties of cellulose extruded / produced. This included dissolving linter cellulose in NaOH/Urea solutions {19, 20}, organic electrolyte solution {21} and ionic liquids {22}. It was noted that the procedure of dissolving cellulose in NaOH (6%wt)/Urea (4%wt) was a non-polluting process. The strength of the regenerated cellulose film so produced was much better than commercially available cellophane film.

Treatment with organic electrolyte solution reduced cellulose degradation significantly and improved the mechanical properties and thermal stability of the film cast. A novel way of dissolving cellulose is by using ionic liquids. The regenerated fibres displayed smooth, highly uniform and dense morphology. The fibres could effectively replace polypropylene and polyethylene in preparing a transparent, biodegradable packaging material.

## (d) Micro Crystalline Cellulose

Microcrystalline cellulose is a form of cellulose having industrial applications and wide variety of uses, Microcrystalline cellulose popularly known as MCC, has received serious attention of researchers and manufacturers alike. MCC is a type of cellulose possessing a balanced degree of polymerization (due to hydrolysis) and mechanical separation of particles. It has a porous structure and density similar to crystalline density of cellulose (1.539-1.545 g/cm3). MCC is dispersive but insoluble in water and acids, organic solvents, oil etc. It swells in dilute alkaline solutions and partly dissolves in it {23}. A white transparent paste or gel is formed if MCC is dispersed in water and this dispersion remains stable but for very dilute solutions. Table-3 below summarizes properties of MCC prepared from linters, {24, 25, 26, 27}.

MCC is produced from bleached linters by treating with dilute acids (hydrolysis) at desired temperatures. Slow hydrolysis (low concentration acid, low temperature, long duration) enhanced the yield and growth of crystals. The duration of hydrolysis affected the yield, quality, and polymeric form of the processed Alpha cellulose.

MCC is widely used in pharmaceutical, food, chemical industry, and synthetic leather industry {28}. Alternate raw materials other than linters have been used for the production of MCC, sometimes with better yield and properties {29, 30}.

| Parameters | Value |
|---|---|
| Yield (%) | 75.3-85 |
| Moisture content (%) | 7.2 |
| Ash content (%) | 0.12 |
| Density (gm/cm3) | 1.38-1.55 |
| Crystallinity (% ) | 65-80 |
| Crystallite width (nm) | 8.8 |
| Crystallite length (nm) | 35-45 |

Note: Properties varied considerably with quality of raw material, hydrolysis conditions, and measurement techniques.

## (e) Nano Cellulose

Bleached cotton linter is one of the most preferred raw material for preparation of nano cellulose be it in a powder form or fibrillar form. Being a pure cellulose form with appropriate

DP and optimum access to reagents, nano-cellulose is one of the most sought after starting material. Several studies have dealt with different pathways for production of nano material from linter/cotton cellulose. J. P. S. Morais et. al., {31} have developed a method to produce nano cellulose structures (composites) from raw cotton linters without the necessity to make pulp. *G. hirsutum* linters, once converted to nano cellulose showed increased hydrophilicity despite higher crystallinity owing to improved surface area for adsorption. The nano crystals so developed possessed good size, measuring up to 177 nm in length and 12 nm wide.

In the hydrolysis- homogenization procedure for nano cellulose powder preparation, pretreatment with zinc chloride solution (70%) for a fixed duration, enhanced the yield of nano cellulose {32}. A pretreatment with cellulase enzyme also improved the yield of nano cellulose {33}. Cellulase pretreatment prior to acid treatment improved the yield of nano crystalline cellulose (NCC) by 12%. This pretreatment reduced sulfur content by 0.8% and average particle size rose to 35nm, and also the concentration of acid could be reduced thereby saving on chemicals. Another variation in the hydrolysis- homogenization routine is the use of ionic liquids to dissolve the cellulose {34}. Nano fibrillated cellulose (NFC) is yet another form of nano cellulose, widely used in various applications such as paper, electronics, pharmaceuticals, fuel cells, and even in fertilizers {35}. A combined process of enzymatic pretreatment and fibrillation (refining) resulted in optimum production of NFC with reduced energy requirement (by 27%) and is one of the areas where NFC production needs serious improvement. The fibrillated cellulose had a diameter ranging from 50 to 200 nm with very good separation into individual fibrils. A cocktail of cellulase and another oxidative enzyme could improve the mechanical fibrillation significantly to increase the yield of NFC. This treatment brings in enhancement in transparency and barrier properties essential for packaging {36}.

Significant advances have been made in the recent past to use nano cellulose efficiently and effectively in various areas. Nano cellulose from cotton linters in fibrillated form has been used as a reinforcing agent for guar gum in film preparation for packaging purposes {37}. Antimicrobial nano materials were prepared using regenerated cellulose from cotton linters by incorporating silver, copper oxide, or zinc oxide nano particles in the dope. Strong antibacterial activity {38}, against *E. coli*, and *L. monocytogens* was noted and this material could be used as filler in antibacterial packaging films containing nano whiskers {39}. As reinforcing material in thermos plastic starch, nano composite films prepared thereby could be effectively used in food and pharmaceutical packaging.

### (f) Chemically Modified Cellulose

Raw cotton fibres, owing to the presence of a primary wall composed of pectin and waxes and a longer chain length, remain inert to most of the chemical reagents. Cotton linter, on the other hand, with appropriate degree of polymerization (DP) and pure cellulose as constituent becomes a perfect raw material for preparation of chemically modified cellulose products, cellulose acetate, cellulose nitrate, and carboxy methyl cellulose, all industrially relevant products.

- **Cellulose Acetate:** Homogeneous acetylation of cellulose to manufacture cellulose acetate (cellophane film) has been attempted employing different chemicals, di methyl sulfoxide (DMSO), and paraformaldehyde {40} and a combination of DMSO and tetrabutyl ammonium fluoride tri hydrate {41}. The cellulose acetate so prepared had degree of substitution (DS), varying from 0.5 to 2.8. Using different temperatures for varying durations, employing acetic anhydride as the reagent, iodine as catalyst, cotton linter was acetylated to DS 2-2.5 when the starting pulp was 98% pure {42}. Cellulose acetate films are ecofriendly materials and exhibit high level of biodegradability {6}. The rate of decomposition of this material is 1.5 times faster than conventional products.
- **Carboxy Methyl Cellulose:** Carboxy methyl cellulose, more popularly called CMC has wide spread applications in textile, paper, detergents, pharamaceuticals, paints, lubricants, food, ceramics, cosmetics, etc. It is specially used as a thickening agent in food, if the viscosity is quite high. Cotton linter in mono chloro acetic acid and NaOH reacts slowly, and when neutralized with acetic acid and methanol, yields CMC. Homogeneous carboxymethylation process is also attempted on cotton linters using NaOH/ Urea system, to achieve a DS of 0.2 to 0.62. The CMC so produced was soluble in water {44}.
- **Cellulose Nitrate:** Popularly known as gun powder, cellulose nitrate is an important industrial product. In the DS range of 1.8 to 2.8, it is a white transparent, odorless, nontoxic and hydrophobic material. Linters are treated in nitric acid at optimum concentration to prepare cellulose nitrate. Cotton linters are preferred for preparation of military grade nitro cellulose {45}. More often, the nitration bath contains sulfuric acid as a condensing agent and a typical bath producing cellulose nitrate has a nitrogen content of 11%, (nitric acid 25%, sulfuric acid 55% and water 20%). Since cellulose nitrate is extensively used for defence purposes, more often than not, cotton linter use within the country and export are regulated by governments.

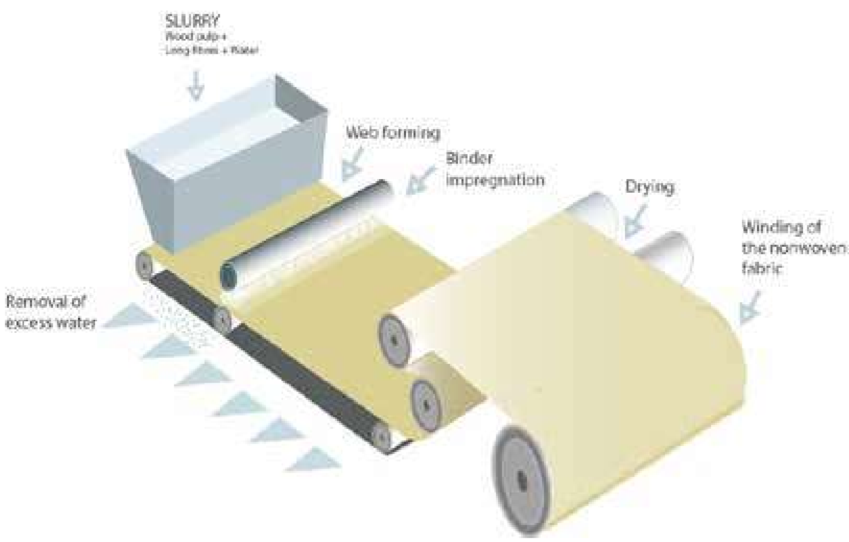
## 4. Recent Innovations in Value Addition

What has been described so far, pertains to value addition areas and products where cellulose holds an upper hand. In this section a few of the most innovative pathways of value creation would be described where cellulose is either entering the synthetic market or where cellulose is effectively and more competitively replacing products traditionally manufactured by using synthetic fibres.

### (a) Non Wovens and Composites

A composite is a select combination of two or more dissimilar materials formed with a specific internal structure with non-woven as one of the component. They are designed to produce materials with unique mechanical properties and superior performance characteristics, not possible with any one of the components, alone {46}. The non-woven material characteristic depends on forming the fibre web and bonding the web suitably (needle punching, thermal bonding, wet–laid etc.). For preparation of cotton, non wovens, cotton linter/ comber noil is extensively used for non- woven in a composite application. Sometimes cotton linters are pretreated with solvents like dimethyl peroxide / acetic anhydride / acrylamide and then incorporated in composite preparation to improve thermal properties {47}. Global non-woven market is a growing sector having a size of US$ 40 billion. A process of non-woven manufacture known as wet laid, a technology taken from the paper industry, enables achievement of cloth-like characteristics without weaving and also without the use of continuous filaments. This process is endowed with high speed and flexibility. The fibres are suspended in an aqueous solution and then formed into a sheet in a moving screen, where the water gets removed.

Figure-3. A schematic layout of wet laid non-woven




Cotton linters of 12 to 15mm preferred in wet laid more often in combination with other fibres (synthetic) . A schematic lay out of wet laid non-woven is shown in the figure-3.

When the web, now devoid of water is moved further, it gets impregnated with a suitable binder (specially required if a blend of hydrophilic and hydrophobic fibres are employed in combination). Here refined cellulosic pulp fibres get better bonded with synthetic fibres to form a good wet laid. Thin wet laid non-woven finds extensive applications in hygiene, filtration, wipes, coverings, upholstery etc. Another application of thin non-woven is as cover material for agricultural crops {48}.

### (b) Bio Degradable Composites and Plastics

With concern for the environment and its conservation rising over the globe, degradability of a material in quick time with least load on the atmosphere has gained importance. Cellulose composites and plastics made from them are proven biodegradables and environment friendly as per their life cycle assessment. Recent interest in research and manufacture of bio-plastics centered around cellulose/cotton linters {49, 50}.

Using cotton linters, cellulose acetate bio-fibre is produced with a yield of 54%. This bio polymer was found to be biodegradable and less affected by acid compared to poly-propylene, and poly-styrene and can find application in food industry and medicine.

A bio-plastic made by hot pressing cellulose solution in alkali hydroxide /urea system resulted in a transparent and uniformly oriented sheet. Compared to common plastics, this biodegradable polymer sheet possessed higher tensile strength, flexural strength, thermal stability, and lower thermal coefficient. The advantage of this method is that the cellulose is not converted to pulp prior to treatment and hot pressing.

### (c) Hydrogels and Aerogels

Hydrogels and aerogels are gel structures prepared from cellulose that have high adsorptive / absorbtive power of oils, water etc., combined with bio compatibility and bio degradability. They are special porous materials, with low density, high porosity, large specific surface area, adequate surface chemical activity. They are prepared by various techniques such as acetylation, and cyano-ethylation of linters {51}.

Subjecting cellulose lint, MCC, or cellulosic powder with high impact mechanical pulses of various amplitudes and frequencies {52}, graft polymerization of acrylic acid in cotton linters {53}, and ultrasonic treatment or dispersion of nano-cellulose or modified cellulose and solvent exchange and drying process {54} are the various methods of preparation.

Hydrogels / aerogels prepared from cellulose possess high compressive strength than synthetic aerogels and are used in oil /water separation, oil absorption or as super absorbents.

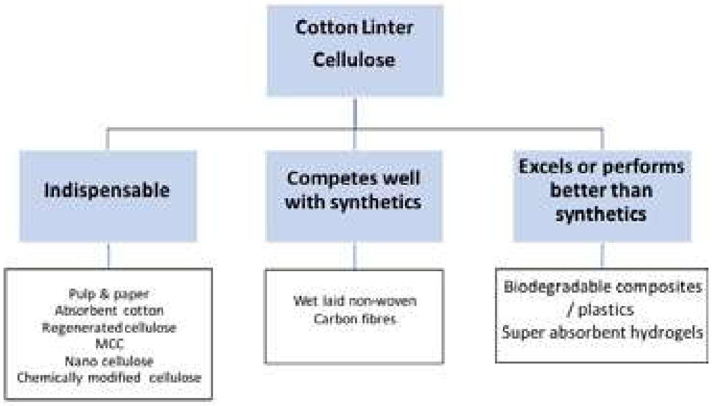
### (d) Carbon Fibres

Carbon fibres are fibres about 5-10 micrometer in diameter that are highly stiff, composed of carbon atoms. These fibres possess high tensile strength, low weight, high chemical resistance, high temperature tolerance, and low thermal expansion. Carbon fibres are generally produced from poly-acrylonitrile (PAN). They are used to reinforce composite materials, such composites known as graphite-reinforced polymers. The strength to weight ratio is much higher than steel or plastic.

Attempts have been made to prepare carbon fibres from cotton linters through a process of Carbonization and wet spinning technology {55}. The carbon fibres prepared had a smooth surface, and round compact morphology in cross section. The tensile strength was about 0.72 Gpa with carbon yield up to 36%, parameters compatible and highly favourable from bio mass material.

## 5. Is linter Cellulose an Effective Replacement for Synthetics?

From the discussions on value addition enumerated here, it is possible to decipher areas where linter cellulose competes well or sometimes even excels synthetic fibres. The diagram below illustrates the point.




## 6. Entrepreneurship Development in Cotton Linters

Although there are several value addition technologies and products where successful business ventures could be set up., manufacture of Micro Crystalline Cellulose (MCC), is one of the fairly simple techniques where both big as well as medium and small entrepreneurs could invest and reap the benefits. This product has an ever growing clientele and market. Even in new and unexplored regions, the MCC is finding its foot hold.

As already noted a CAGR of 4.71% is expected between 2018-2028, to this already burgeoning market.

A project report /feasibility report and plant lay out prepared by NIIR project consulting services {56} is available for consultation. A snap shot of the report indicates the following details:

The figures below would entail revision in values depending on the place, availability of raw materials, labour and other incidentals. These figures are provided to give a rough idea of estimated investment.

Estimated Investment and returns

Plant Capacity = 8 MT/day
Plant and Machinery = US$ 0.2 million (Approx.)
Working Capital = US$ 1.1 to 1.2 million (Approx.)
Return on Investment = 45%
Break even = 36%

## 7. Future Out Look on Cotton Linters

The discussions and observations made in this report clearly bring out the versatility of cotton linter as a raw material for use in many varied applications.

The crucial point at this juncture would be the availability of raw material. Although global potential for cotton linter production is around 5 million metric tonnes (based on available ginned seeds), one report estimates the availability at 1 million metric tonnes, whereas as another survey states that the current availability of linter worldwide could be as much as 2.5 million metric tonnes. Be that as it may, this clearly points out to the lack of prevalence of scientific processing of cotton seeds in many regions of the world.

Going by the Indian experience, there is hardly 10% of ginned seeds that undergo the rigorous processing to extract invaluable constituents (linter, hulls etc.), and the rest 90% seeds are directly crushed for oil extraction. The impediment in large scale adoption of linter extraction is cited to be high recurring cost. It is known that more than 50% of the incidental expenses go in power to run huge saw machines for extraction.

An urgent need to devise a highly energy efficient or an alternate novel mechanism to extract linters is felt seriously. Just like ginning, if delinting is also made a way of life, by introducing an appropriate sized delinter capable of serving a ginning industry year- long for extraction of linters from its seed, the situation could improve for the better.

However the fact remains undisputed that there exists a huge untapped potential for creating, value adding and establishing successful business ventures world over by using this veritable cellulosic raw material.

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