IDEA / PROPOSAL:

Cellulose based technology platform for biodegradable polymer applications.

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Summary:

This proposal discusses opportunities for converting cellulose into value added biodegradable materials by using targeted chemical modifications to drive the changes.

Background:

Plastic waste is a huge concern for society. Plastics from petroleum are stable materials that have a wide range of properties. These can then be formed into a variety of different products, from the common disposable plastic bags to plastic bottles and containers, to healthcare materials, building materials and more. Many of these properties of stability and durability are now becoming a challenge for society, especially for single-use commodity consumer plastics, like plastic bags, bottles etc. Discarded plastics often find themselves in landfills and water bodies (Evers J., 2024) and now are even being detected in our blood (Parker, 2023). Some of these plastics, like PET, HDPE and PP can be recycled to a certain degree but challenges in the process remain (Anon_4, 2023). Glass and non-alloyed metals are much more recyclable than plastic at end-of-use. There are however issues, like mixture composition, weight and contamination for metal and glass, and fragility in the case of glass.

Refuse, reduce, reuse and, to an extent, recycle are strategies in the R-Ladder (Crisp, 2021) that can be adopted to limit our use of non-biodegradable plastics. The ability of society to make use of these options depends on other eco-friendly plastic options being made plentiful, price competitive, and able to address a wide variety of applications and challenges.

Opportunity:

While compostable plastics are becoming more common (Linge, 2022), (Fernandez, 2017), (Seelution, 2020), the challenge to make these bio-plastics more widespread and economical, remains. On average, a kilogram of petroleum based plastic resin currently costs $1.2/Kg, depending on the price of petroleum, while biodegradable resin costs $3/Kg (Anon_1, 2022). Providing value added, versatile and cost competitive biodegradable renewable materials that can target a variety of applications, can facilitate the expansion of the biodegradable plastics market. This requires innovation at both the technical and the business model fronts.

The Solution:

The technical solution to this challenge is to look at using polysaccharides, primarily cellulose, as the source of the biomaterials for plastics.

Cellulose occurs primarily as lignocellulose in plants and forms the most abundantly available renewable raw material on the planet. Celluloses are available from many sources such as jute, hemp, corn, rice, wheat straw, sisal, bacterial sources etc. (Lavanya, 2011). Other potential sources such as sugarcane bagasse and bamboo (Gupta, 2019), and jack fruit (Tristantini, 2017) also exist. As cellulose is not digestible by humans it does not add any nutritional value to human diets, and cellulose in food contributes mainly to dietary fiber needs.

Celluloses are polymers made of monomeric glucose units linked in a linear chain (Sabbaghi, 2023). They are hydrophilic solids but are insoluble in water. This insolubility is due to the strong intramolecular hydrogen bonding between the glucose units in the cellulose chains, and the crystalline domains in the cellulose polymers. This insolubility provides them with a degree of toughness in natural settings, but can make them difficult to work with for developing extensive applications.

Celluloses are highly chemically modifiable and many artificially modified cellulose derivatives, such as methyl cellulose (MC), hydroxy-propyl cellulose (HPMC), carboxy methyl cellulose (CMC), ethyl cellulose (EC) etc., that provide increased solubility in water, have been synthesized. (Sabbaghi, 2023) Similarly several methods for dissolving and regenerating cellulose from solutions have been developed, especially in the fiber and clothing industry (Kihlman, 2012), with others studies being more of a basic research nature (Pinkert, 2010). However, most of these processes make use of many highly toxic and caustic chemicals that are non-renewable nor ecofriendly, and are not suitable for the applications envisaged.

The Proposal:

This proposal/venture explores chemical methodologies to modify cellulose and explore diverse functional opportunities. The aim is to further explore the physical and chemistry property potential of cellulose, in an eco-friendly manner,

The reason for cellulose structure modifications is to controllably break down the cellulose polymer chains into smaller oligomeric segments. These shorter cellulose chains are targeted at being more soluble, preferably in aqueous solution, leading to greater processibility. Chemical modifications of the shorter chains will also aid in exploring their processibility. The oligomeric cellulose molecules can then be functionalized with suitable orthogonal reactive groups using environmentally benign chemistries. These functionalized oligomeric celluloses can be used to build back the molecular weight of cellulose through linear chain extension or crosslinking, to aid in compatibilization and composite formation, and/or to tailor the physical and chemical properties of the final materials. These changes will make the biodegradable modified-cellulose molecules more amenable to formation of higher order complex structures through casting, extruding, molding, additive manufacturing, fiber-drawing, or resin curing techniques, and in a more eco-friendly manner.

Figure1 and Table1 highlight the dimensions (in 2D and 3D respectively) for making controlled changes to the cellulose molecules to go from the current state of insoluble high molecular weight polymer to more value-added materials.

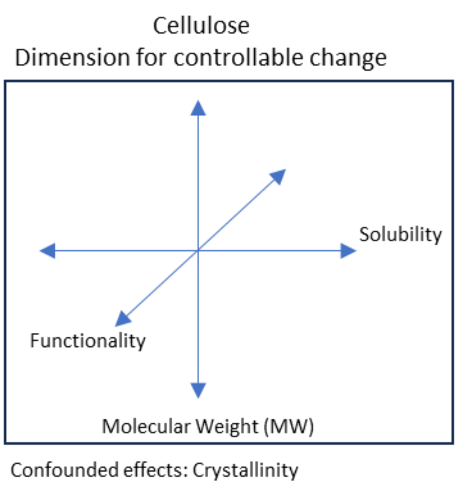

Fig 1: 3-Dimensions for making controllable change in cellulose, with confounded effects.

	Insoluble	Soluble
HIGH MW	<u>Current Status Quo</u> • Fibrous material for filler and support. • Can be chemically functionalized. • Hydrophobic chemical functionalization that leads to no/limited aqueous solubility and processibility eg HPMC, Ethyl cellulose.	<u>Highly physically or chemically modified.</u> • <u>Current</u>: Kraft (NaOH), Viscose (CS_2), Lyocell (NMMO) processes etc. • Used in industrial fiber spinning. • CMC is a highly water-soluble high MW cellulose derivative that is used commercially.
LOW MW	• Of Limited uses. • Intermediate MW's may have application in drug delivery.	<u>Highly cleaved backbone</u> • <u>Current:</u> None commercial. • Suitably functionalized low MW cellulose oligomers can be used to build back MW through chain extension and/or crosslinking. • Other chemical modifications.

Table 1: The dimensions for making controllable change in celluloses (blue = area of interest).

This concept broadly and ironically takes inspirations from the oil industry where crude oil cannot be used as extracted and has to be extensively processed / refined in order to make useable products from it. (USEIA, 2023) Similarly, I believe that the appropriate chemical modification of cellulose will allow access to many useful biodegradable products, which can aid in the transition away from fossil fuel based materials.

Advantages or Benefits:

The advantages of this proposal are the development of more easily processable and more chemically functional cellulosic materials that can be used to create polymeric biodegradable materials having different properties and applications. These can then be used as a platform polymer technology to construct useful higher dimensional objects, that can feed different industries/markets.

Applications:

The aim of this invention is to provide technical bio-plastic alternatives that will be used to make regular everyday materials/items (commodity) and high-performance items (differentiated). Based on the obtained properties and the ability to tune the obtained properties, these bioplastic compositions may find end uses in household consumables, industrial applications to other areas like biomaterials, medical devices, bio-sensors, additive manufacturing etc.

A business aim is to look at the supply chain models and channels, and create ecosystem or platform-based systems, to make these bio-based products, especially the commodity products, widely available to and accepted by consumers. These will add value, and that are meant to drive customer acquisition and retention. Take back supply chain models for used materials from users that cannot compost / recycle used items can later also be examined.

Technical:

A lot of initial work on the basic chemistry required to facilitate these transformations has been demonstrated in the publicly accessible published literature and can be considered as common knowledge. (Fukuoka, 2018), (Nypelo, 2021) (Coseri, 2017). This proposal builds on these discoveries/ inventions. The novelty and challenge of this proposal will be to use this current knowledge in unique ways, and/or combine them with new methodologies, to successfully unlock the desired value from the targeted properties of the cellulose. These new methods/ processes can be patented to provide intangible assets that provide a barrier to entry.

Economics and Scale:

Cellulose is the most abundantly available renewable raw material on the planet (Sabbaghi, 2023) and is currently a relatively cheap raw resource, with the commodity price of cellulose being about US$1000-1380 per metric tonne. (Anon_2, 2021) Crude oil (brent) traded at around US$605 per metric tonne. (Anon_3, 2024) Decreasing demand for cellulose in the printing industry is expected to decrease prices and open up room for other cellulose markets/demand. (Anon_2, 2021) The future price trends for each of these commodities will depend on global economic climate, geopolitical forces and policy decisions. The overall global policy sentiment is a general shift away from petroleum-based materials to renewables. The marginal cost for adding value at each step, to get to the final products, will determine whether biodegradable materials from cellulose are competitive with petroleum-based materials, on a per weight basis. This will determine how general or niche a market these cellulose based biomaterials can supply.

The markets being targeted are large (Table 2) and the ability to capture even a few percent of these markets will result in significant revenues. The ability to control costs will determine profits and free cash flows.

Market	Global Market size $ (year), CAGR %, End Year
Surface Disinfectant,	5.85B $, CAGR 7.1% to 2030
Biocides – labile quats, long-R chain	8.5B $, CAGR 4.5% to 2030
Surfactant, detergent– hydrophobe	120B $ (2021), CAGR 4.3% to 2030
Cosmetic/Bar Soaps – fatty esters	30B $, CAGR: 4.6% to 2030
-Med devices- contact lens	17.4B $, CAGR 8.9% to 2030
-Medical Plastics	22.B $(2019), CAGR 6.8% to 2030
- adhesive bandages	2.2B $, CAGR 3.6% to 2030
- 3D printing	20B %, CAGR 23.3% to 2030
- 3D printing resins (all)	0.51B$(2023) to 1.2B$ (2030)
-Dry Eye Treatment	5.1B $, CAGR 6.4% to 2033
-Allergic Conjunctivitis	2.74B $(2022), CAGR 5.7% to 2030
-3D printing resins (UV type)	2.1B$(2023), CAGR 3.5% to 2030
-molded plastics market	500B $ CAGR 6.2% to 2027
-packaging films	149B$, CAGR 4.1% to 2033
-biodegradable plastics	2.2B $, CAGR 6.9% to 2031
Topical/Trans dermal drug delivery	207.4B(2022), 8.9% to 2027

Table 2: Possible target global markets and their size.

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Execution Strategy:

The current execution plan is to target the OTC / generics market for medical products for dry-eye (Chiang, 2023) and ophthalmic conjunctivitis - AC: allergic conjunctivitis (Dupuis, 2020), VKC: Vernal Kerato conjunctivitis (Alemayehu, 2019) and possibly AKC: Atopic Kerato conjunctivitis. (Li, 2018) These markets have an unmet need for therapies that are single dose application and last through the day. The differentiated solution is to provide sustained release options for addressing these disease states. The challenge will be to create safe, effective, and biodegradable sustained release drug-device combinations which can achieve zero order release kinetics over the duration of 12-16 hours, while minimizing ocular irritation and device motion on-eye. This differentiated solution will provide added value to the customers, compared to the current eye drops, which we aim to capture. Both disease states provide opportunities for repeat customers from a large and growing patient base population.

The regulatory process for these drug device combination products can be long. In the US the PMA (FDA, 2022) or ANDA/505(d)(2) (Anon_5, 2023) process can be up to 36 months. During this period, based on our learning with the basic cellulose modification chemistry, we plan to explore applications in other less regulated markets or more commodity markets. This allows us to absorb most of the R&D cost of developing the differentiated drug-device products, while using economies of scope and scale, and the learning curve, to drive down the costs of developing the more commoditized products.

Environmental:

While cellulose is highly biodegradable, extensive chemical modifications to cellulose can slow down the degradation process. (Erdal, 2022) The biodegradability rates of novel modified cellulose derivatives and products will have to be evaluated. On the flip side, appropriately modified cellulosic material could be targeted as low degradable biocompatible biopolymers for use in high value biomedical applications.

General Challenges

One of the main challenges will need to be confirmed at the outset (pre-seed or seed stage):

(i) The process of controlled chemical break down the cellulose into water soluble oligomers with terminal functional groups orthogonal to -OH in functionality.

(ii) Use the telechelic cellulose oligomers to build back the molecular weight through linear chain extension.

(iii) Backbone chemical functionalization for crosslinking and property modification.

Other challenges include managing the techno-economics of the processes required to deliver on the target features of the technology. Application specific challenges may exist, and some are identified and addressed in this document as and when these arise, e.g. achieving zero order release kinetics, ocular irritation and device motion for ophthalmic drug-device combinations for dry-eye and allergy products.

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