Valorisation of European Citrus Waste: From Citrus Waste to Essential Oils and Bacterial Cellulose-Based Textile Fibres

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BACKGROUND

- **11.5 million tons/a of citrus fruit** are produced within Europe.
- 25-30% of produced volume, **approx**. **3.5 million tons/a**, **remain as semi-solid citrus waste** following fruit processing.
- Citrus waste poses **a major environmental and economic issue** for citrus processors and waste management (mainly due to drying and transportation).
- Citrus waste contains **high levels of valuable compounds**, such as soluble sugars, essential oils, organic acids, proteins, vitamins and polyphenolic compounds.

Figure 1: Annual citrus waste generation across Europe [in million tons]

MULTI-STAGE, CASCADING PROCESS

- **Stage 1 – Essential oil extraction** via supercritical CO_2 to obtain a complex mixture of natural essential oils
- **Stage 2 – Acid hydrolysis** to obtain fermentable sugars from peels and fibres of discarded fruits that contain complex carbohydrates
- **Stage 3 – Bioproduction of bacterial cellulose** via high-yielding *Komagataeibacter xylinus* strain in oxygen supplied stirred or air-lifted fermentation at 29.0±1°C and acidic to near-neutral conditions (pH 4.0 - 6.0), and with an expected yield of 5.7-7.2 g/L bacterial cellulose after 8 days of incubation
- **Stage 4 – Textile fibre formation** via mechanical defibrillation and dispersion of cellulose fibres and use of state-of-the-art fibre formation processes (e.g., direct spinning, dry spinning, gel collection, etc.)

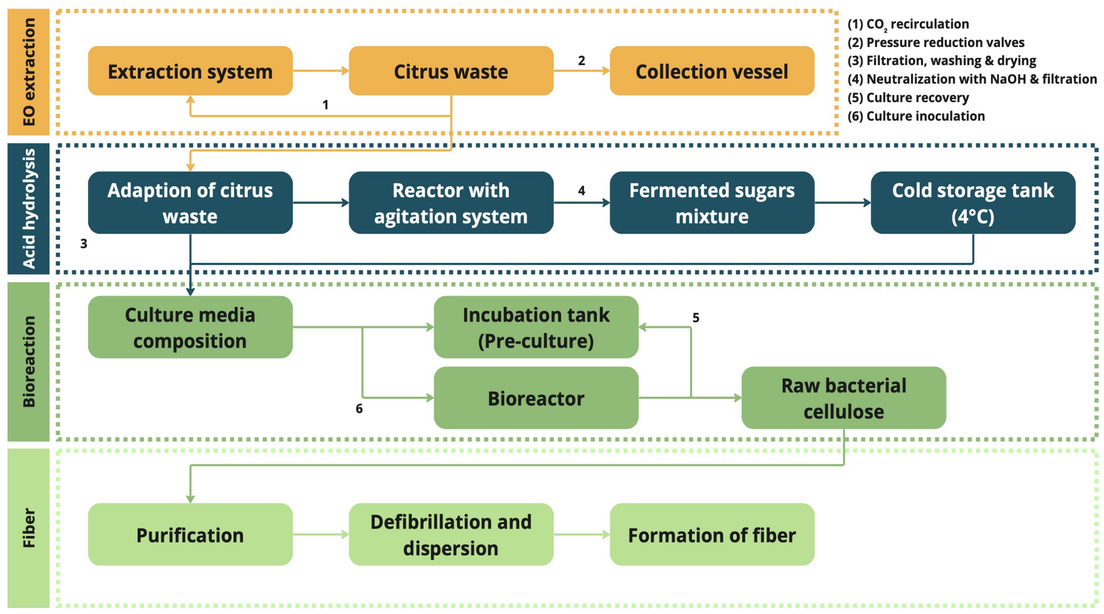

Figure 2: Overview of integrated process

MARKET POTENTIAL

- **EU essential oil market** is projected to expand to **4,589 million USD by 2030**, with a compound annual growth rate of 10.6%
- EU is second largest **market for bacterial cellulose** (20.6% share) and is projected expand to **245 million USD by 2028**, with a compound annual growth rate of 8.1%
- Increasing consumer awareness & desire for sustainable and environmentally friendly products/practices, may allow to command premium prices in all markets.
- Main **cost factors** are **raw material, energy, labour & equipment cost**

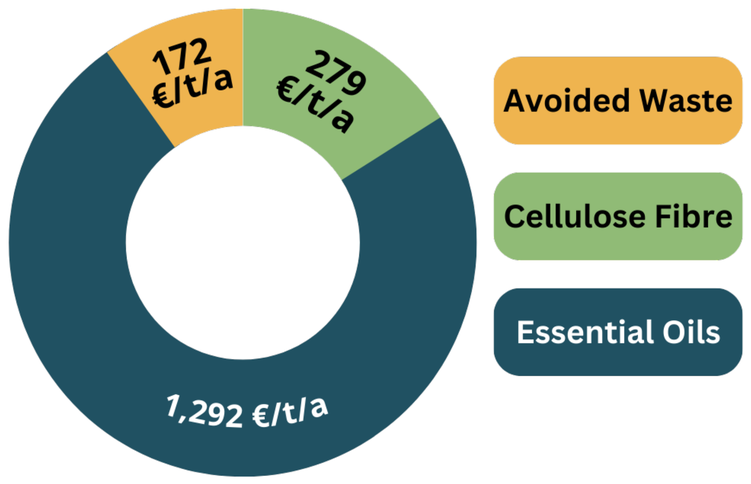

Figure 3: Expected annual revenue per ton of citrus waste

BENEFITS & SDG CONTRIBUTION

Environmental benefits

- Emission & pollution reduction from current inefficient waste management of citrus waste

Social benefits

- Rural development through creation of local employment opportunities and increasing salaries
- Human resource development

Economic benefits

- Facilitation of the bioeconomy transition by increasing the biobased material market share & substitution of fossil products
- Avoidance of waste processing and management cost
- Possible entry to other markets via bacterial cellulose platform

9 INDUSTRY, INNOVATION AND INFRASTRUCTURE

12 RESPONSIBLE CONSUMPTION AND PRODUCTION

13 CLIMATE ACTION

Strengths
- Food waste prevention & valorisation of waste product
- Efficient waste management & emission reduction
- Innovative process
- Natural and vegan products

Weaknesses
- Energy intensive process
- Raw material dependency (quality/quantity/transport)
- Time dependency
- High start-up cost
- Locally bound

Opportunities
- Current niche raw material
- Industrial symbiosis and cooperation possible
- Potential for CSR & rural development
- Likely development of process technology

Threats
- Competition
- Market-entry obstacles
- Increasing raw material & energy prices
- Decreasing raw material availability (harvest loss & alternative application)

Figure 4: SWOT Analysis process & SDG contributions

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