

Life Cycle Comparison of Two Carpet Products

Yong Li¹, Michael Overcash¹, Matthew Realff², Kellie Ballew³, Jeff Segars³, Jeff Wright³,

- 1. Department of Chemical & Biomolecular Engineering, North Carolina State University**
- 2. Department of Chemical & Biomolecular Engineering, Georgia Institute of Technology**
- 3. Shaw Industry Inc**



Carpet Tile Products

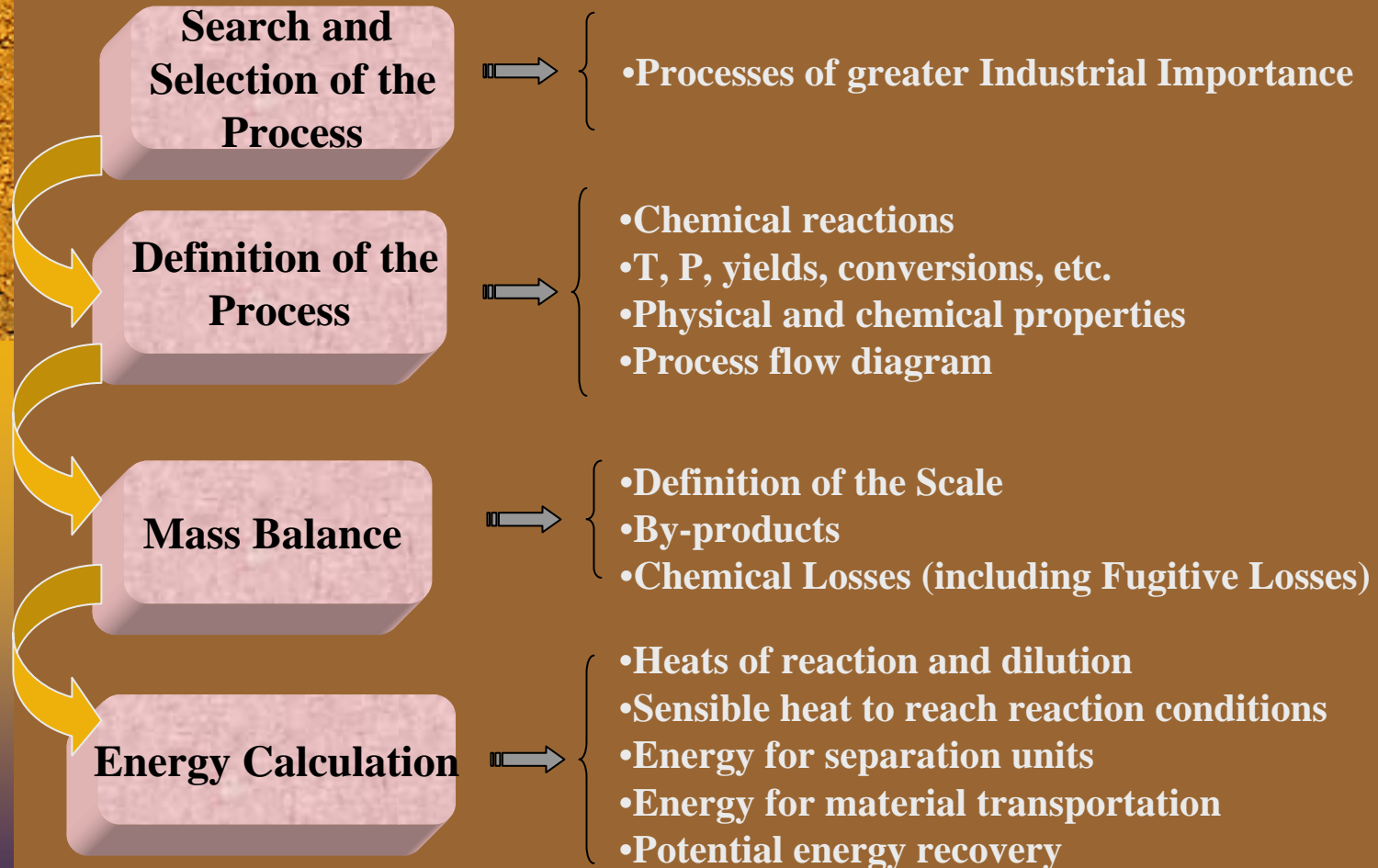
- **ECOWORX™**
Polyolefin backing (First non-PVC tile backing system)
- **PERMABAC™**
PVC backing



Goal and Motivation

- **Comparison of ECOWORX and PERMABAC carpet tile products**
- **Life cycle inventory profile**
- **Impact assessment**
- **Green purchasing**
- **Sustainable product**

Design Based Methodology (Inventories)

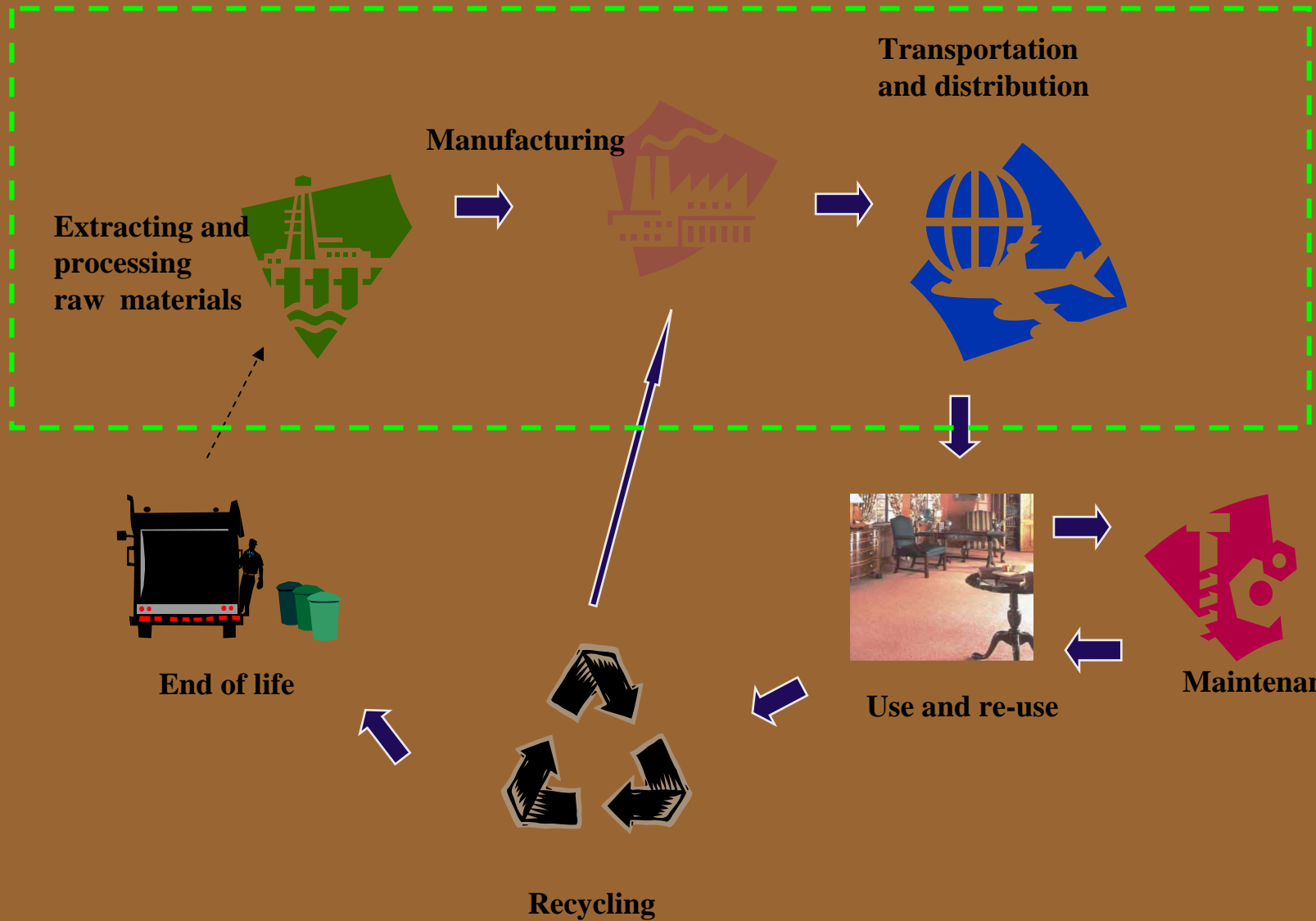




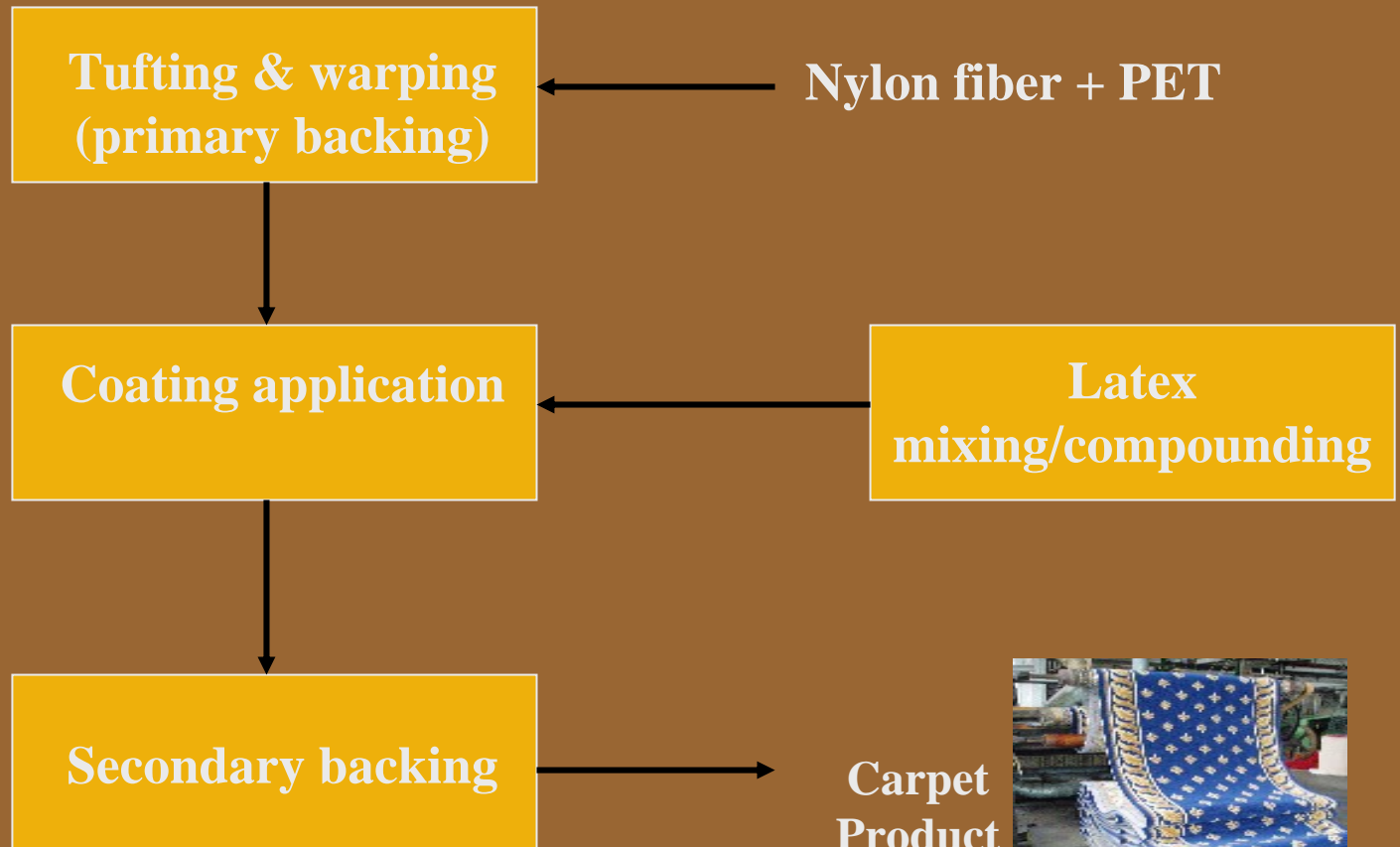
List of Assumptions

- **Capital process and office utilities are not included.**
- **Human labor is not included.**
- **One representative manufacturing process is chosen for each chemical.**
- **Heuristics are written for unit operations.**

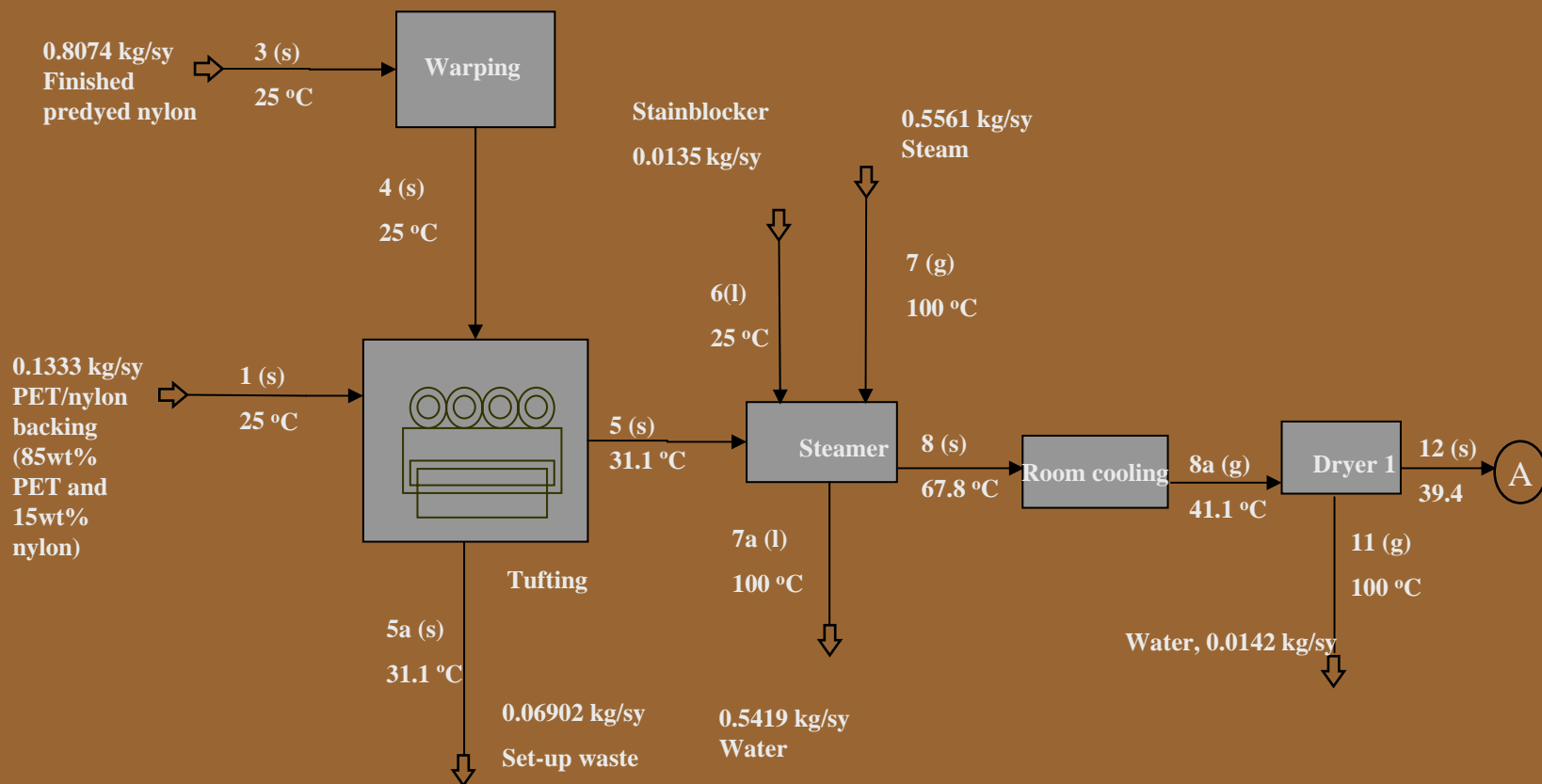
Life Cycle of Carpet Products



Major Steps of Carpet Manufacturing Process



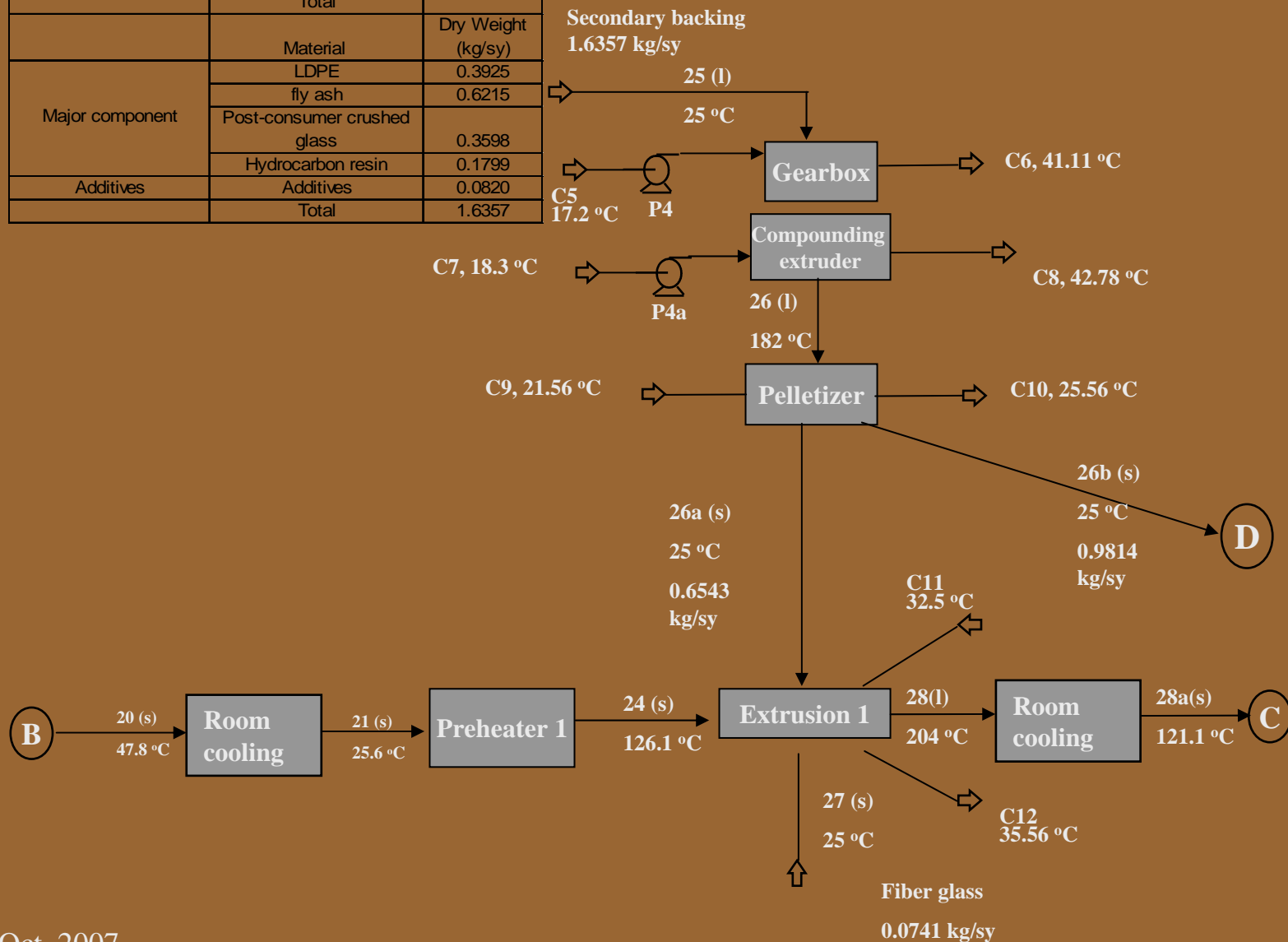
Detailed Process Flow Diagram of ECOWORX™ Tile Manufacturing Process- Page 1



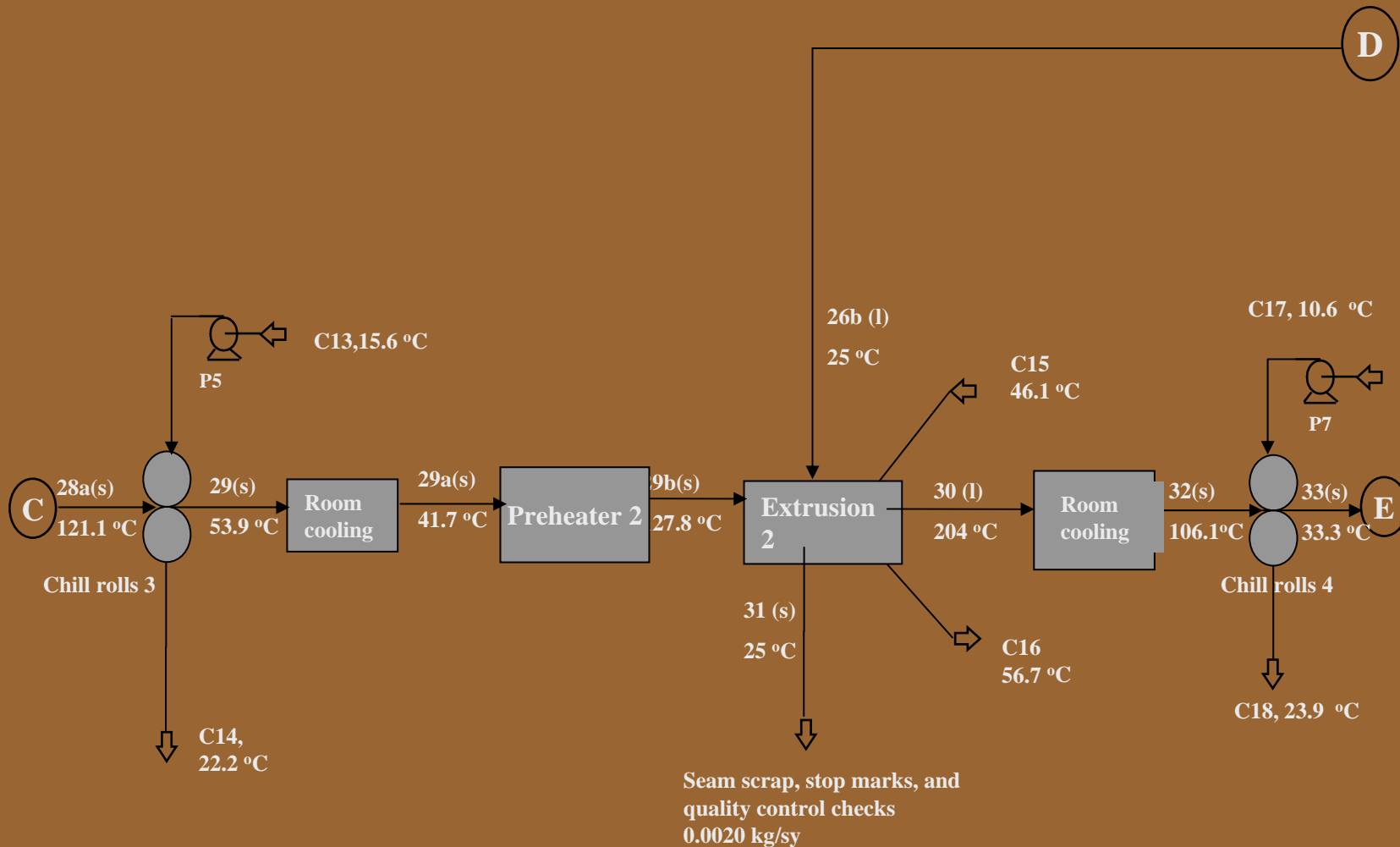
Detailed Process Flow Diagram of ECOWORX™ Tile Manufacturing Process- Page 3



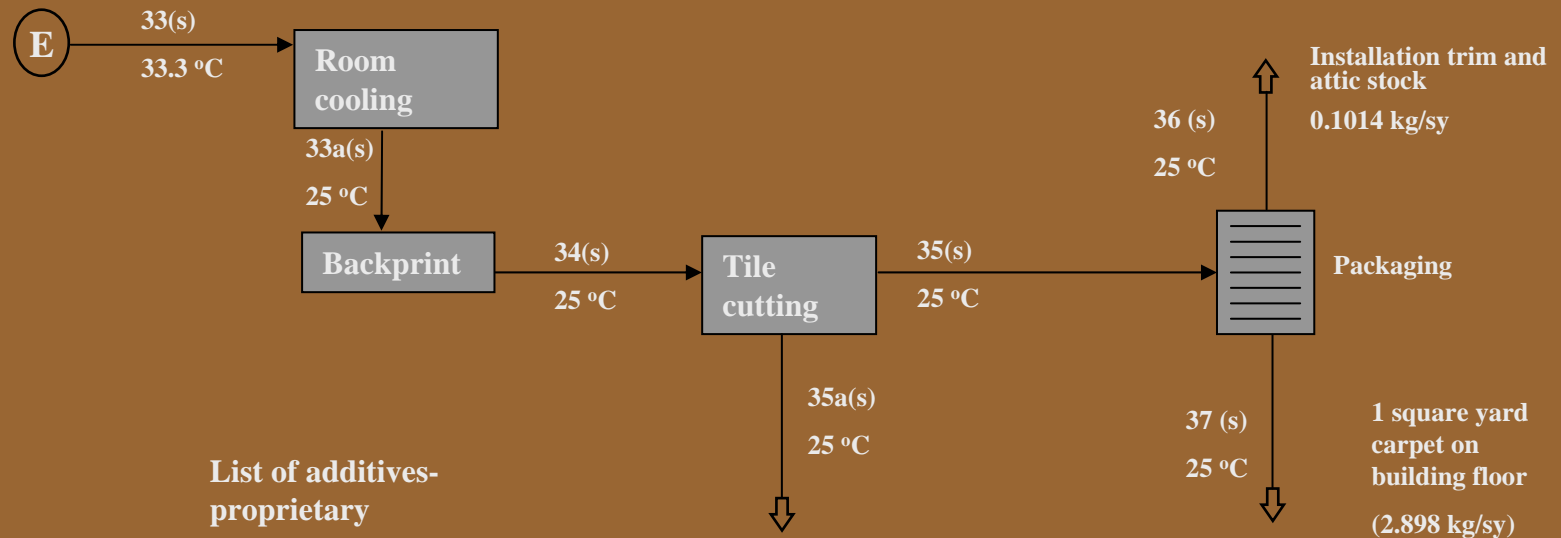
	Total	Dry Weight (kg/sy)
Major component	LDPE	0.3925
	fly ash	0.6215
	Post-consumer crushed glass	0.3598
	Hydrocarbon resin	0.1799
Additives	Additives	0.0820
	Total	1.6357



Detailed Process Flow Diagram of ECOWORX™ Tile Manufacturing Process- Page 4



Detailed Process Flow Diagram of ECOWORX™ Tile Manufacturing Process- Page 5



List of additives-proprietary

Chemical Name
Anionic Surface modifier methylenebisthiocyanate
Anionic surfactant
2,5 Furadione modified ethylene/hexene-1 polymer Maleic Anhydride/2,5-furadione
Parrafinic oil
Sodium Polyacrylate Thickener
Phenolic/Methacrylate Stainblocker
Chlorphenyl Ether
Fluorochemical

Window waste, seam scrap, warranty & inspection loss
0.1463 kg/sy

Carpet product composition

Materials name	Mass, kg/sy
Dyed nylon fiber	0.6847
PET core/nylon sheath	0.1131
Fiber glass	0.0682
LDPE	0.3614
Hydrocarbon resin	0.1656
Proprietary carboxylated butadiene/acrylate polymer	0.2031
Aluminum Trihydrate	0.3068
Fly ash	0.5722
Post-consumer crushed glass	0.3313
Additives	0.0915
Total	2.898

LCI of ECOWORX and PERMABAC

Manufacturing Processes – (I) Process Mass Input

	Carpet composition	Chemical name	Unit	Mass of process input, kg/sy	
				PERMABAC	ECOWORX
Face fiber	Face fiber	Predyed nylon fiber	kg/sy	0.65	0.78
Backing sheet	Woven /nonwoven fabrics	PET	kg/sy	0.13	0.11
		Nylon sheath			0.02
		Fiber glass	kg/sy	0.04	0.07
Secondary backing	Backing polymeric system	PVC homopolymer	kg/sy	0.21	
		Ethylene-vinyl acetate copolymer	kg/sy	0.26	
		Diisooheptyl phthalate (DIHP)	kg/sy	0.52	
		poly (methylacrylate-co-vinyl chloride)	kg/sy	0.32	
		LDPE	kg/sy		0.38
		Hydrocarbon resin	kg/sy		0.17
		Proprietary carboxylated butadiene/acrylate polymer	kg/sy		0.21
	Backing fillers	Calcium carbonate	kg/sy	2.06	
		Fly ash	kg/sy		0.95
		Aluminum hydroxide	kg/sy		0.32
		Total	kg/sy	4.20	3.03

LCI of Carpet Manufacturing Processes – (II)

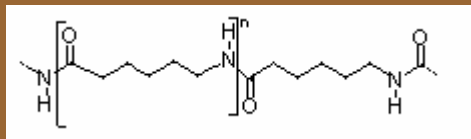
Process Energy Consumption

Source	Units	PERMABAC	ECOWORX	Comments
Electricity	kJ/sy	1,294	3,993	
Dowtherm	kJ/sy	0	0	
Heating steam	kJ/sy	1,477	1,477	85% efficiency has been included to determine how much steam is needed for heating process fluid
Natural gas	kJ/sy	7,823	2,696	
Energy input requirement	kJ/sy	10,594	8,165	Electricity + steam + direct fuel oil + Dowtherm+ diesel
Cooling refrigeration	kJ/sy	-226	-1,763	Energy removed from the system by refrigeration
Potential Heat Recovery	kJ/sy			
Net energy	kJ/sy	10,594	8,165	Energy input requirement minus potential heat recovery from cooling systems.



Face Fiber

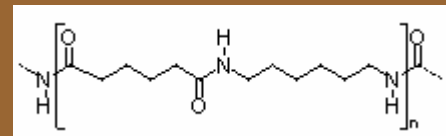
nylon 6



or



nylon 66



Nylon 6 Chemical Tree



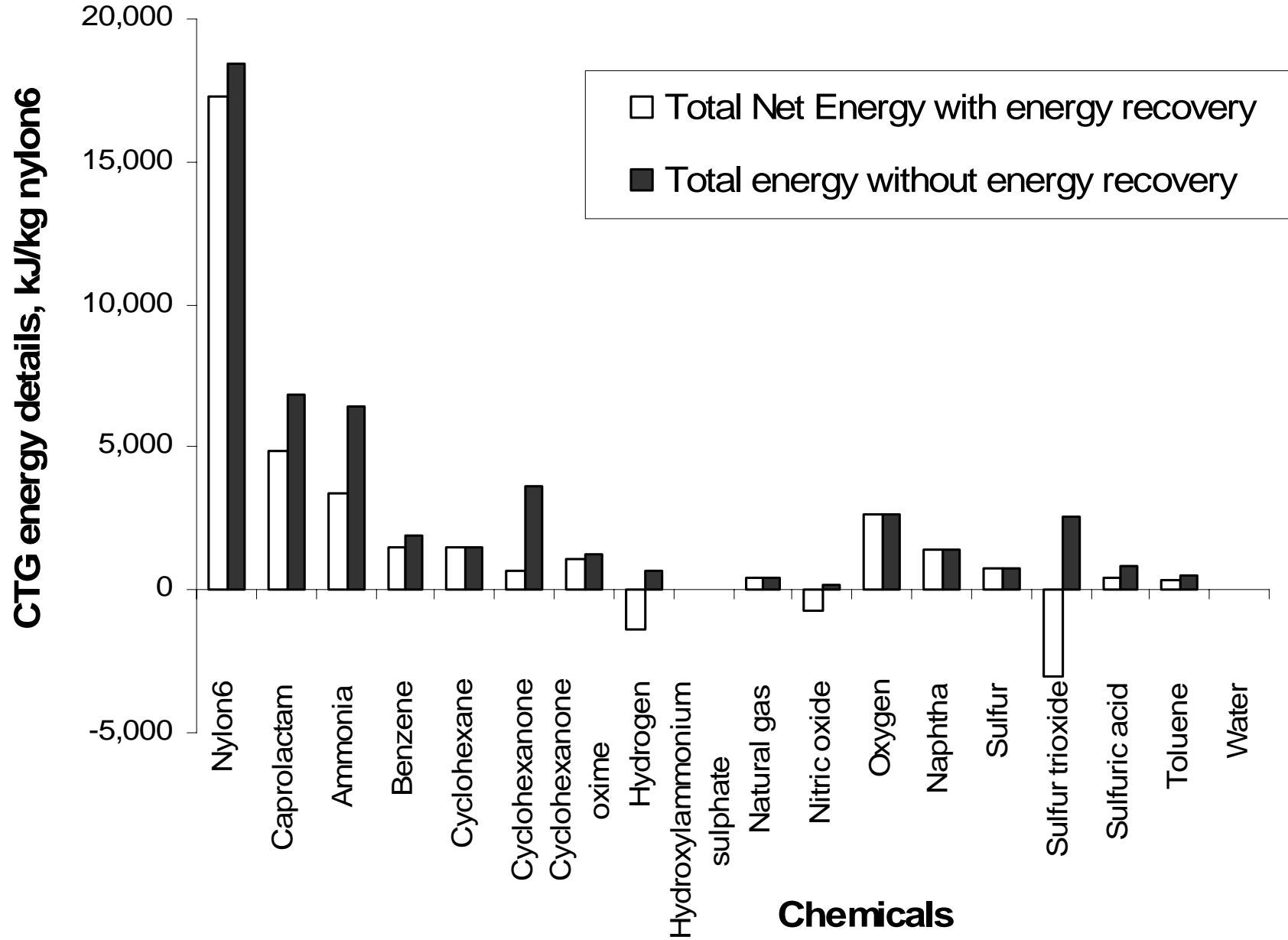
Primary	1st	2nd	3rd	4th	5th	6th	7th	Natural resources		
Nylon 6	Caprolactam	Cyclohexanone oxime	Cyclohexanone	Cyclohexane	Benzene	Petroleum extraction/refinery		Crude oil		
					Hydrogen	Natural gas				
						Oxygen		Air		Air
					Hydroxylammonium sulfate	Hydrogen		Natural gas		
							Oxygen	Air		
						Sulfuric acid	Sulfur trioxide	Sulfur	Petroleum extraction/refinery	Crude oil
								Air		
						Nitrogen monoxide		Water		
							Ammonia	Air		
								Natural gas		
								Water		
								Air		
						Ammonia		Air		
								Natural gas		
								Water		
						Sulfuric acid	Sulfur trioxide	Sulfur	Petroleum extraction/refinery	Crude oil
								Air		
								Water		
								Water		
					Sulfuric acid	Sulfur trioxide	Sulfur	Petroleum extraction/refinery	Crude oil	
					Air					
					Water					
					Water					
		Ammonia			Air					
					Natural gas					
					Water					
		Sulfur trioxide	Sulfur	Petroleum extraction/refinery	Crude oil					
		Toluene	Petroleum extraction/refinery	Crude oil						
					Water					
	Nitrogen				Air					

Nylon 66 Chemical Tree

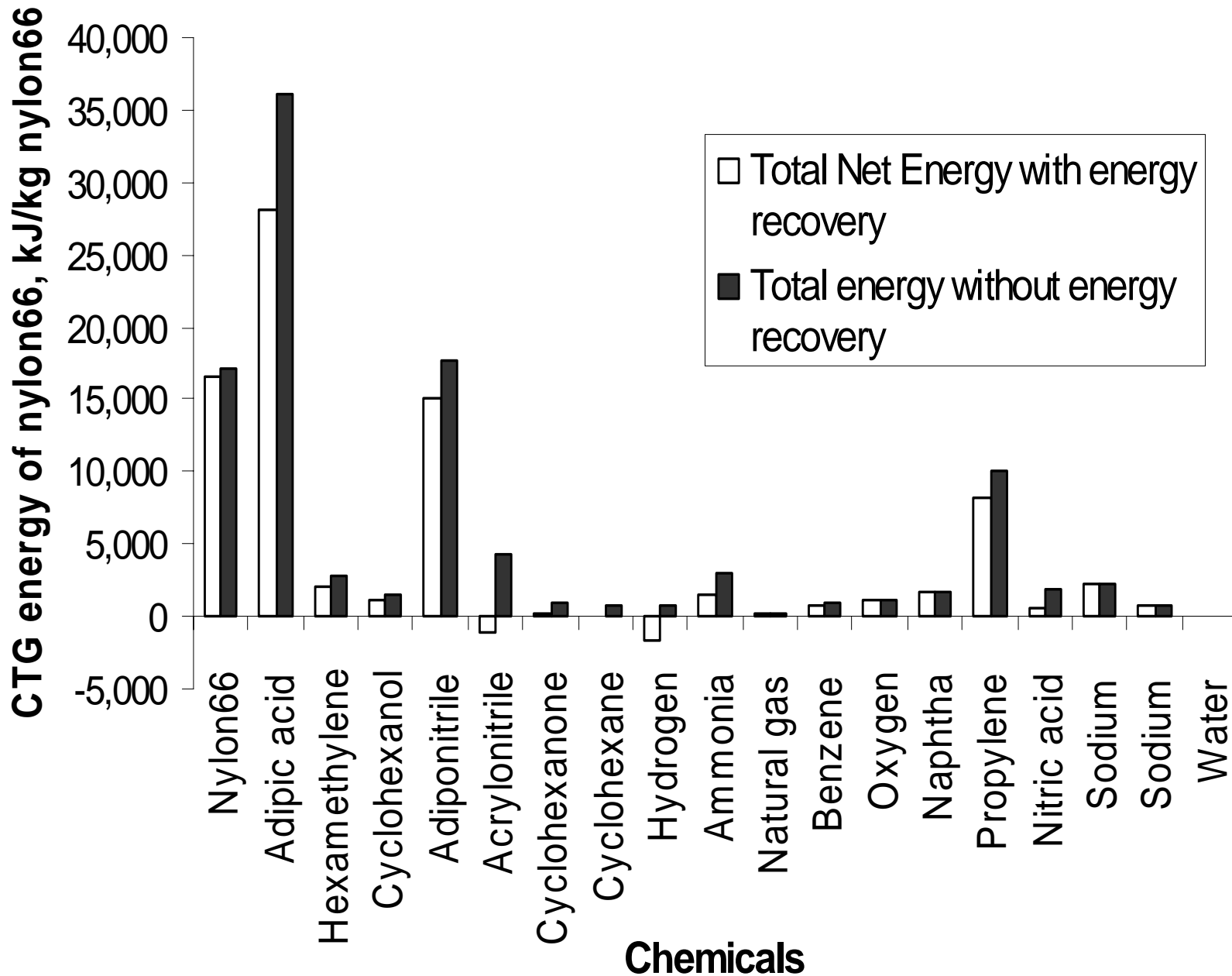


Primary	1st	2nd	3rd	4th	5th	6th	7th	Natural resources		
Nylon6-6	Adipic Acid	Cyclohexanone	Cyclohexane	Benzene	Petroleum extraction/refinery		Crude oil			
				Hydrogen			Natural gas			
			Oxygen			Air				
						Air				
		Cyclohexanol	Cyclohexane	Benzene	Petroleum extraction/refinery		Crude oil			
				Hydrogen			Natural gas			
			Oxygen			Air				
						Air				
		*Nitric acid	Ammonia				Water		Air	
							Natural gas		Water	
						Air		Water		
							Air		Water	
							Air		Water	
							Air		Water	
	Hexamethylenediamine	Adiponitrile	Acrylonitrile	Propylene	Petroleum extraction/refinery		Crude oil			
					Ammonia			Air		
							Natural gas		Water	
				Oxygen			Air			
				H2SO4	Sulfur trioxide	Sulfur	Petroleum extraction/refinery	Crude oil		
							Air		Water	
NaOH			Sodium chloride			Salt rock				
							Water		Water	
							Water		Water	
							Water		Water	
Hydrogen						Natural gas				
		Oxygen					Air			
		Ammonia					Air			
							Natural gas			
					Water					

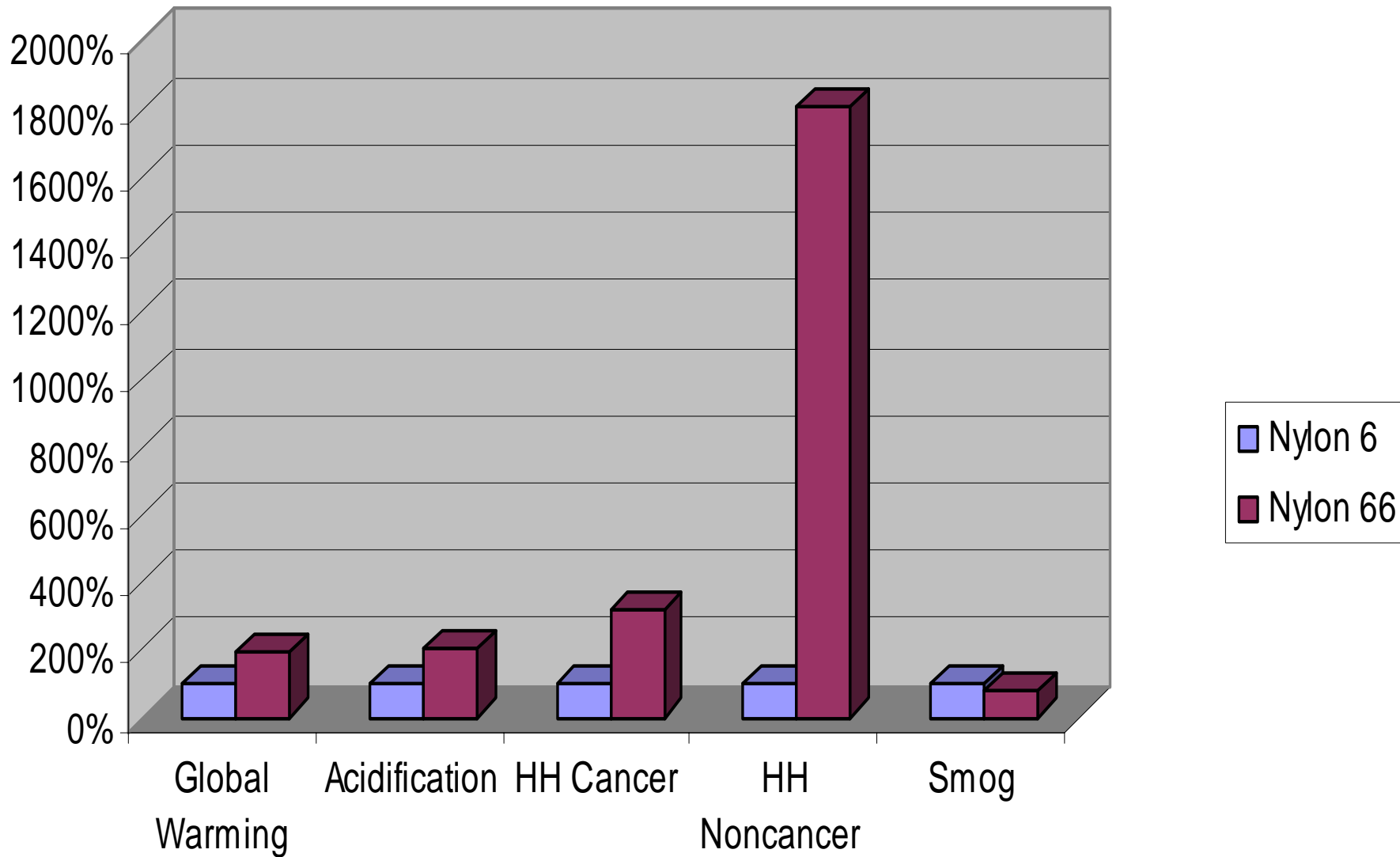
CTG energy details of nylon 6 with allocation



CTG energy details of nylon66 with allocation



Environmental assessment comparison of nylon 6 and nylon 66



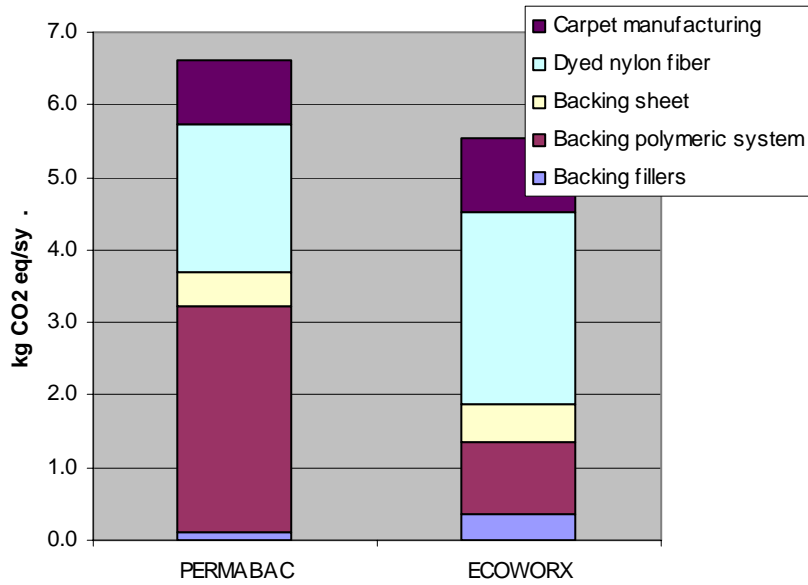
Chemicals	Mass kg/sy Permabac tile	Energy without allocation, kJ/kg chemical					By products mass/kg chemical	Allocation factor	Energy with allocation, kJ/sy Permabac tile				
		Electricity	Dowtherm	Steam	Fuel*	Total Energy			Electricity	Dowtherm	Steam	Fuel	Total Energy
1 sy Permabac tile	4.170							1.00	1,294		1,255	7,823	10,372
nylon6	0.787	4,307	785	3,217	440	7,823		1.00	3,388	617	2,531	346	6,882
PET	0.133	1,969	1,248	215	440	3,706		1.00	262	166	29	59	516
Fiberglass	0.074	9,711			10,767	20,478		1.00	719	0	0	797	1,515
PVC	0.156	149		2,614	440	3,181		1.00	23	0	409	69	501
Poly(methylacrylate-co-vinyl chloride)													2,552
EVAC copolymer													117
Diisooctyl phthalate													795
Aliphatic hydrocarbons													106
Calcium carbonate													1,216
4-Methyl-1-Pentene													719
5-Methyl-1-hexanol													329
Acetic acid													493
Acrylic acid													1,060
Aluminum oxide													223
Ammonia													883
Bauxite													25
Benzene													763
Boric acid													65
Boric oxide													15
Caprolactam													4,385
Carbon dioxide													600
Carbon monoxide													1,323
Chlorine													2,114
Corn													3
Cyclohexane													363
Cyclohexanone													1,590
Cyclohexanone oxime													356
Dichloroethane,-1,2													612
Ethanol													16
Ethyl Acetate													26
Ethylene													6,491
Ethylene glycol													135
Ethylene oxide													77
Hydrogen													165
Hydrogen chloride													1,068
Hydroxylammonium sulphate													156
K fertilizer													0
Methanol													546
methyl acrylate													91
N fertilizer													1
Naphtha													3,085
Natural gas													430
Nitric oxide													37
Oxygen													702
o-Xylene													331
P fertilizer													0
p-benzenedicarboxylic acid													2,101
Phthalic anhydride													2,830
Propylene													1,480
p-Xylene													302
Sodium chloride													1,460
Sodium hydroxide													16
Sulfur													40
Sulfur trioxide													173
Sulfuric acid													66
Toluene													561
vinyl acetate													414
Vinyl Chloride													2,356
Water	0.5883	1				1		1.00	0	0	0	0	0
Total									13,226	878	23,562	28,648	66,314
							Natural resource energy		41,332	1,097	29,453	28,648	100,530

Chemicals	Mass	Energy without allocation, kJ/kg chemical					By products	Allocation factor	Energy with allocation, kJ/kg chemical					Energy with allocation, kJ/sy ECOWORX tile				
	kg/sy ECOWORX tile	Electricity	Dowtherm	Steam	Fuel*	Total Energy	mass/kg chemical		Electricity	Dowtherm	Steam	Fuel	Total Net Energy	Electricity	Dowtherm	Steam	Fuel	Total Energy
1 sy ECOWORX carpet tile	2.898							1.00						3,993		1,255	2,696	7,943
nylon6	0.807	4,307	785	3,217	440	8,749		1.00	4,307	785	3,217	440	8,749	3,474	633	2,595	355	7,057
PET	0.113	1,969	1,248	215	440	3,872		1.00	1,969	1,248	215	440	3,872	223	141	24	50	439
Fiberglass	0.074	9,711			10,767	20,478		1.00	9,711	0	0	10,767	20,478	719	0	0	797	1,517
LOPE																		1,231
Hydrocarbon resin																		360
Butadiene-acrylate copolymer																		183
Fly ash class C																		518
Aluminium hydroxide																		3,442
1,3-butadiene																		170
Acetic acid																		74
Acetone																		151
Acetone cyanohydrin																		25
Aluminium oxide																		223
Ammonia																		1,204
Bauxite																		651
Benzene																		783
Boric acid																		66
Boric oxide																		
C4 Hydrocarbons																		332
Caprolactam																		4,437
Carbon dioxide																		35
Carbon monoxide																		77
Cyclohexane																		379
Cyclohexanone																		1,630
Cyclohexanone oxime																		380
Ethylene																		6,660
Ethylene glycol																		115
Ethylene oxide																		66
Hydrogen																		112
Hydrogen cyanide																		83
Hydroxylammonium sulphate																		160
Isopropanol																		871
Methanol																		190
Methyl methacrylate																		305
Naphtha																		2,201
Natural gas																		205
Nitric oxide																		38
Oxygen																		605
p-benzenedicarboxylic acid																		1,787
Propylene																		123
p-Xylene																		257
Sodium chloride																		281
Sodium hydroxide																		410
Sulfur																		114
Sulfur trioxide																		495
Sulfuric acid																		183
Toluene																		516
Water	0.657	1				1		1.00	1	0	0	0	1	1	0	0	0	1
Total	7.261													13,296	1,047	16,988	18,523	49,854
														41,550	1,309	21,235	18,523	82,617

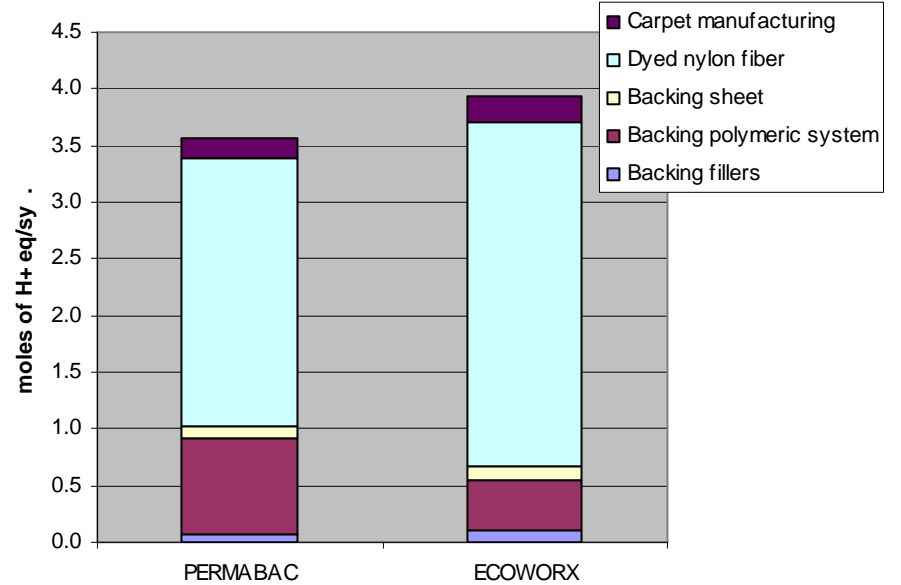
Comparison of Natural Resource Consumption

Natural resource	PERMABAC		ECOWORX	
	Process related	Energy related	Process related	Energy related
	kg/sy	kg/sy	kg/sy	kg/sy
Nitrogen used from air	0.20		0.21	
Oxygen used from air	1.71	5.41	1.57	5.36
Coal	0.00	0.74	0.00	0.72
Crude oil	1.84	0.28	1.99	0.26
Natural gas	0.23	0.34	0.03	0.44
Salt rock	0.20		0.15	
Water in reactions	1.13		1.25	
Copper ore	0.29		0.36	
Rutile	0.01		0.01	
Calcium carbonate	2.22			
Bauxite ore	0.01		0.65	
Borax	0.01		0.01	
Limestone	0.02		0.04	
Silicon dioxide	0.03		0.04	
Fly ash			0.62	
Total	7.88	6.77	6.94	6.79

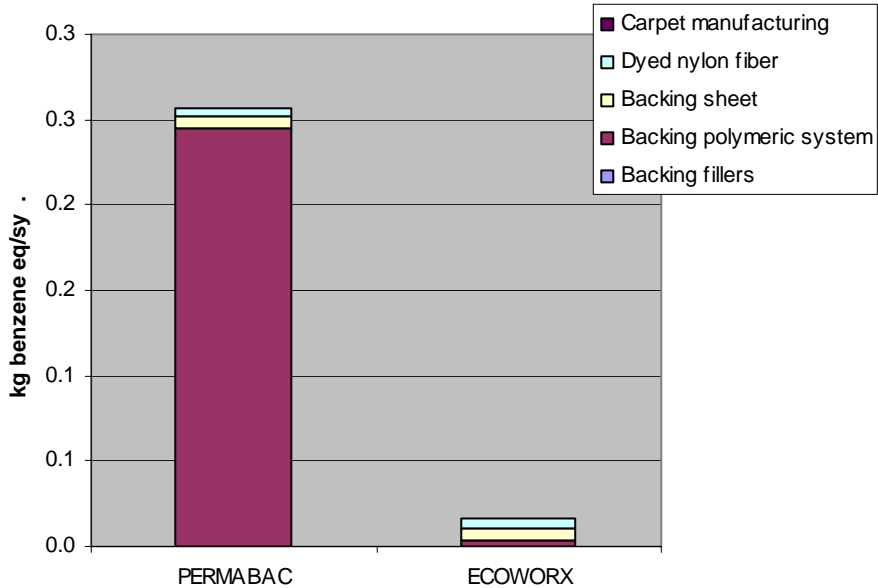
Global warming impact



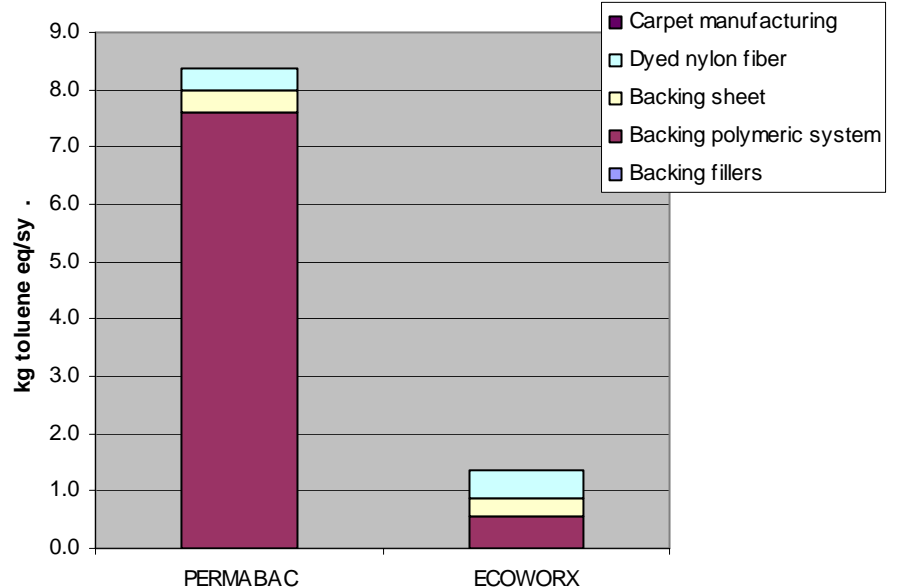
Acidification impact



Cancer impact



HH Noncancer impact



Conclusion

- **Nylon fibers, as the economically significant component in carpet products, are also environmentally significant in the life cycles of carpet products. This makes recycling of carpet product more meaningful if face fiber can be reused.**
- **Carpet backing filler, as the heaviest component, has little environmental impact contribution to the life cycle of carpet product.**
- **PERMABAC tile has more global warming impact, HH cancer and non cancer impacts than ECOWORX tile.**

Future Work

- **LCI of carpet use phase and recycle phase.**
- **Incorporate the use phase and recycling phase of carpet products to analyze the cradle-to-grave life cycle of carpet products.**



Acknowledgement

Dr. Evan Griffing

Celia Ponder

