

**NIST Workshop: Facilitating a
Circular Economy for Textiles
21-23 September 2021**

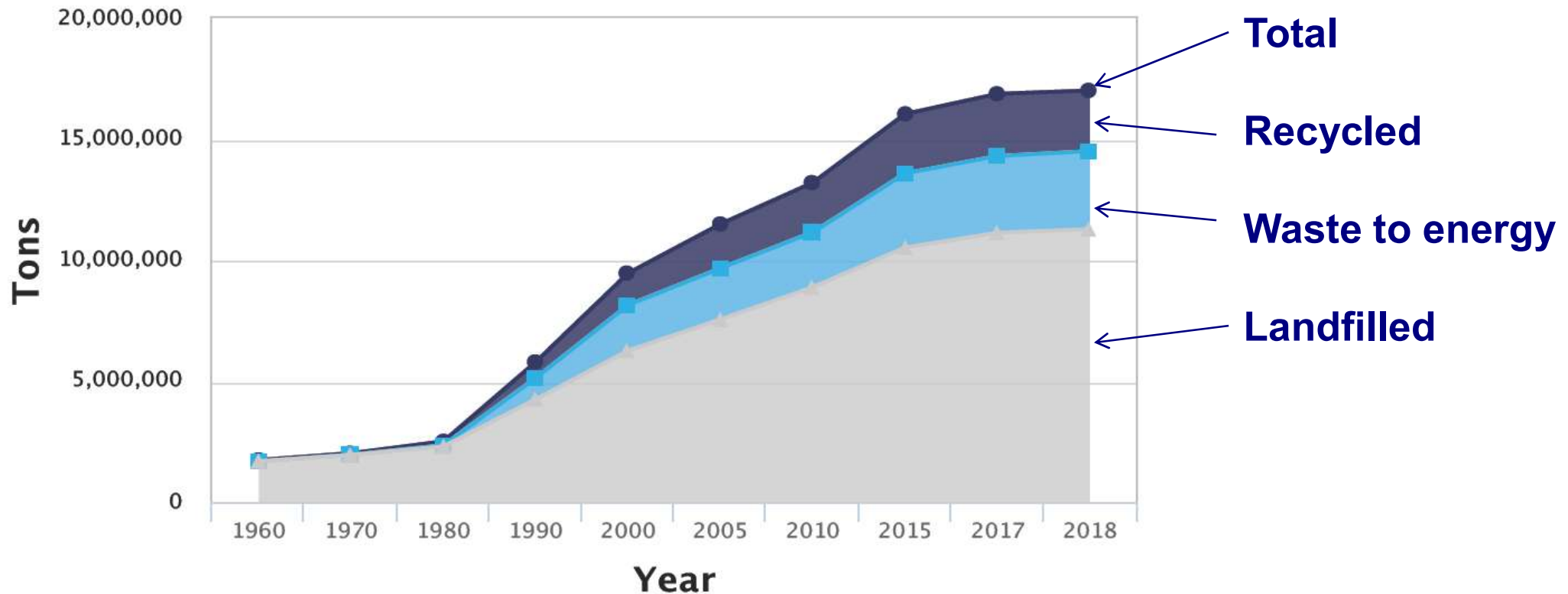
**Challenges to Mechanical and
Chemical Recycling of Textiles**

Dr. Youjiang Wang
School of Materials Science & Engineering
Georgia Institute of Technology
Atlanta, Georgia

Textile waste

(US EPA, 2021)

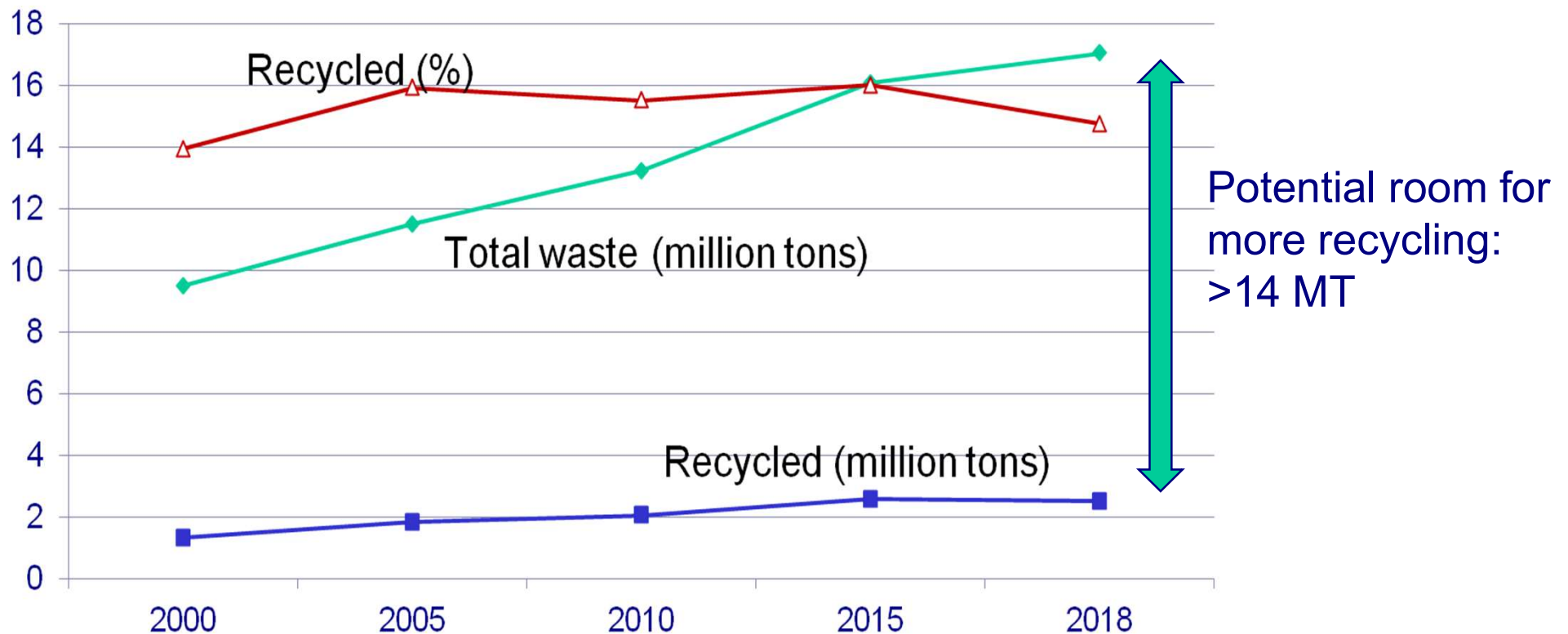
Textiles Waste Management: 1960–2018



Click on legend items below to customize items displayed in the chart

Recycled Composted Combustion with Energy Recovery Landfilled

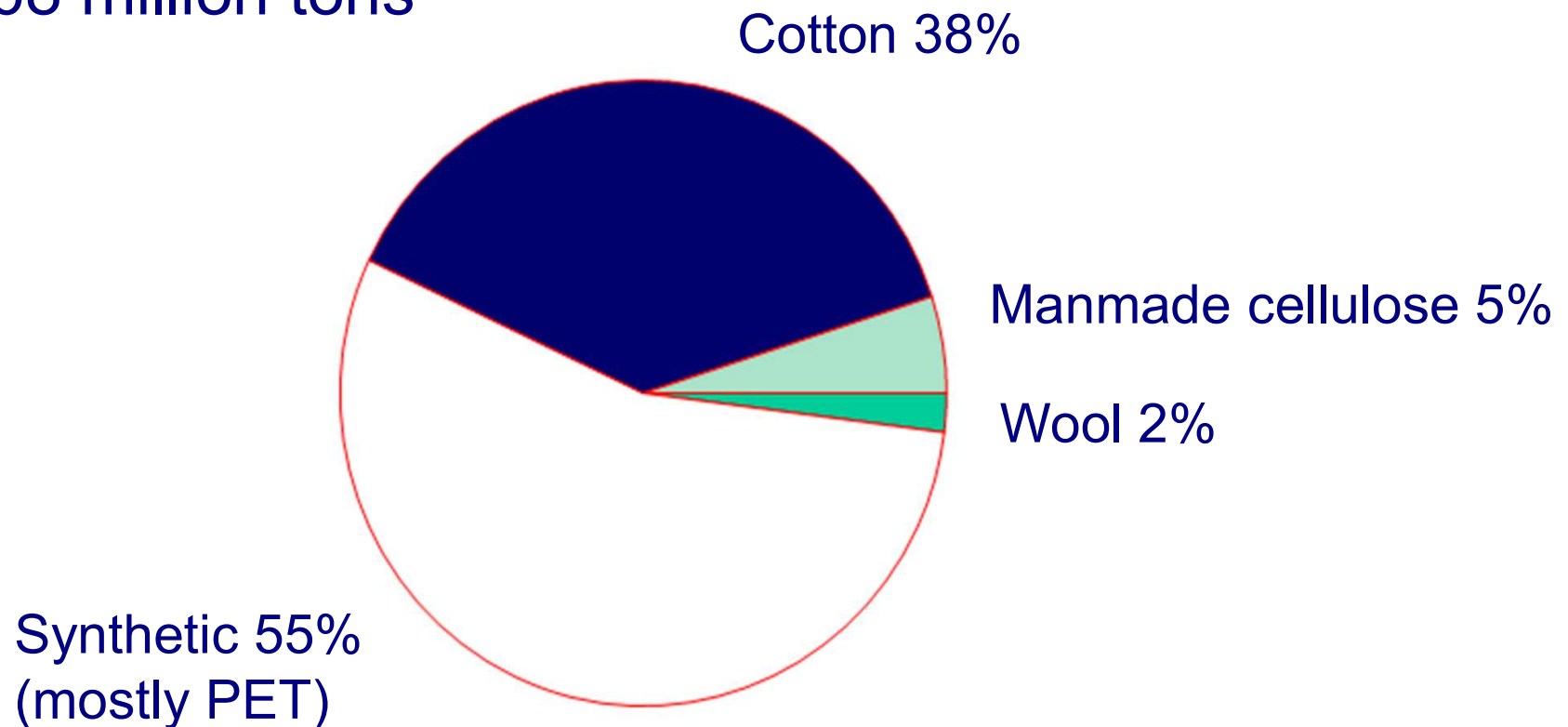
Textile waste & recycling rate



2000-2018: waste: x1.8, **recycling: x1.9**, %recycled ~15%
Significant effort on textile recycling; more needed

Fiber consumption

- **Worldwide fiber demand (natural & synthetic):**
 - 68 million tons



Circular economy



Recycling technologies

- Many mechanical/chemical/etc recycling technologies
 - are developed, improved, commercialized
 - contributing greatly to increased recycling
- A few examples given – not a comprehensive review

Sorting/ID fiber types



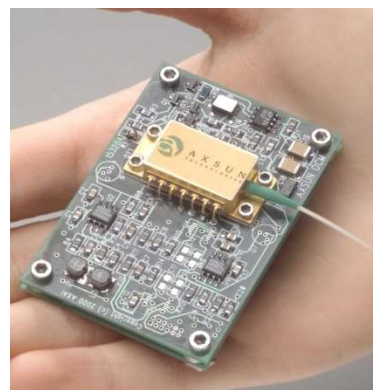
Hand-held
(Honeywell)



NIR (Bruker)



Raman
Spectroscopy

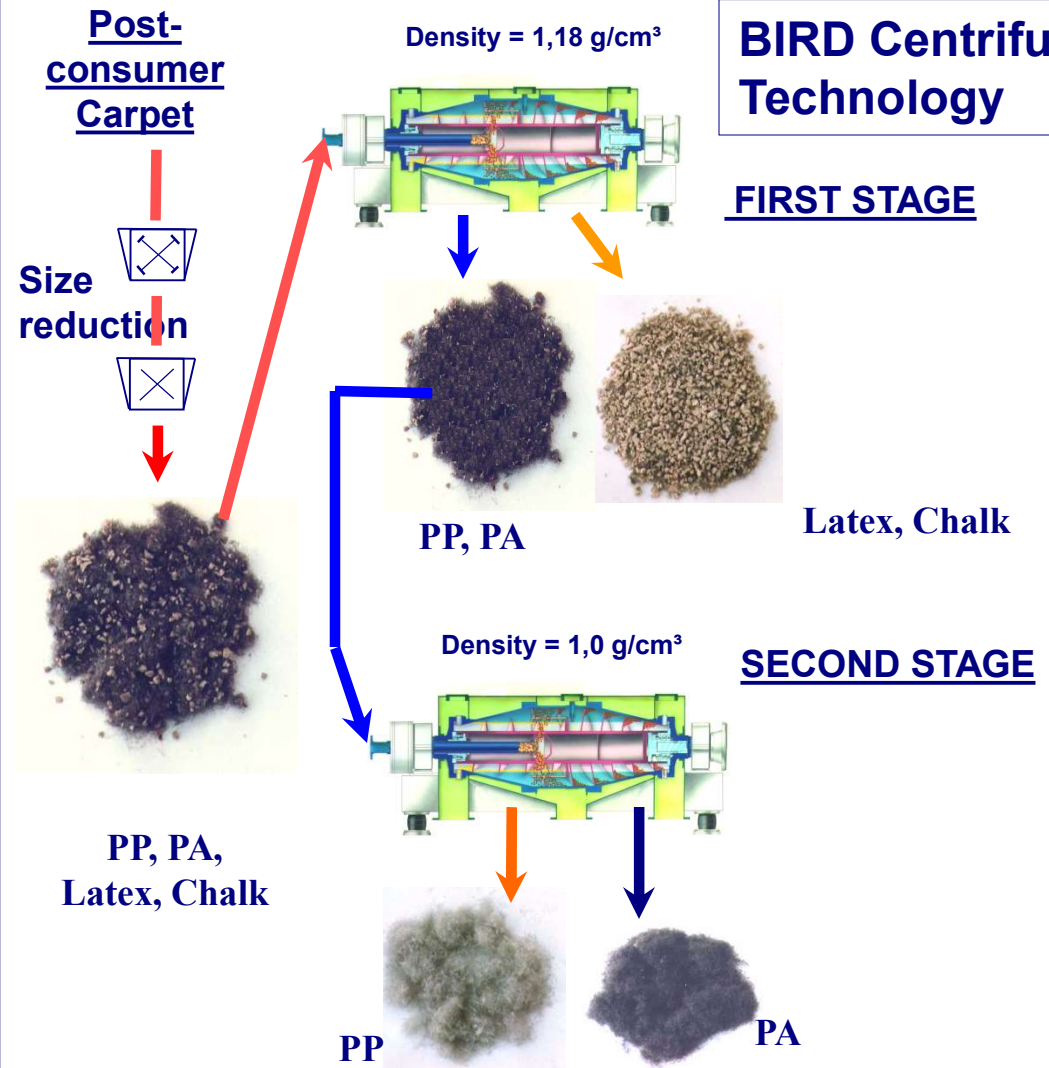
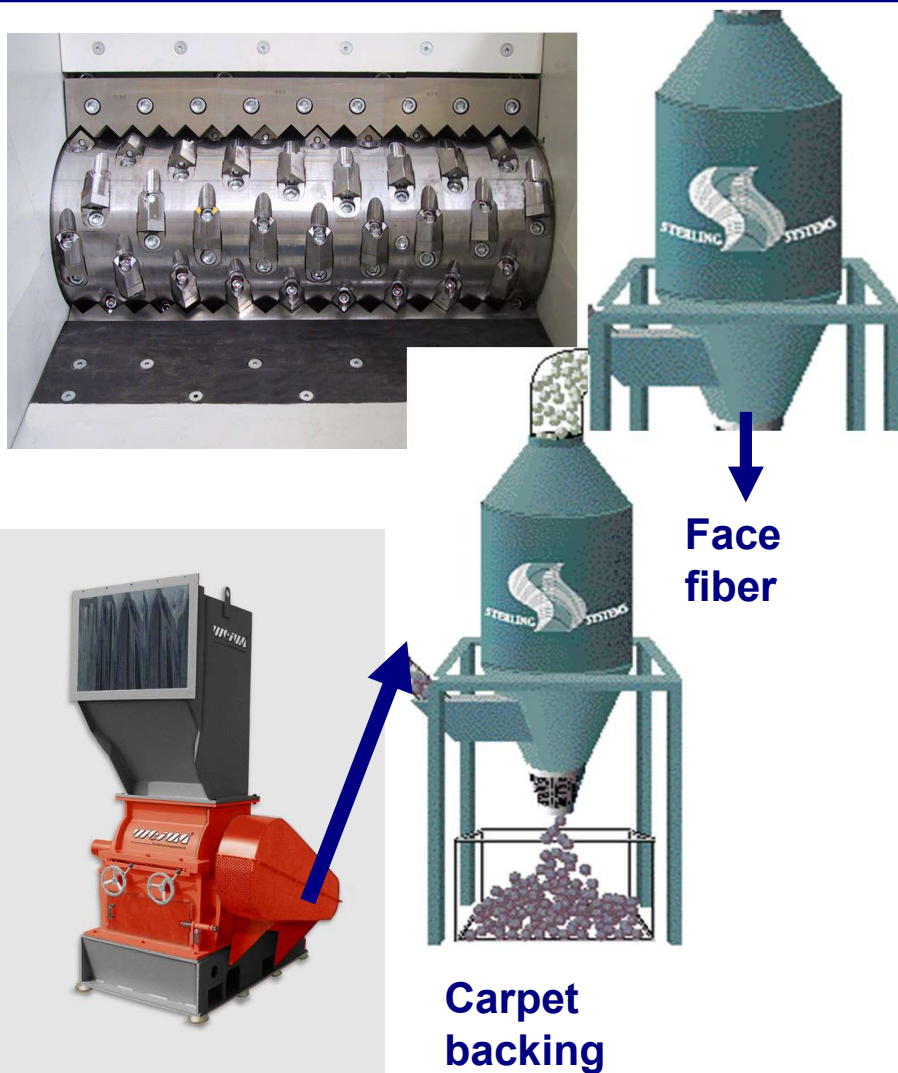


Spectrometer
-on-a-chip
(Bruker)



Carpet Recycling Europe

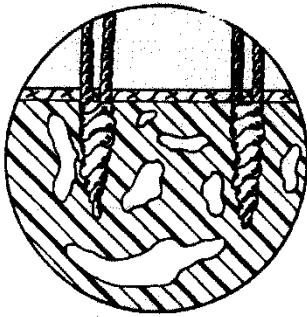
Size reduction (grinding, separation)



Harvesting fibers from carpet

1. Removing backing

Fig.-7A



2. Pulling out face fibers

Fig.-8B

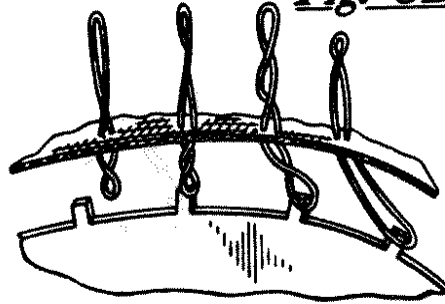


Fig.-8D

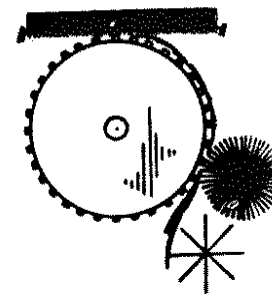


Fig.-7B

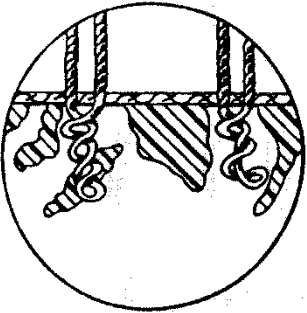
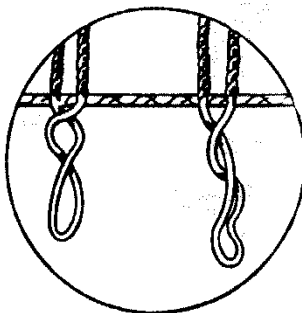


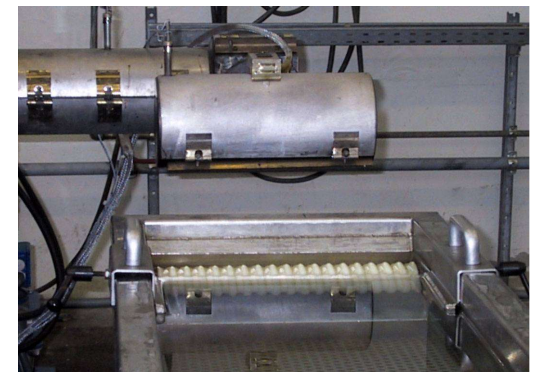
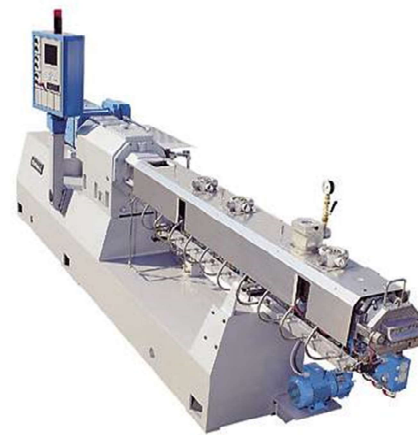
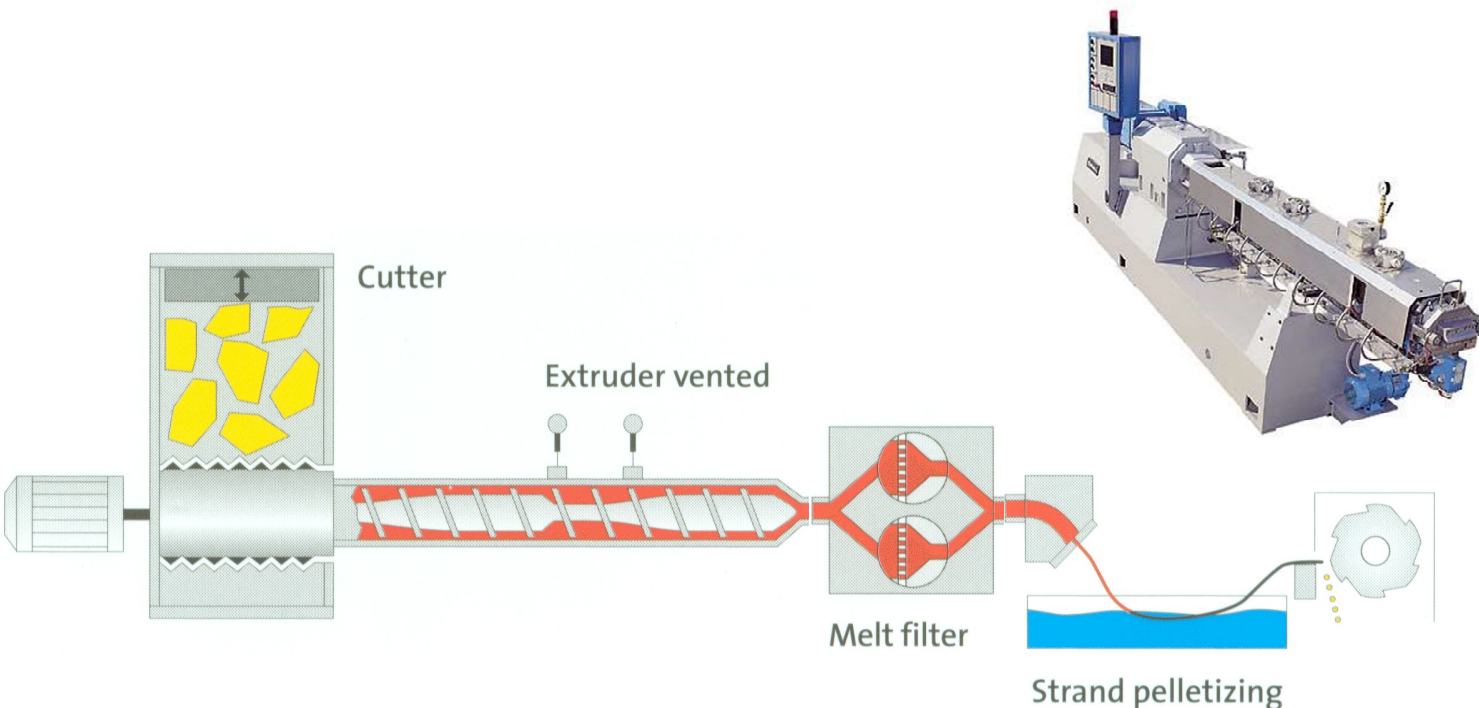
Fig.-7C



- Other approaches
 - Mechanical shearing
 - Hot-wire cutting

Thermoplastic compounds

- Recovered thermoplastic fibers are pelletized
- To use for extruded products, composites
- Quality, value strongly dependent on purity



Fiber applications

(Carpet Recovery America Effort)



Recovered fibers in composites

(Georgia Tech research)

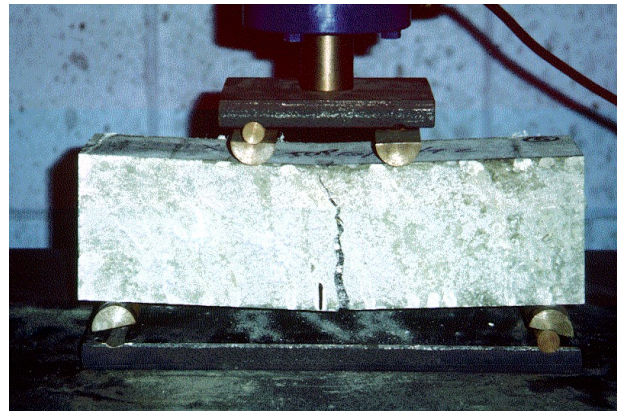
- Use waste fibers in composites as fibers or matrix
- such as lumber-like products & examples below
- Tolerating mixed fiber types & contaminants

Waste fiber as reinforcement in concrete and soil

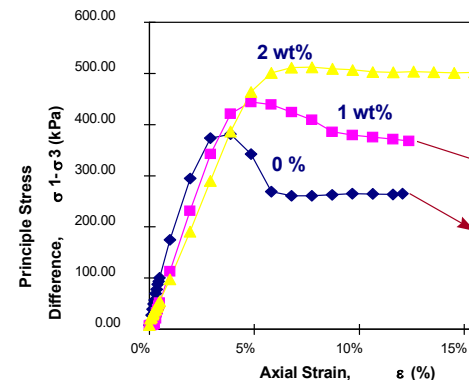


N6 PCC + 20 wt % 1" GF

**Glass fiber reinforced
composites: waste
polymer as matrix**



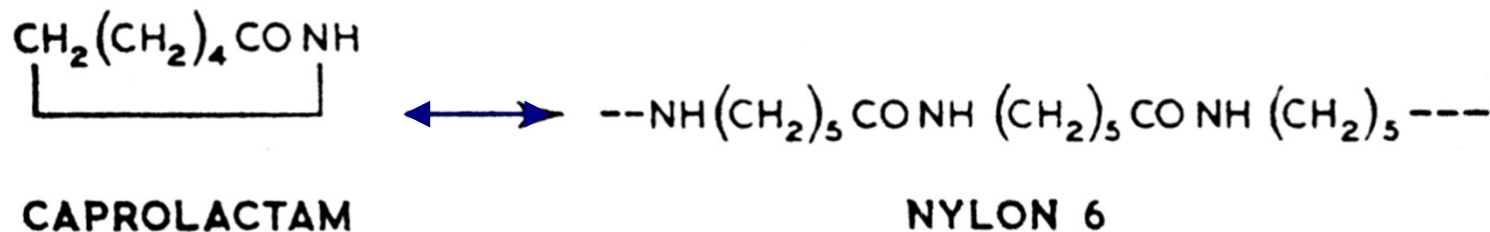
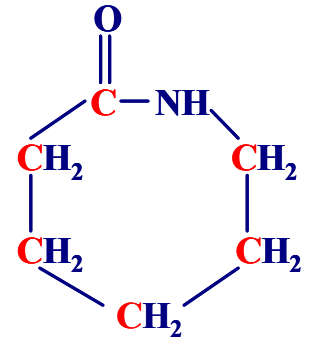
Unsaturated Triaxial Tests, Confined at 5 psi (34.5 kPa)



Chemical processes

- Solvent extraction
 - Aliphatic alcohol, methanol, alkyl phenols, and hydrochloric acid
 - Issues: Solvent recycling, purification, processing windows
- Supercritical fluid extraction
 - Dissolving nylon in a solvent (formic acid), then using supercritical CO₂ to precipitate out nylon.
 - Batch process
- Depolymerization
 - Recover monomers for virgin-like polymers

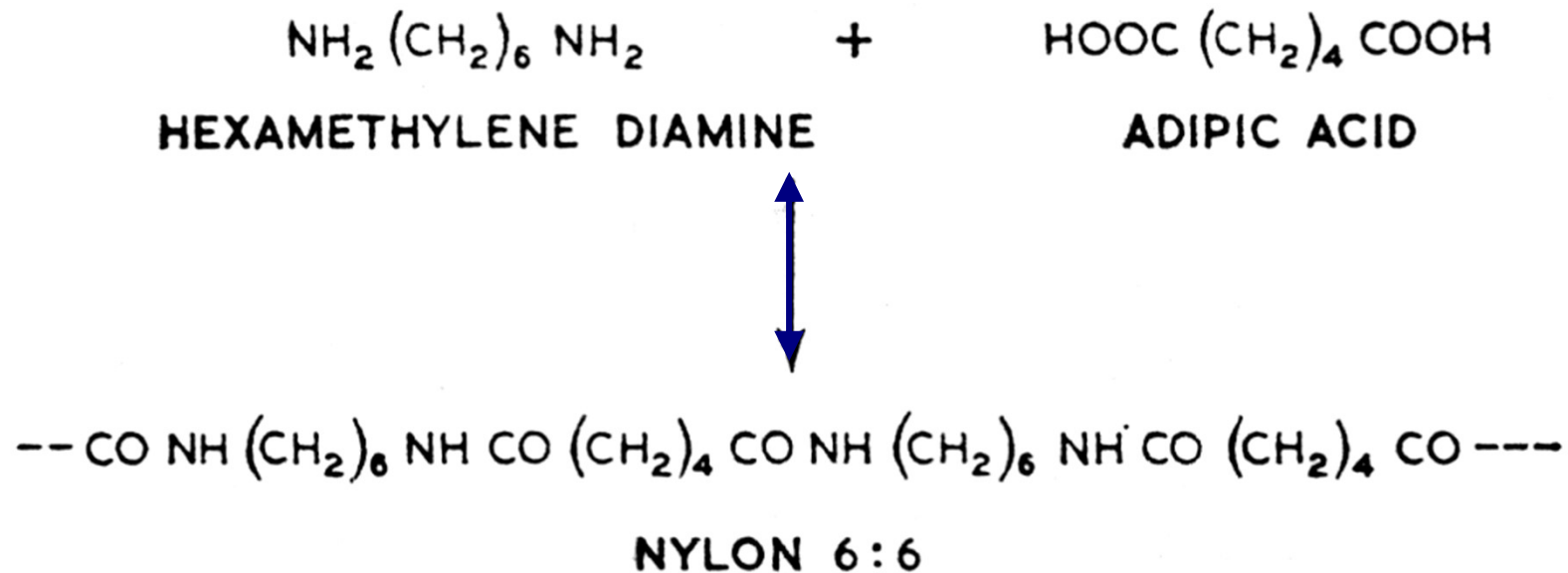
Nylon 6 depolymerization



- Nylon 6 waste \Rightarrow caprolactam \Rightarrow N6 \Rightarrow Nylon 6 fibers
- Shaw Industries' Evergreen Nylon Recycling
 - Initially built by Honeywell & DSM, operated ~ 2000. Became part of Shaw Industries
 - 2010: recycled 40,000 tons of nylon 6 carpet
- Aquafill Group
 - Depolymerization facilities in Slovenia started in 2010
 - Capacity to recycle 12,000 tons of nylon 6 waste
- Carpet Recycling Europe, etc

Nylon 66 recycling

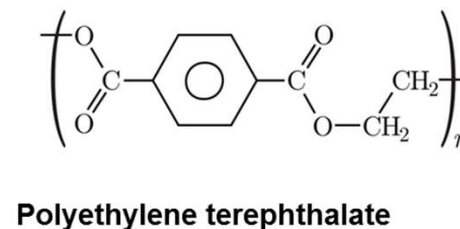
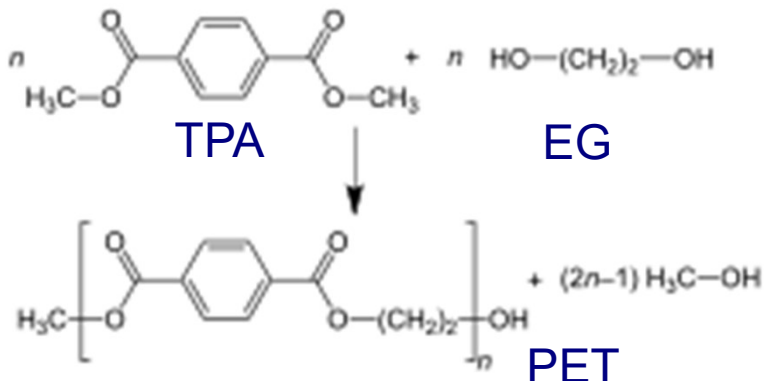
- Depolymerization is possible



- more difficult than with nylon 6 (two monomers vs one). Not commercialized
- (N66 is mostly recycled by melt processing)

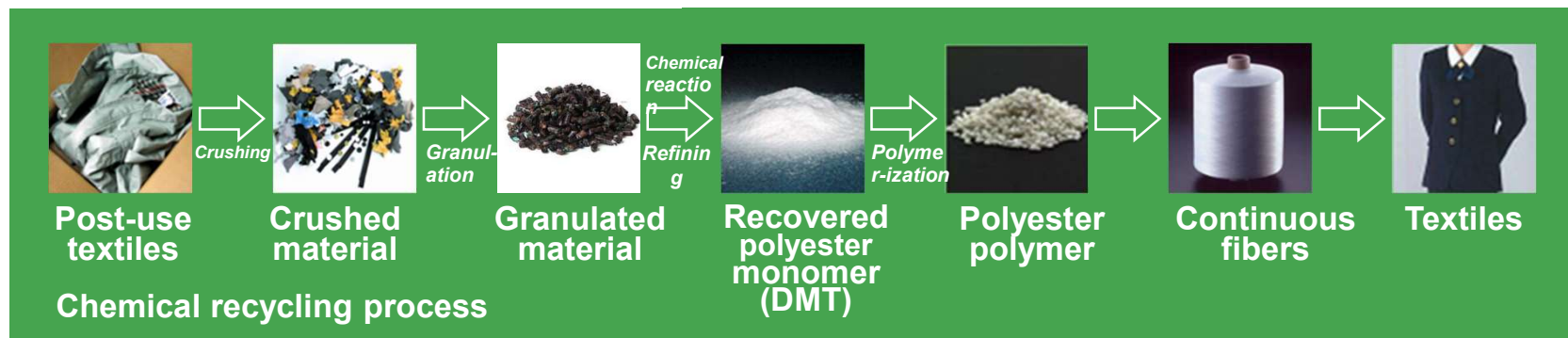
PET depolymerization

- Polyethylene terephthalate (PET) may be depolymerized & repolymerized to obtain virgin quality PET.
- Routes of depolymerization (examples)
 - **Hydrolysis** \Rightarrow ethylene glycol (EG) & terephthalic acid (TPA)
 - **Methanolysis** \Rightarrow dimethyl terephthalate (DMT)
 - **Glycolysis** or **solvolysis** \Rightarrow oligomers



PET recycling: depolymerization

- Eco Circle program of Teijin, Ltd.
 - Converts used PET textiles into DMT, then repolymerizes to make virgin quality fibers
 - World-wide participation, including USA
 - Feedstock mostly limited to its own fiber products

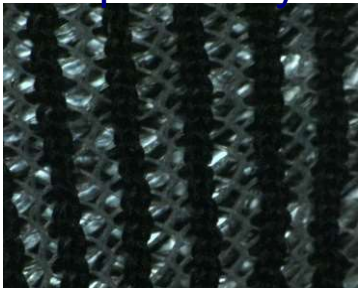


Blended fabrics recycling

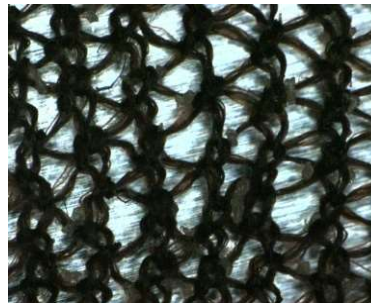
(Georgia Tech research)

- Growing use of spandex/nylon 6 blended fabrics
- To recover Nylon 6 by removing spandex
 - Hydrolysis under proper condition (T, p, t)
 - Atmospheric pressure, 220C, 2 hours, no added water
 - Spandex degraded, readily washed away with ethanol
 - Nylon remains as fabric, ready for melt processing or depolymerization

(24% Sp/76% nylon)



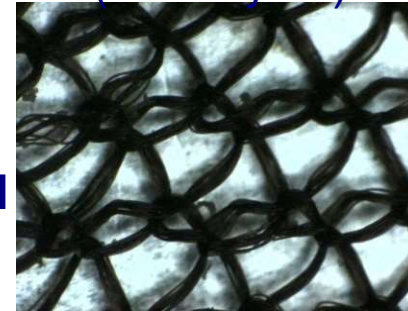
Heat treatment



Wash w/ ethanol



(99% nylon)



Cotton fiber recycling

- **Reuse:** Use cotton textiles as wipes
- **Down-cycle:** Process into insulation, mats, etc.
- **Renew:** Back to cotton fibers
 - Circle LLC converts **post-industrial** cotton cloths into fibers, suitable for
 - High-quality long staple apparel yarns
 - Nonwovens

The challenge

- There are so many promising recycling technologies. Why the recycling rate is not higher?

Challenges to textile recycling

- Limitations
 - Technologies, Economics, environmental impacts
- Homo-polymer vs mixed materials
 - Best value from homo-polymer
 - Potential value* vs types
 - Nylon (\$4255/MT) > polyester (\$3290) > PP (\$1950)
- Post industrial or designated streams are more successful but less in volume than post-consumer
 - May isolate “single polymer” type at source
 - Designated stream with known waste for specific brands

* 2017 US export data for virgin polymers, statista.com (2021)

Challenges to textile recycling

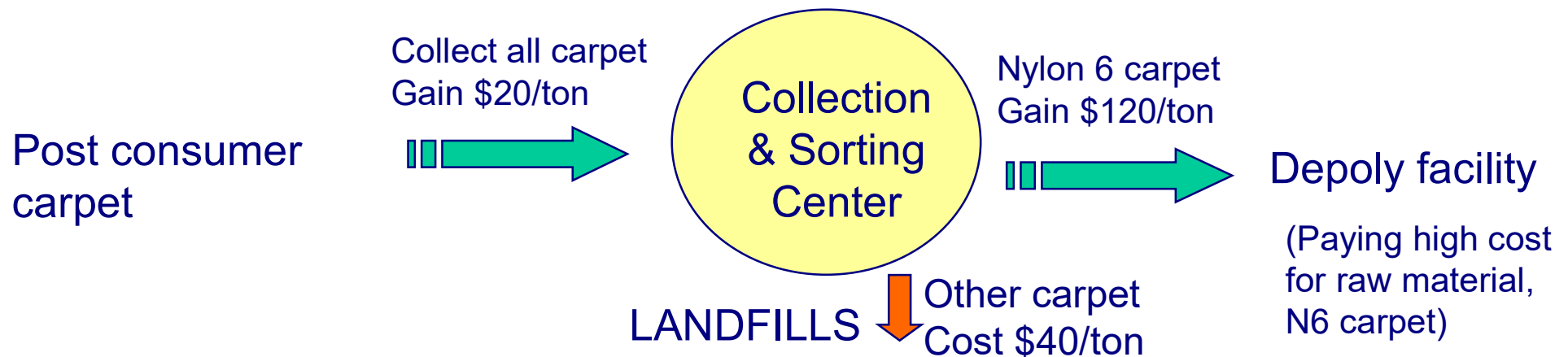
- Post-consumer from general public
 - Bulk of textile waste
 - Waste stream: mixed materials
 - cotton T-shirts + polyester pants
 - shirts of cotton/poly blend
 - carpet (e.g., nylon+PP+CaCO₃+latex)
 - Unknown types of post consumer waste

Network for depoly N6 only (illustration only)

**Reference:
No recycling**



Recycling (cost & revenue of a collection center)



Center: net income \cong \$33/t (labor, utility, facility, other costs; profit)

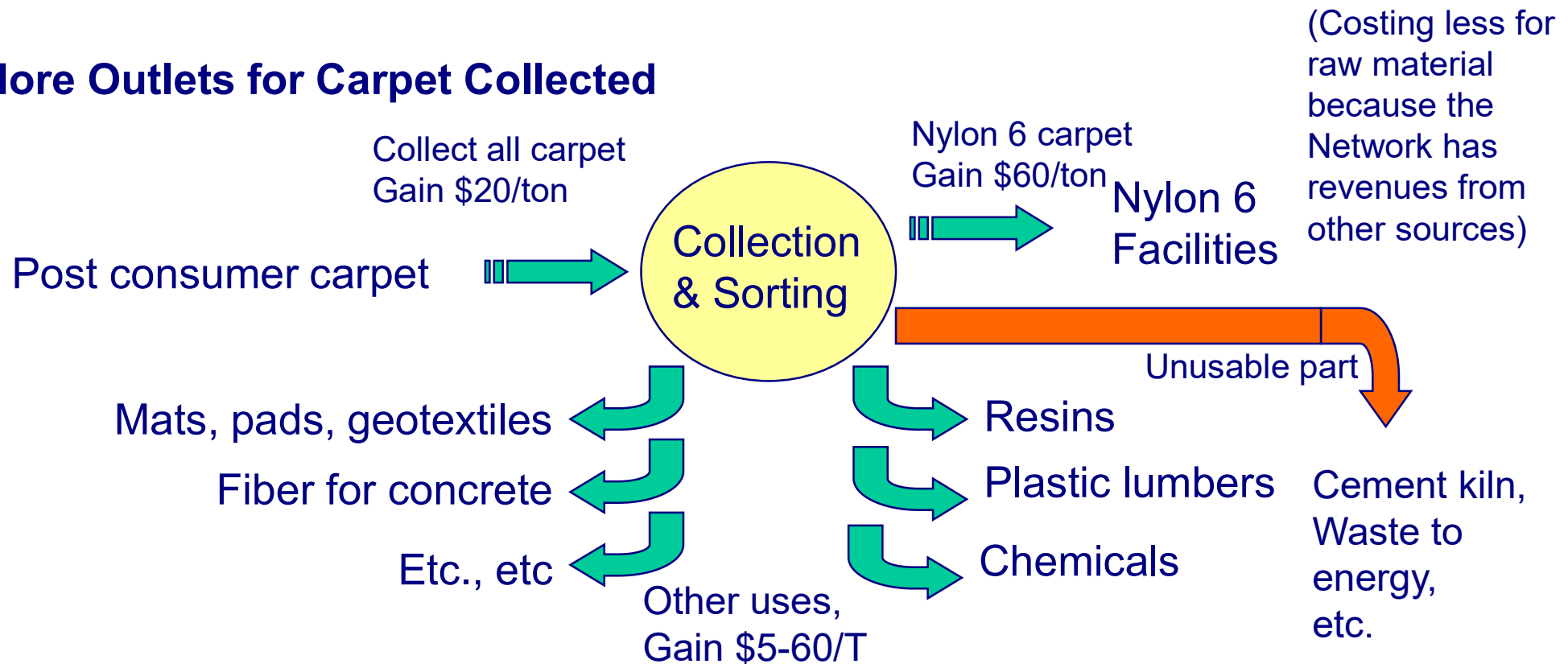
(for 1t N6 carpet waste, needs to collect 3t waste carpet, landfill 2t)

Cost to Depoly Facility is \$360 per ton of N6 waste fiber + shipping

(per 1t of N6 carpet waste, 1/3 is N6 fiber, 2/3 is backing/filler)

Network with more outlets

More Outlets for Carpet Collected



“integrated approach makes sense”

“Good” recycling

- **Environmental:** Energy saving & pollution from recycling must outweigh the alternative, e.g., virgin materials, other recycling approaches, Waste-To-Energy
- **Economical:** Commercially viable, market & cost competitiveness for products
- It can change ...
 - by many factors , such as political, economic environment, knowledge
 - **R&D for better technologies**

Challenges to textile recycling

- A challenge due to incoming waste contains “desired” & “undesired” fiber types - the reality
- Should find use for “all” waste collected (or as close as possible)
 - Integrated approach, including “down-cycling”, which may contribute to the success of “upcycling”, “recycling”
- Need to develop/support technologies that are high-volume, less processing, tolerating mixed waste types and contaminants

Summary

- Sustainable, circular economy requires resource conservation and waste minimization. Recycling plays an important role.
- Large amount of fibrous waste: a resource & opportunity.
- Waste of mixed materials: diversified technologies & commercial operations provide synergetic effect for successful textile recycling.
- R&D leads to better technologies
 - Talent: people & their creative ideas
 - Time: act now for the future



Thank You

