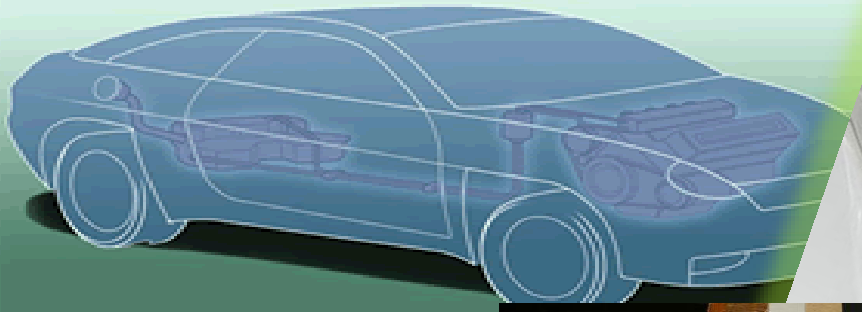


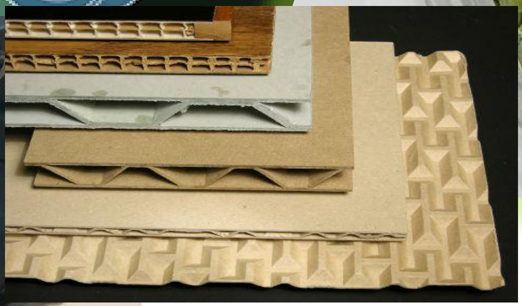


Roadmap for the Development of Nanocellulose as a Sustainable Nanomaterial

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Santa Barbara, CA
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Objectives

- Approach - NANO Life Cycle Risk Framework
- Exposure: market analysis of nanocellulose
  - Methodology
  - Volume estimates
  - Implications for Exposure and Research Needs
- Toxicology
- Outline the roadmap to sustainable development

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Dimensions of New Product Sustainability

Production

Safe/Transparent Applications

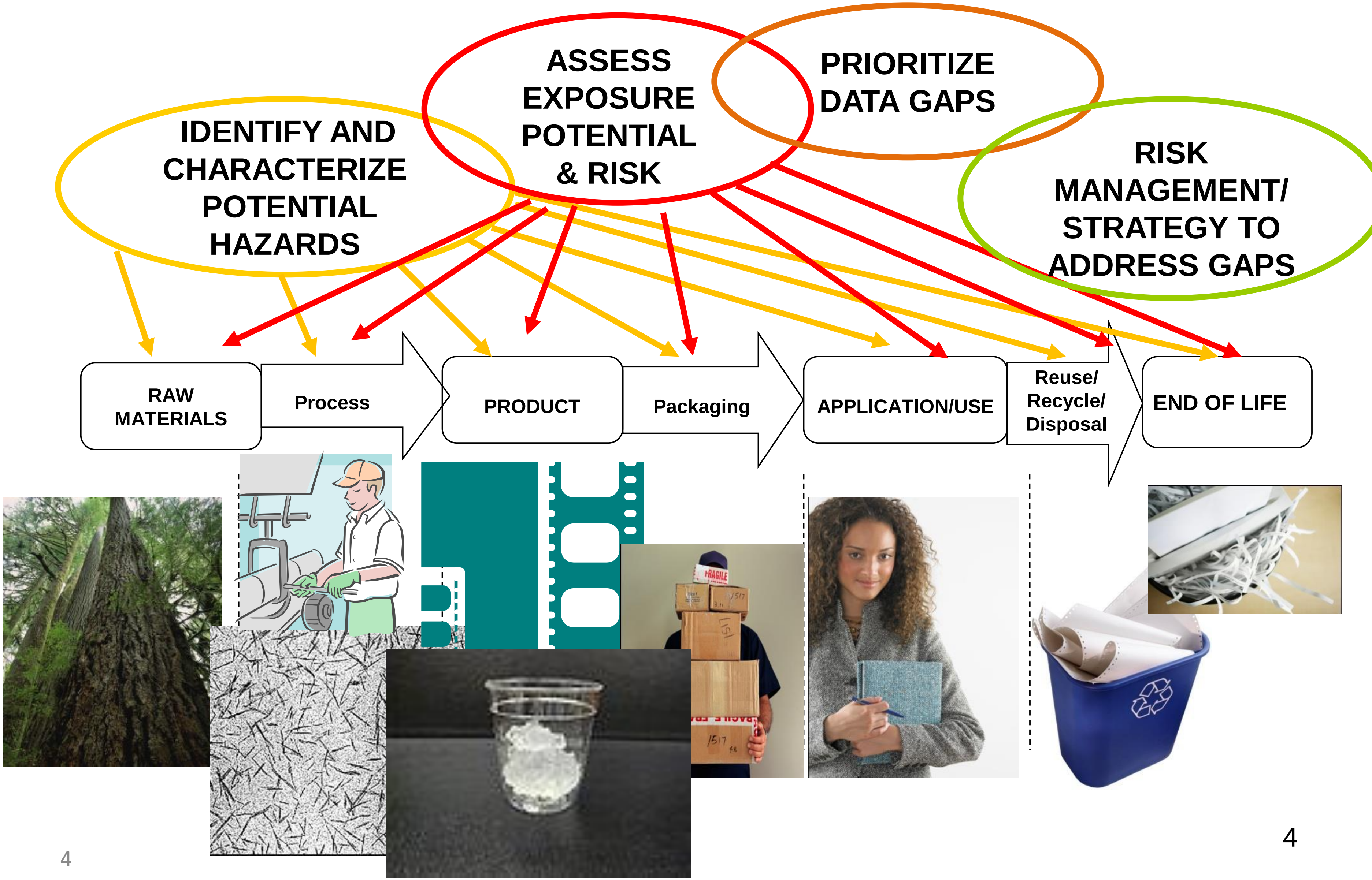
Stewardship

Critical for Pre-commercial Assessment

Life Cycle Impacts

RAW MATERIALS → Process → PRODUCT → Packaging → APPLICATION/USE → Reuse/ Recycle/ Disposal → END OF LIFE

NANO LCRA for Nanocellulose Iterative Risk Assessment



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Environmental Market Drivers

Retailer demand	Regulatory
Light-weighting to improve fuel efficiency	Café standards
Energy Efficiency	Stretch codes; building codes
Bio-based materials	Shopping bag/water bottle bans
Greener Consumer Products	EU Directive –vehicle recycling
Carbon Dioxide targets	
Renewable/compostable	Landfill bans/ recycling targets

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Targeted Applications

HIGH VOLUME	LOW VOLUME	NOVEL and Emerging APPLICATIONS
Cement	Wallboard Facing	Sensors – medical, environmental, industrial
Automotive Body	Insulation	Reinforcement fiber - construction
Automotive Interior	Aerospace Structure	Water filtration
Packaging Coatings	Aerospace Interiors	Air filtration
Paper Coatings	Aerogels for the Oil and Gas Industry	Viscosity modifiers
Paper Filler	Paint-Architectural	Purification
Packaging Filler	Paint-Special Purpose	Cosmetics
Replacement -Plastic Packaging	Paint -OEM Applications	Excipients
Plastic Film Replacement		**Organic LED**
Hygiene and Absorbent Products		**Flexible Electronics**
Textiles for Clothing		**Photovoltaics**
		Recyclable Electronics
		3D printing
		Photonic Films

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Volume Estimates

Vol = M *NC content* MP

M = recent market size

NC Content = % nanocellulose

MP = market penetration rate

Market Study Assumptions

- Recent research reports/expert network to identify target applications
- Current market size is maintained (no growth)
- Commercialization within the next 3-12 years
- Dry yield 40%
- Cost competitive with current alternatives
- Technical issues addressed
- No barrier to adoption

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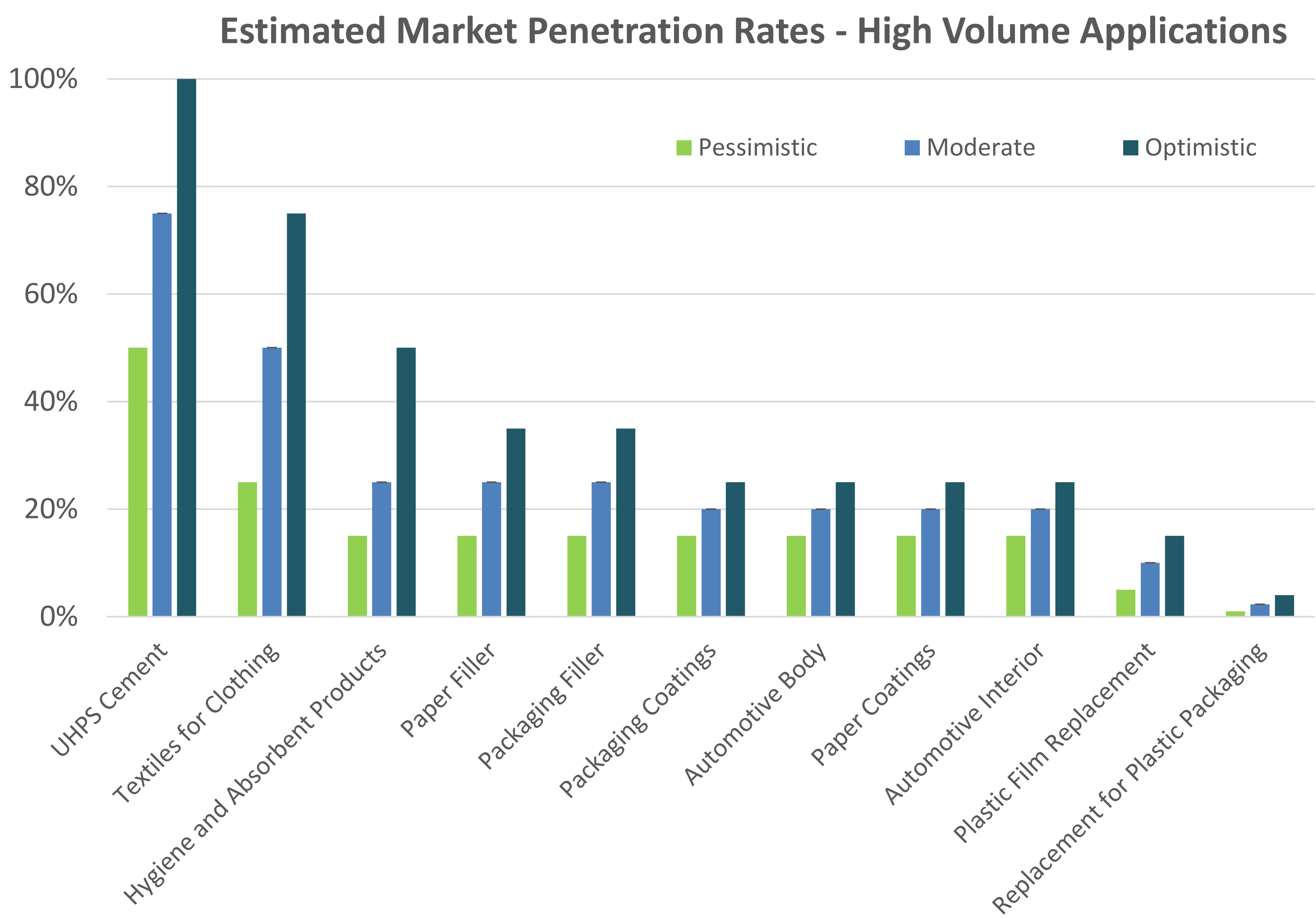
Adding Nanocellulose to Cement

- 0.5% adds 20% to strength; allows 17% less cement in concrete
- Global cement market volume is 3.3 Billion TPY
  - Weight addition of 0.5% CNC (Cao et al. 2013) >>> 16.5 million tonnes CNC
- This study – U.S. adoption for ultra-high performance structural cement market – pre-stressed and pre-treated only (5.7 M tonnes cement >> 21,000 tonnes CNC @75% market penetration)



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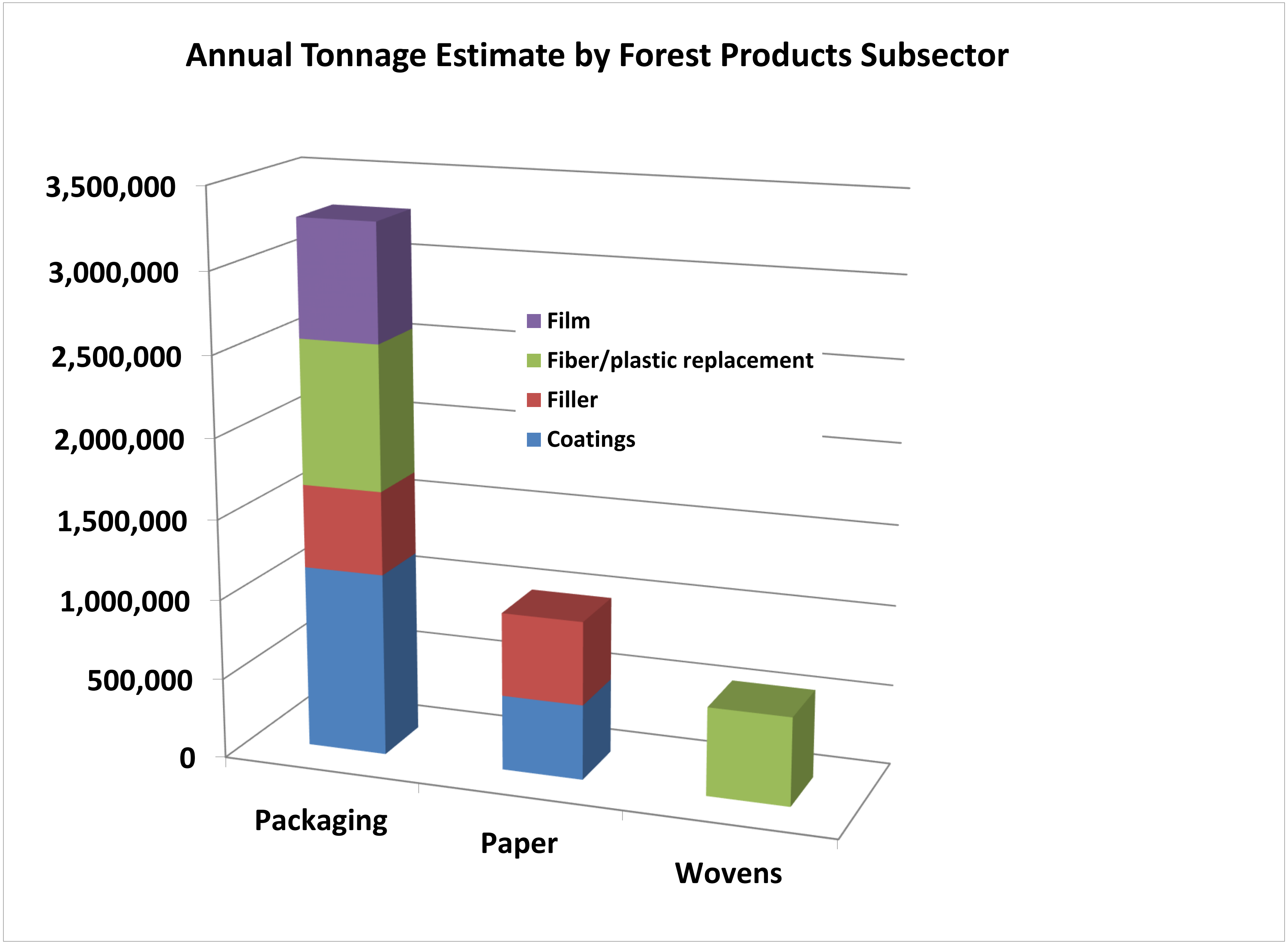

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Exposure Scenarios

- Worker
  - inhalation exposure to dry particles
  - Manipulating composites
- Consumer
  - Dermal
  - Food contact
  - Shredding/recycling
- Environmental
  - Water; waste; recycling

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TOXICITY ENDPOINTS / HEALTH EFFECTS

IN VITRO ASSAYS

Exposure Duration	Study	Material	Immunotoxicity	Cytotoxicity	Neurotoxicity	Genotoxicity	Carcinogenicity	Lethality	Systemic	Pulmonary	Cardiovascular	Dermal	Underlying
Acute	Vartiainen, et al (2011)	CMC	▼ (red) ▽	▽ (red)									
		CMF	▼ ▽	▽									
	Norppa (2012)	CNF	● (red)	⊙	×	**O** (red) ⃠			×				
	Ferraz, et al (2012)	CNF-PPy (as-is)	☒	■									
		CNF-PPy (aged)	☒ (red)	■ (red)									
	Pitkänen, et al (2010)	Whisker-type UFC		◆ ◇		※							
		CNF		◆ ⟐ ◇		✦							
Subchronic													
Chronic													

SYMBOL	ASSAY ORGANISM	SYMBOL	ASSAY ORGANISM
▽	Mouse macrophage	✦	Bacterial Ames Test
▼	Human macrophage	⊙	Human cervix carcinoma cells & Boar sperm
■	Human fibroblast	●	Human macrophage
☒	Human monocyte	**O**	Human bronchial epithelial cells
□	In vivo mouse	⃠	Human bronchial epithelial cells
◆	Human keratinocyte	⊗	In vivo mouse
⟐	Human cervix carcinoma cells	×	Nematode-C. elegans
◇	Mouse hepatoma		

TOXICITY ENDPOINTS | **HEALTH EFFECTS**

Pathway	Exposure Duration	Study	Material	Immunotoxicity	Cytotoxicity	Neurotoxicity	Genotoxicity	Carcinogenicity	Lethality	Systemic	Pulmonary	Cardiovascular	Dermal	Underlying
INHALATION														
Occupational	Acute													
	Subchronic													
	Chronic													
General Population	Acute	Pitkänen, et al (2010)	CNF	⊗			⊗				⊗			
	Subchronic													
	Chronic													
INGESTION/DERMAL														
Occupational	Acute													
	Subchronic													
	Chronic													
General Population	Acute													
	Subchronic													
	Chronic													
INJECTION														
General Population	Acute	Ferraz, et al (2012)	CNF-PPy		□				□	□				
	Subchronic													
	Chronic													

SYMBOL	ASSAY ORGANISM
□	In vivo mouse
⊗	In vivo mouse

State of the Science on Safety

Weight-of-Evidence

- In general, several studies indicate CNC and CNF nanocelluloses ***non-toxic*** based on available data

- But, more complete data sets are needed
  - Longer term studies
  - More materials
  - Additional endpoints

Knowledge gaps

- Comparative data
  (Weight of Evidence)
- Functionalized or modified material data
- Data on composites/products
- Occupational inhalation data
- Consumer /environmental exposure data
- Nano-specific standards
- Standardized measurements
- Validated methods

EHS Priorities

- Safe Handling Processes
- International Safety Standards Development
- Sustainability Assessment and Certification

Source: Extremetech.com

Cellulosic Nanomaterial EHS Roadmap

1. **Methods to assess occupational and environmental impacts**

   a) <u>**Occupational safety guidelines**</u>

      1. Material handling; labeling; disposal; research
      2. Assess and build on existing wood dust/cellulose standards

   b) **Develop exposure assessment & testing procedures**

      1. Estimate exposure levels through modeling
      2. Assessment and measurement methods for air, water, other media
      3. Migration studies

   c) **Verify/"validate" toxicology testing**

      1. Confirm *in vitro* tests valid for nanocellulose
      2. Assess additional exposure pathways/scenarios
      3. Criteria for new assessments (e.g. size distribution; functionalization)

Cellulosic Nanomaterial EHS Roadmap (2)

2. Develop/adopt Standardized EHS Methods

a) Sampling and Measurement Standards Development

1. Develop sampling protocols, including sample preparation
2. Develop test approaches for different materials and applications

b) Occupational Exposure Standards

a) Guidance for sampling and worker protection

c) Environmental Impact Standards

1. Guidance for monitoring environmental impacts
2. Measurement methods for air, water, other media
3. Decision tree analysis

d) Consumer Product Standards

1. Guidance for testing nano-enabled products

Cellulosic Nanomaterial Roadmap (3)

3. Sustainability Measurements

a) Process impacts

1. Chemical use and disposal
2. Energy consumption
3. Carbon impacts

b) Life cycle comparisons with alternatives

1. Select applications
2. Develop data for LCIA
3. Build database and models

c) <u>Establish certification standards</u>

1. Draft standards
2. Convene stakeholders to vet and approve
3. Publish standards

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Thank you

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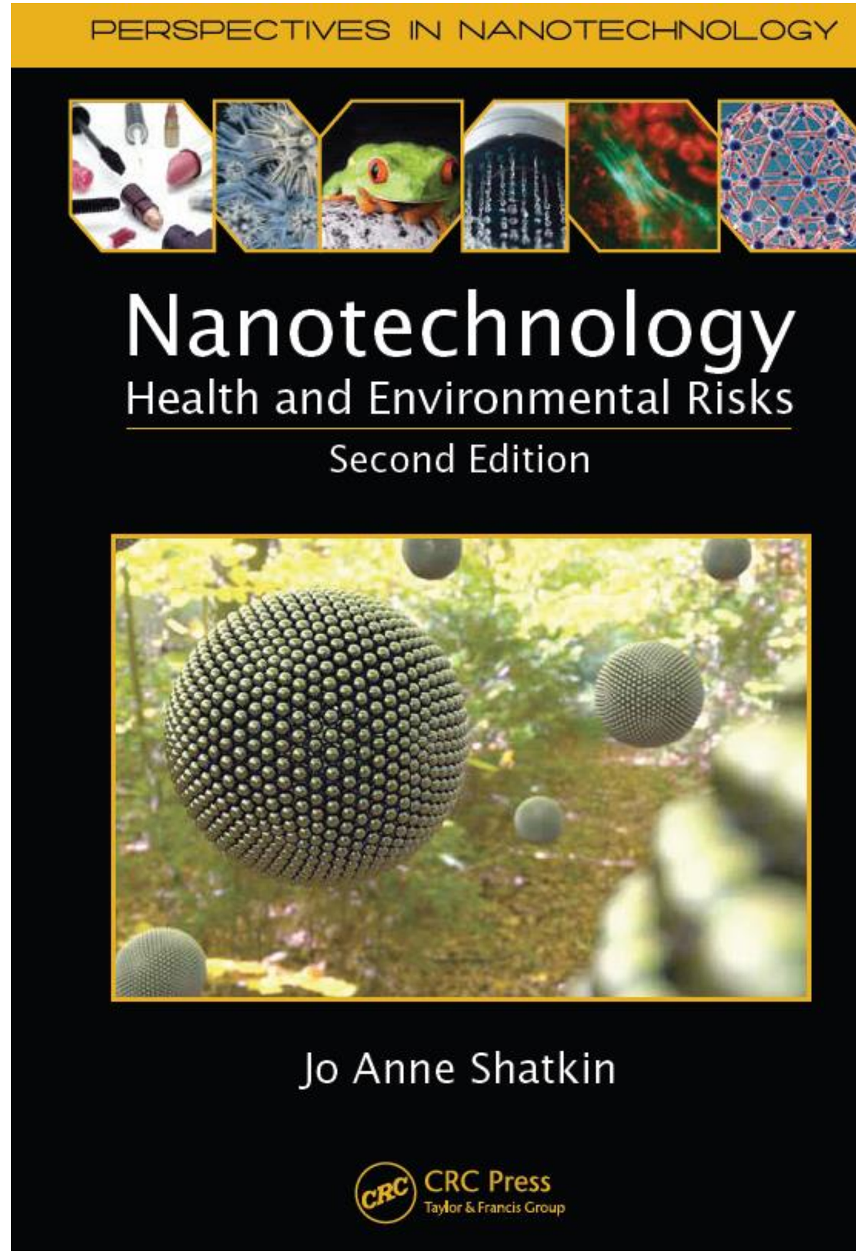

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Recent Analysis of Patent Applications for Wood-based Nanocelluloses

- 10% -Paper Coating
- 8% - Paper Furnish
- 22% - Composites
- 9% - Film

[Source Salmenkivi 2013]

Alternative U.S. Acreage Estimates of Cellulose Needed*

	Green Tons/ Acre		Acres per Year	Hectares
PLANTATION GROWN TREES	470		183,000	72,000
NATURAL FORESTS	92		935,000	370,000
FOREST RESTORATION "THINNINGS"	22		3,900,000	1,500,000

*Assuming 100% from virgin wood pulp

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