

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

---

# Challenges to Mechanical and Chemical Recycling of Textiles

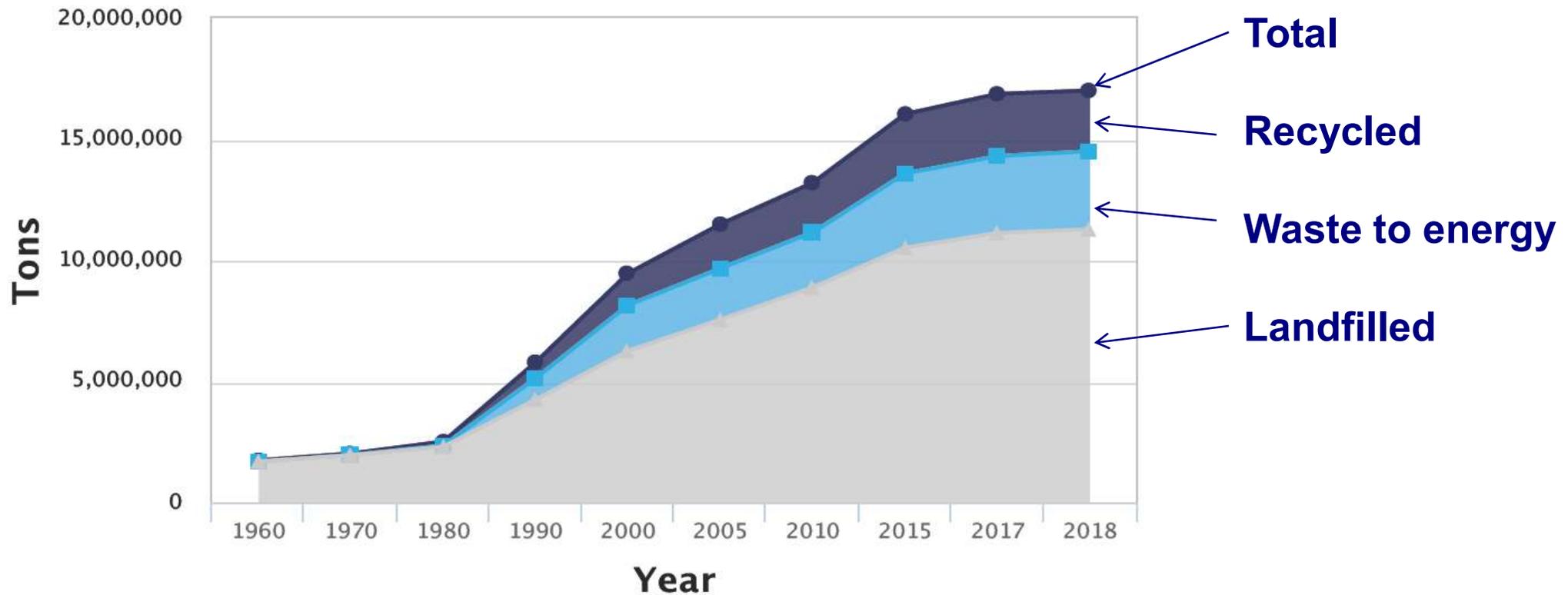
---

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

# Textile waste

(US EPA, 2021)

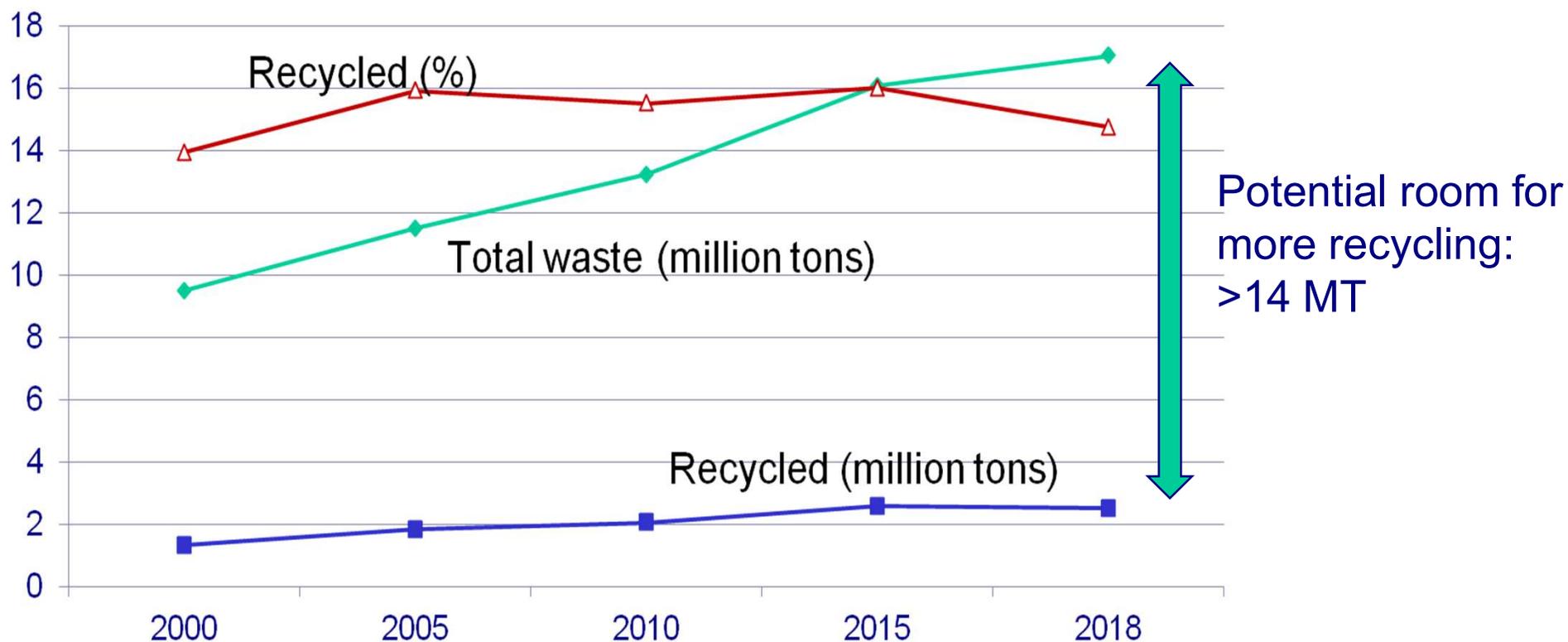
## Textiles Waste Management: 1960-2018



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

Recycled Composted Combustion with Energy Recovery Landfilled

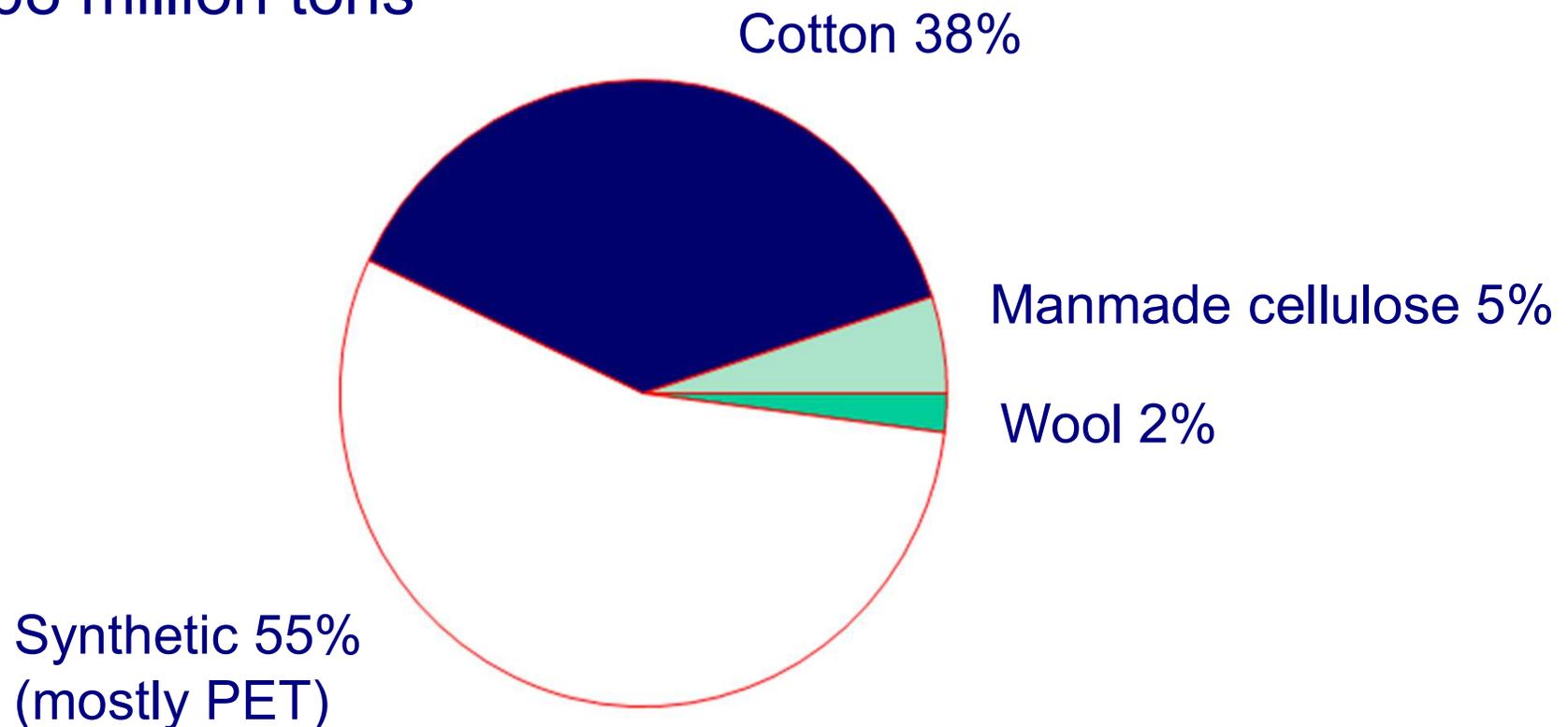
# Textile waste & recycling rate



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



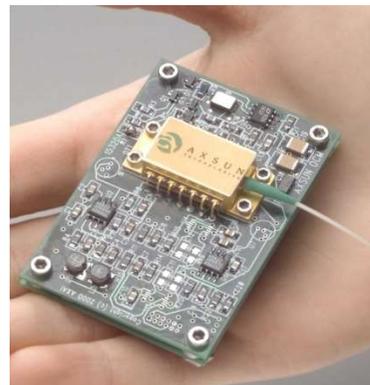
Hand-held  
(Honeywell)



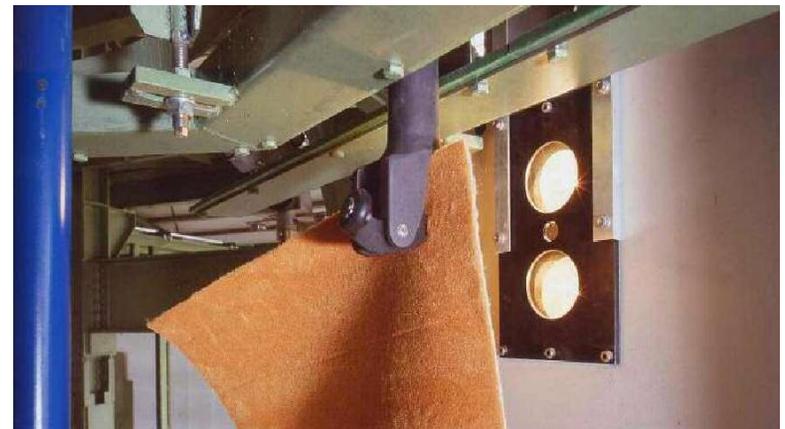
NIR (Bruker)



Raman  
Spectroscopy

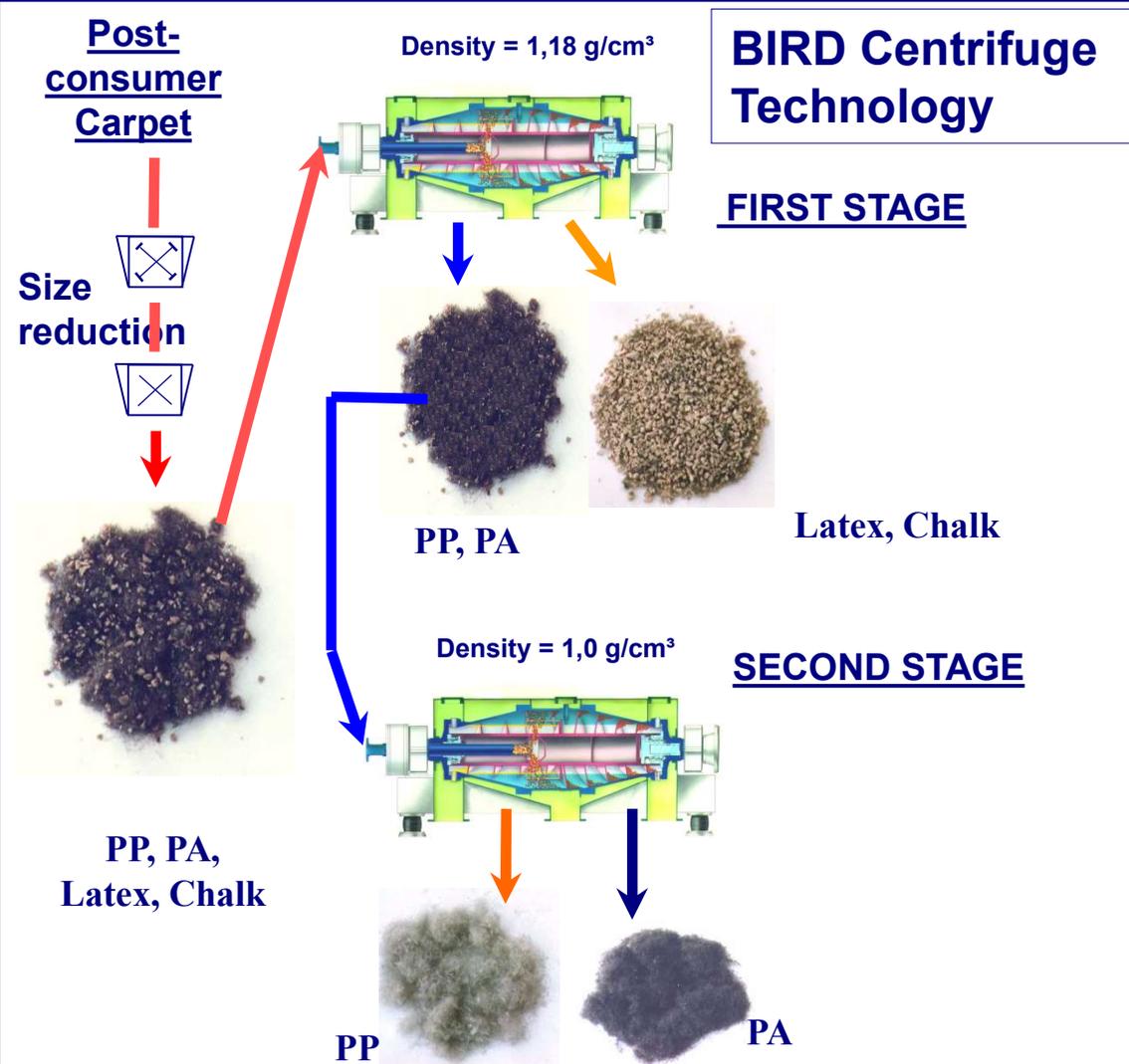
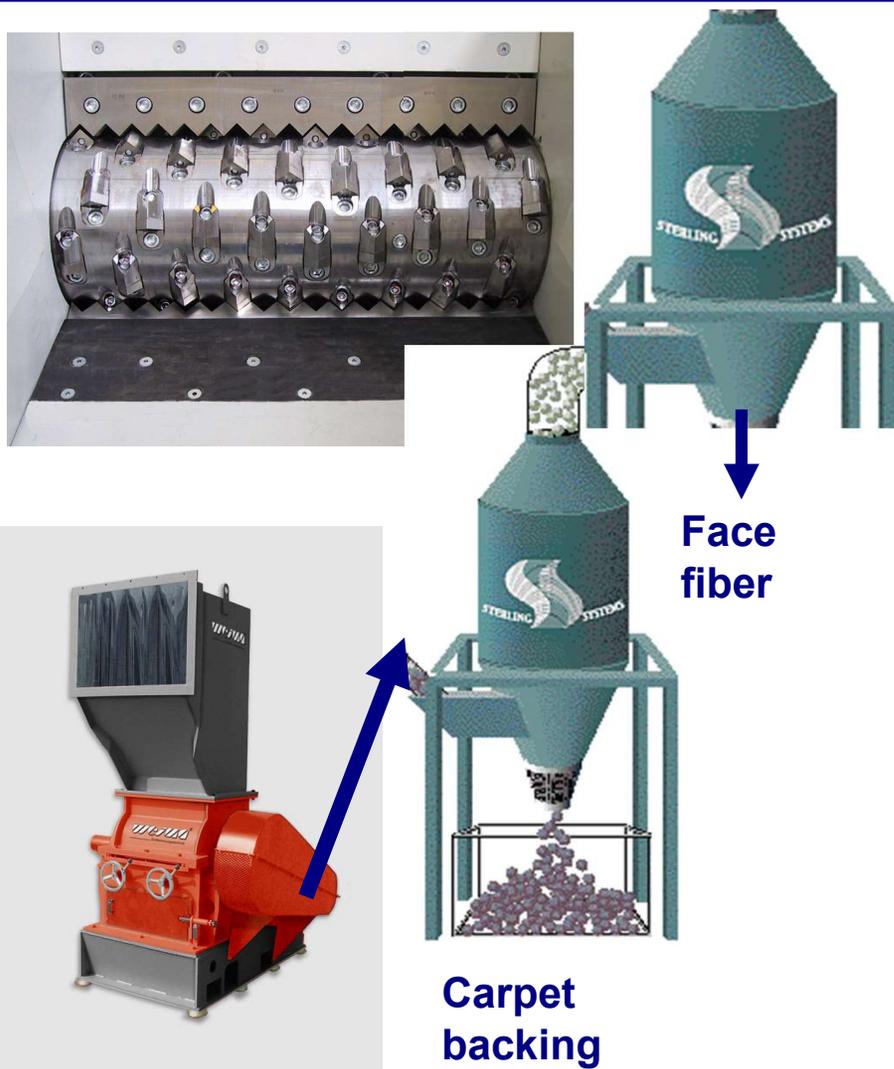


Spectrometer  
-on-a-chip  
(Bruker)



Carpet Recycling Europe

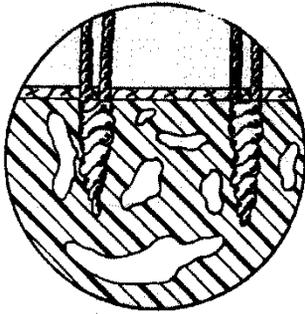
# Size reduction (grinding, separation)



# Harvesting fibers from carpet

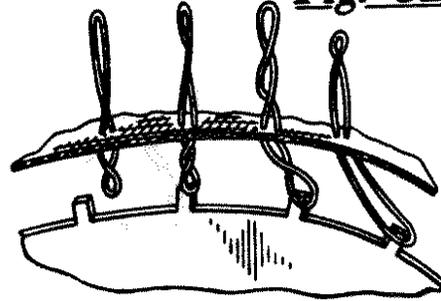
## 1. Removing backing

*Fig.-7A*

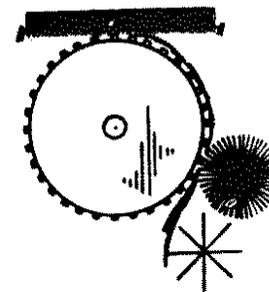


## 2. Pulling out face fibers

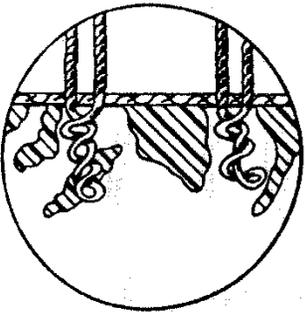
*Fig.-8B*



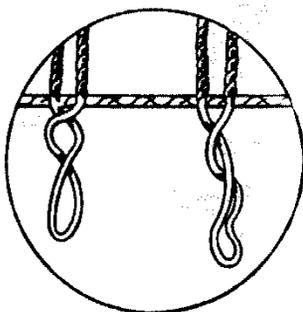
*Fig.-8D*



*Fig.-7B*



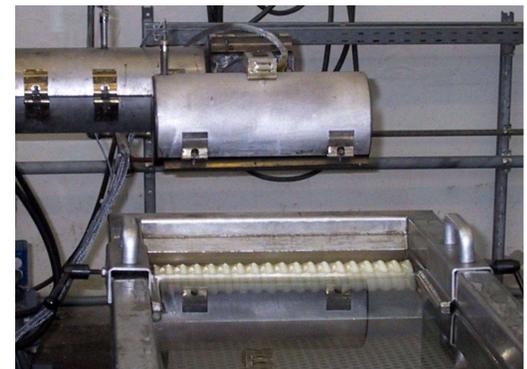
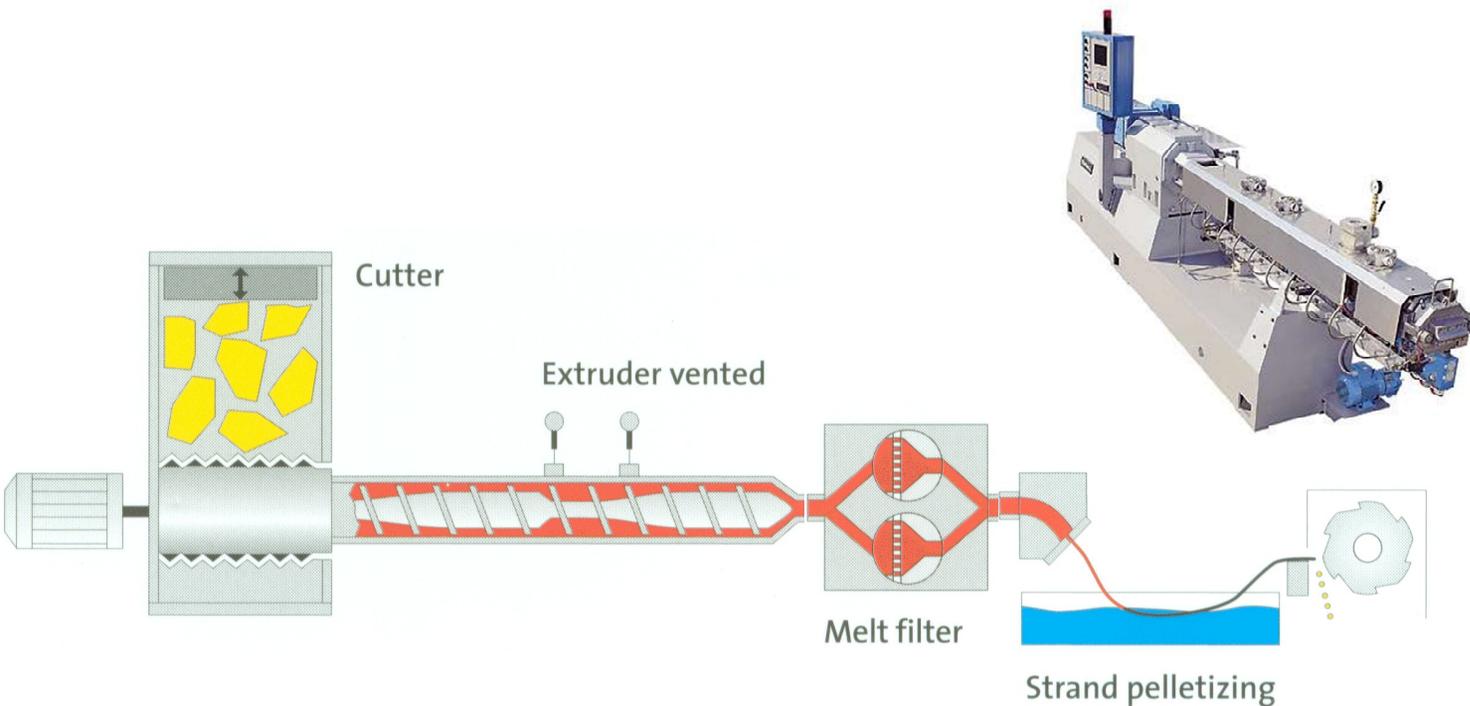
*Fig.-7C*



- Other approaches
  - Mechanical shearing
  - Hot-wire cutting

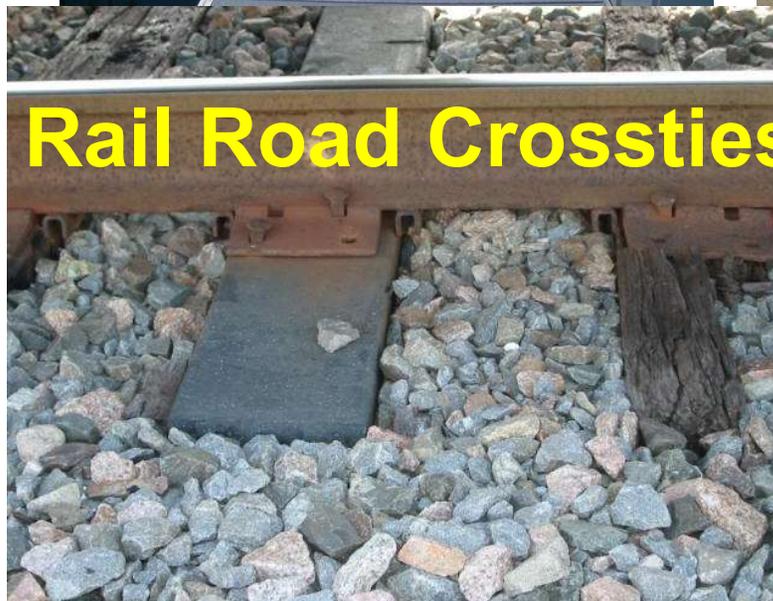
# Thermoplastic compounds

- 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)

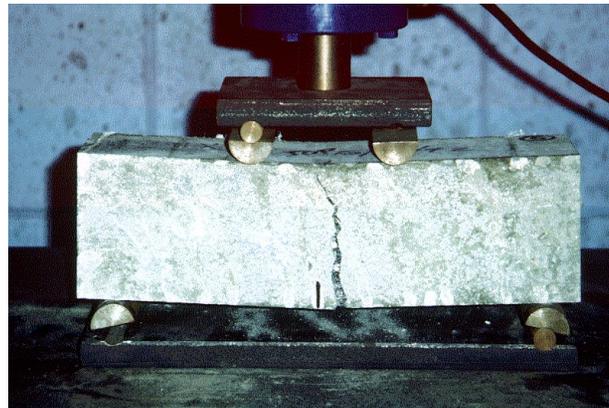
- Use waste fibers in composites as fibers or matrix
- such as lumber-like products & examples below
- Tolerating mixed fiber types & contaminants

## Waste fiber as reinforcement in concrete and soil

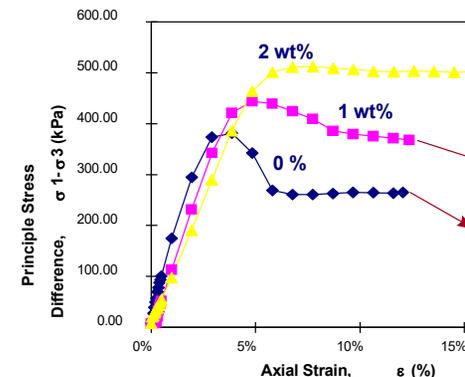


N6 PCC + 20 wt % 1" GF

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



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

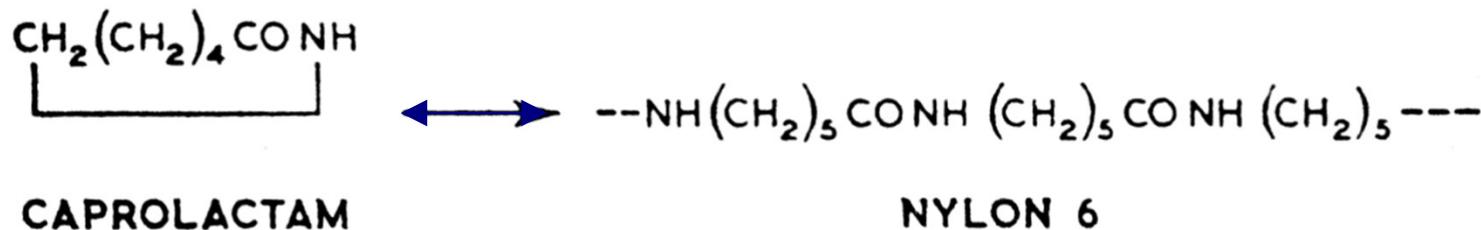
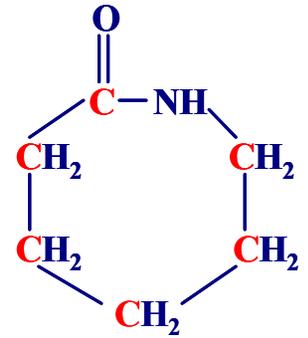


# Chemical processes

---

- 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 CO<sub>2</sub> to precipitate out nylon.
  - Batch process
- Depolymerization
  - Recover monomers for virgin-like polymers

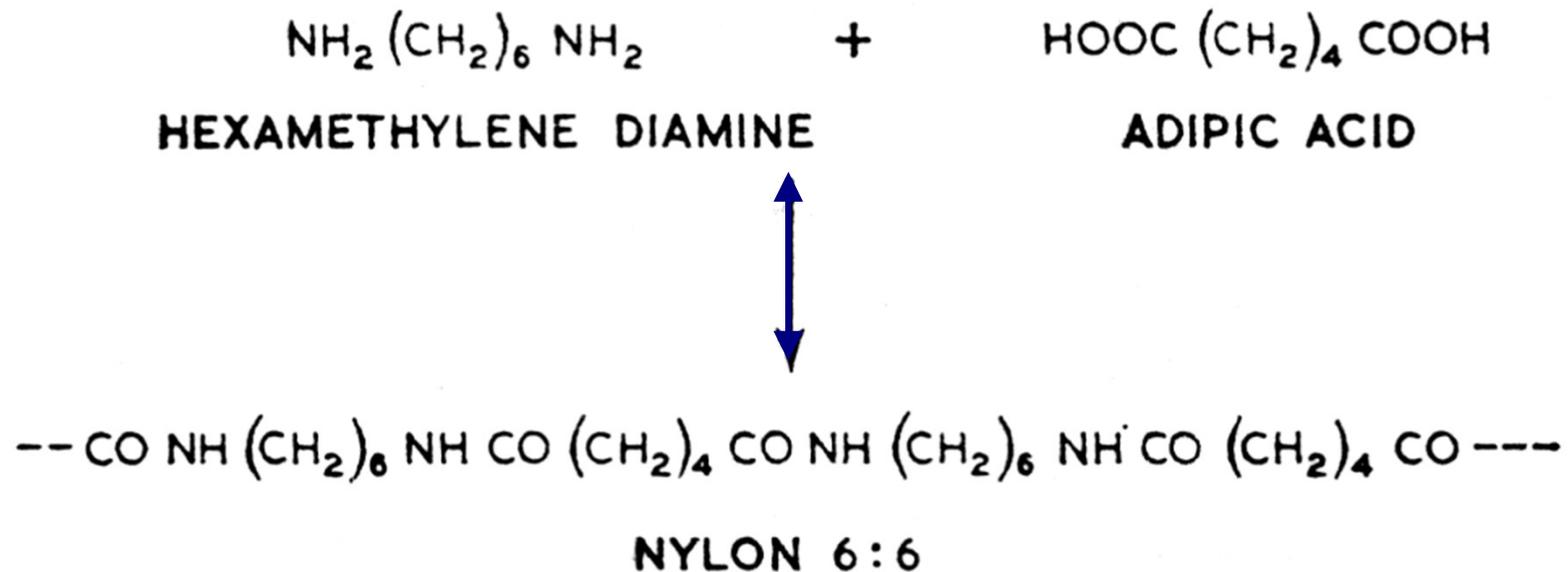
# Nylon 6 depolymerization



- 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

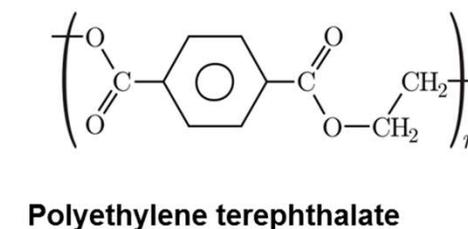
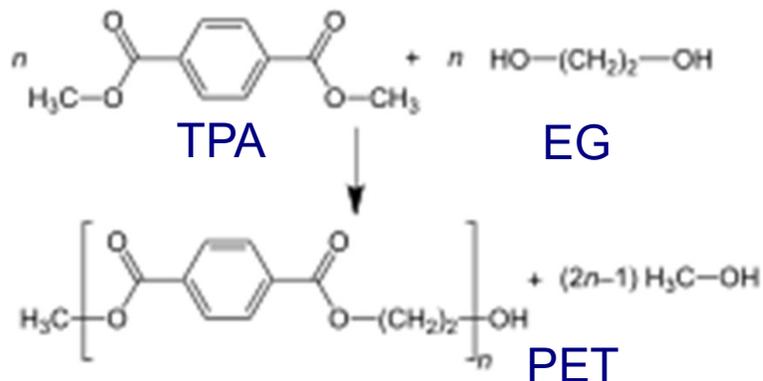
- Depolymerization is possible



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

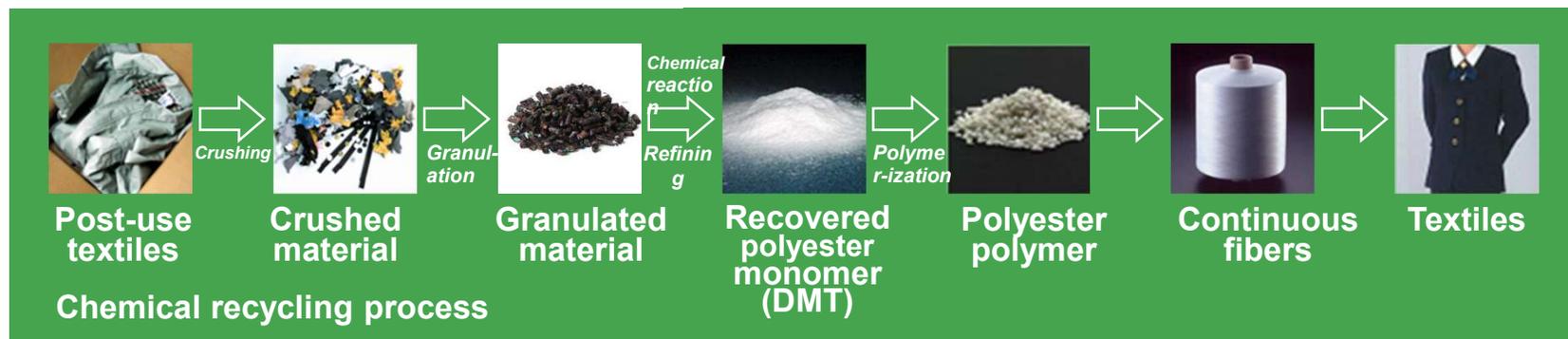
# PET depolymerization

- 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

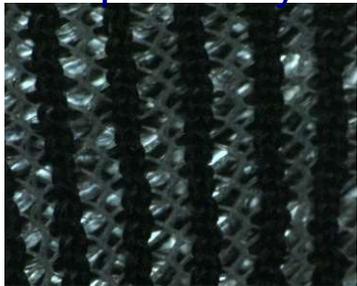


# Blended fabrics recycling

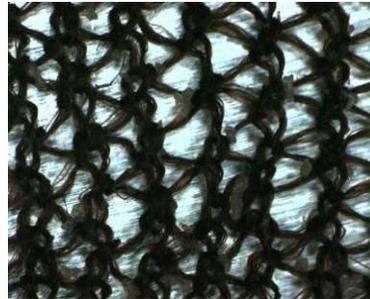
(Georgia Tech research)

- 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)



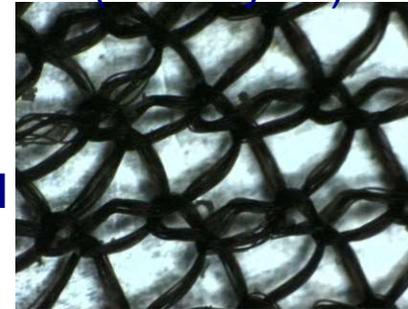
Heat treatment



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

---

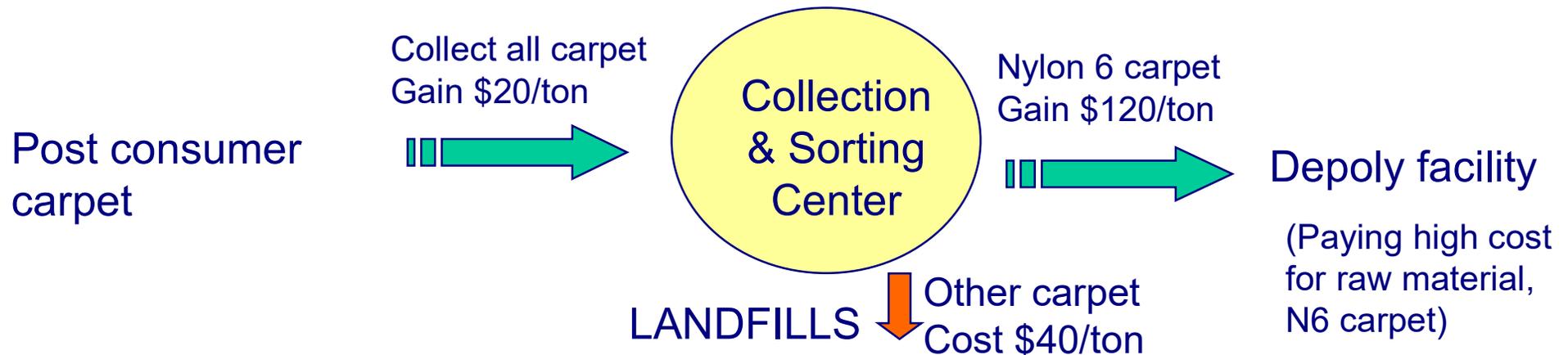
- Post-consumer from general public
  - Bulk of textile waste
  - Waste stream: mixed materials
    - cotton T-shirts + polyester pants
    - shirts of cotton/poly blend
    - carpet (e.g., nylon+PP+CaCO<sub>3</sub>+latex)
  - Unknown types of post consumer waste

# 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)**

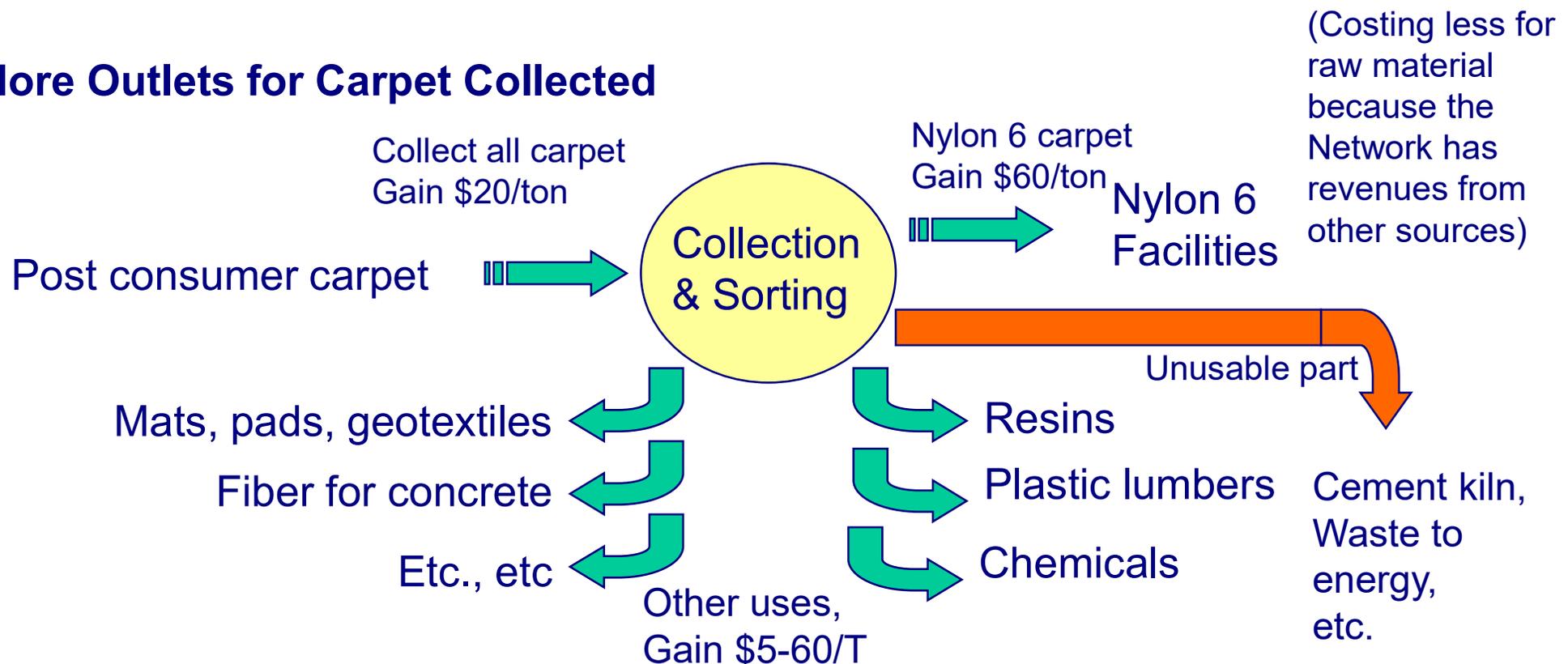
(for 1t N6 carpet waste, needs to collect 3t waste carpet, landfill 2t)

**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

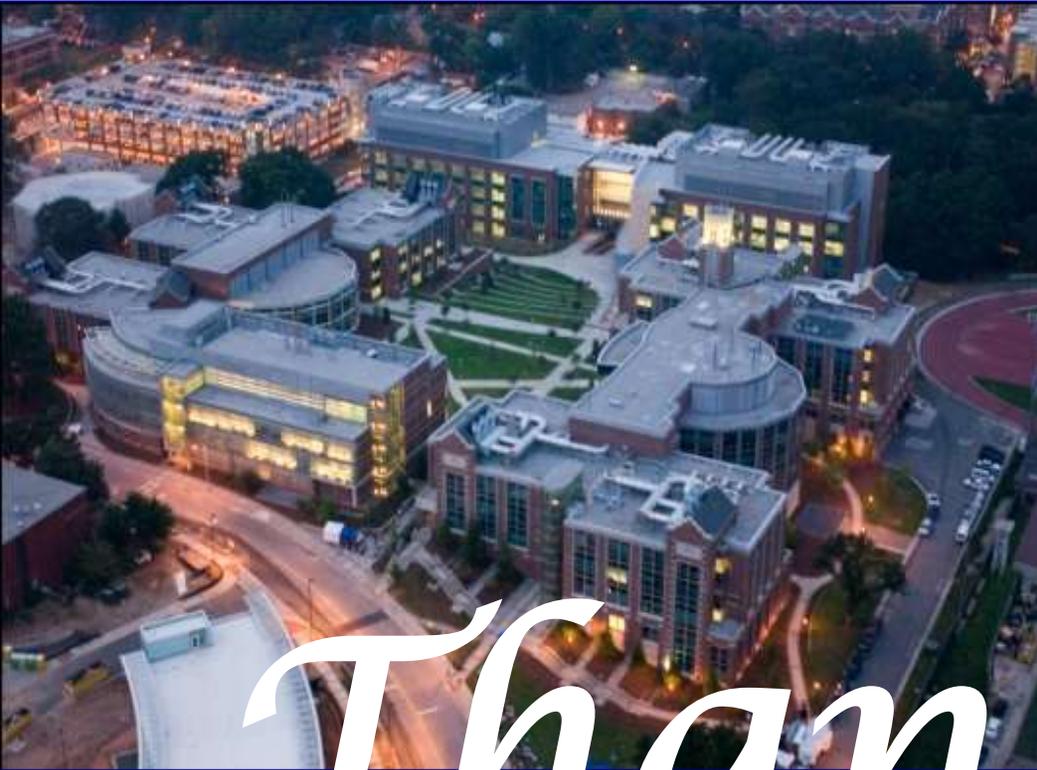
---

- 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*

