

# Nanocellulose – Role of Pulp & Paper Industry in hailing it as “The Material of the Millennium” (Part I: Performance, Types and Developments)

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Nanocellulose merits being termed the “Material of the Millennium” because it is derived from abundantly available, sustainable plant materials and can replace products based on fossil fuels, namely plastics. It exhibits unique properties, such as high strength, high modulus, light weight, a surface rich in functional groups, and biodegradability, and has versatile applications in practically all fields [1,2].

This paper highlights the vital techno-economic aspects remaining to be addressed for further growth of nanocellulose, reducing the cost of production using appropriate raw material and processing techniques. The various raw materials and techniques used at the pilot plant or industrial scale have been assessed in terms of efficiency, productivity and cost of production.

The different technologies available in the production of nanocellulose, including mechanical, chemical and enzymatic routes, are discussed, suggesting the synergy for attaining optimum yield, quality and production cost. The latest trends in the applications of nanocellulose, including the paper and packaging sectors, are discussed. The industrial production capacities of nanocellulose are indicated.

This part (Part I) presents the superior properties of nanocellulose and its versatile applications. This part introduces the different types of nanocellulose and discusses the past and present developments.

## INTRODUCTION

The spectacular market growth of nanocellulose in the last decade is due to its expanding applications in several industries, producing materials with superior performance, justifying it to be the “material of the millennium”. The impetus to assured development of new products with enhanced performance of nanocellulose emanates from the facts that nanocellulose is produced from abundantly available renewable plant materials; it is biocompatible and environmentally benign, with the ability to replace the fossil-based petrochemical products.

The pulp, paper, and packaging industries have started taking the initiative in mass-scale production and utilisation worldwide. The huge potential for the pulp and paper industries to embrace the nanocellulose production technologies and applications is explained here, citing the level of involvement by some of the progressive units and the future course of action [1,2].

The number of publications and patents on nanocellulose has been rising every year. Admittedly, the expansion in mass-scale production technologies and applications of nanocellulose confronts the barrier of high-energy consumption and overall high cost.

The cost of production and quality of nanocellulose are the two most important current concerns, which depend upon [1,2]:

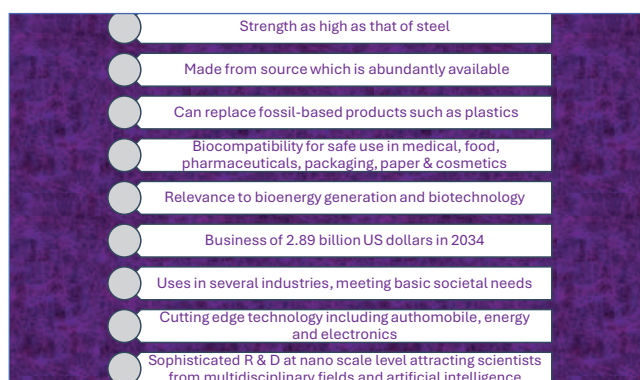
- Raw materials [1],
- Technologies adopted [2], and

- Application in different domains.

This paper encompasses the salient features of the above three aspects towards reducing the cost of production.

## RESULTS AND DISCUSSION

The reasons justifying nanocellulose as the “Material of the Millennium” are discussed below from the literature data. The basic reasons to qualify as the material of the millennium are presented in *Figure 1*. It possesses exceptionally high performance with strength as high as steel wire and made from plant materials, which is abundantly available and sustainable. Moreover, it can replace the fossil-based products such as plastics and it is biocompatible for which it can be used to replace body organs and can safely be used in food, pharmaceuticals, paper and packaging and cosmetics. It is a sophisticated material that works at nano scale level, where sophisticated analytical tools such as electron microscope, X-ray diffraction, Atomic force microscope etc are used. It is also of multidisciplinary interest spreading from paper technology to biology, chemistry and physics, engineering and technology. It has relevance to research in bioenergy generation and in biotechnology. Business point of view, it is presently USD 0.56 billion dollars annually and predicted to grow at a CAGR of 20.4% to reach USD 2.89 billion dollars by 2034.



**Figure 1. Reasons for hailing Nanocellulose as the “Material of the Millennium”**

### Superior Performance

Nanocellulose is being given so much priority as it is endowed with superior properties over all the existing materials and thus possesses the potential for extraordinary performance, as can be seen in *Table 1*.

The tensile strength of nanocellulose is much higher than that of steel wire and general carbon fibre, reaching 7.5-7.7GPa, while the density (1.6g/cm<sup>3</sup>) is only one-fifth of that of steel [3].

Apart from the mechanical and thermal properties mentioned in *Table 1*, the increasing applications of nanocellulose in many