Cradle-to-Use Life Cycle Inventory of Medical Gowns

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Sustainable Textiles and Medical Protections Conference

UC Davis

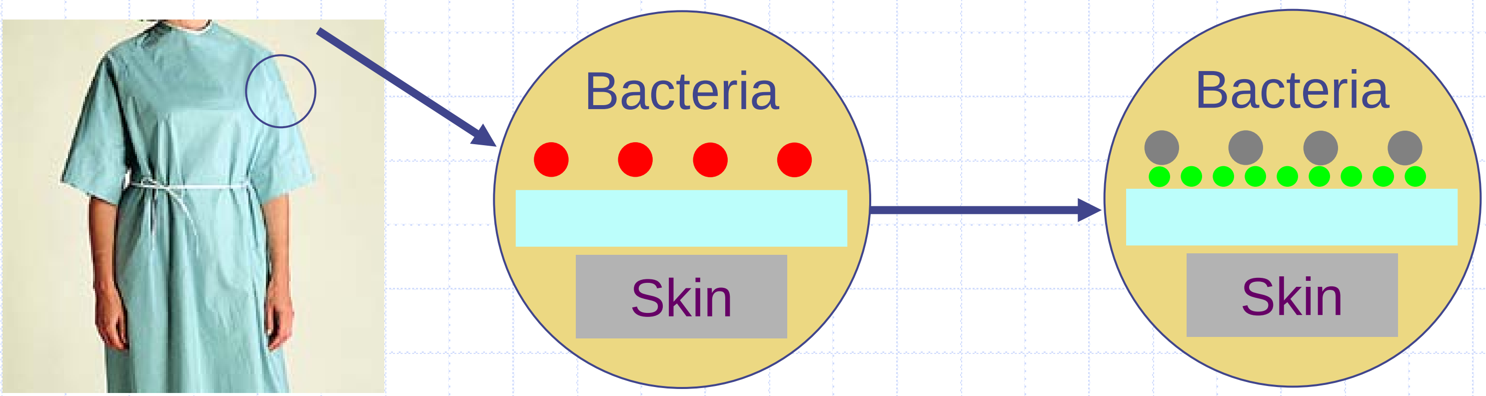
NC STATE UNIVERSITY

Biocidal Medical Garment

- Part of an interdisciplinary team assessing performance, environmental impact, health risk reduction impact, and social factors regarding material choice of healthcare garments
- NSF-MUSES: Health Protective Textiles: Bridging the Disposable/Reusable Divide

NC STATE UNIVERSITY UCDAVIS UNIVERSITY OF CALIFORNIA Berkeley University of California

- Use life cycle inventories to compare environmental impact of reusable biocidal and disposable healthcare garments
- Use life cycle inventories during gown design to minimize use of raw materials and energy and generation of emissions/waste



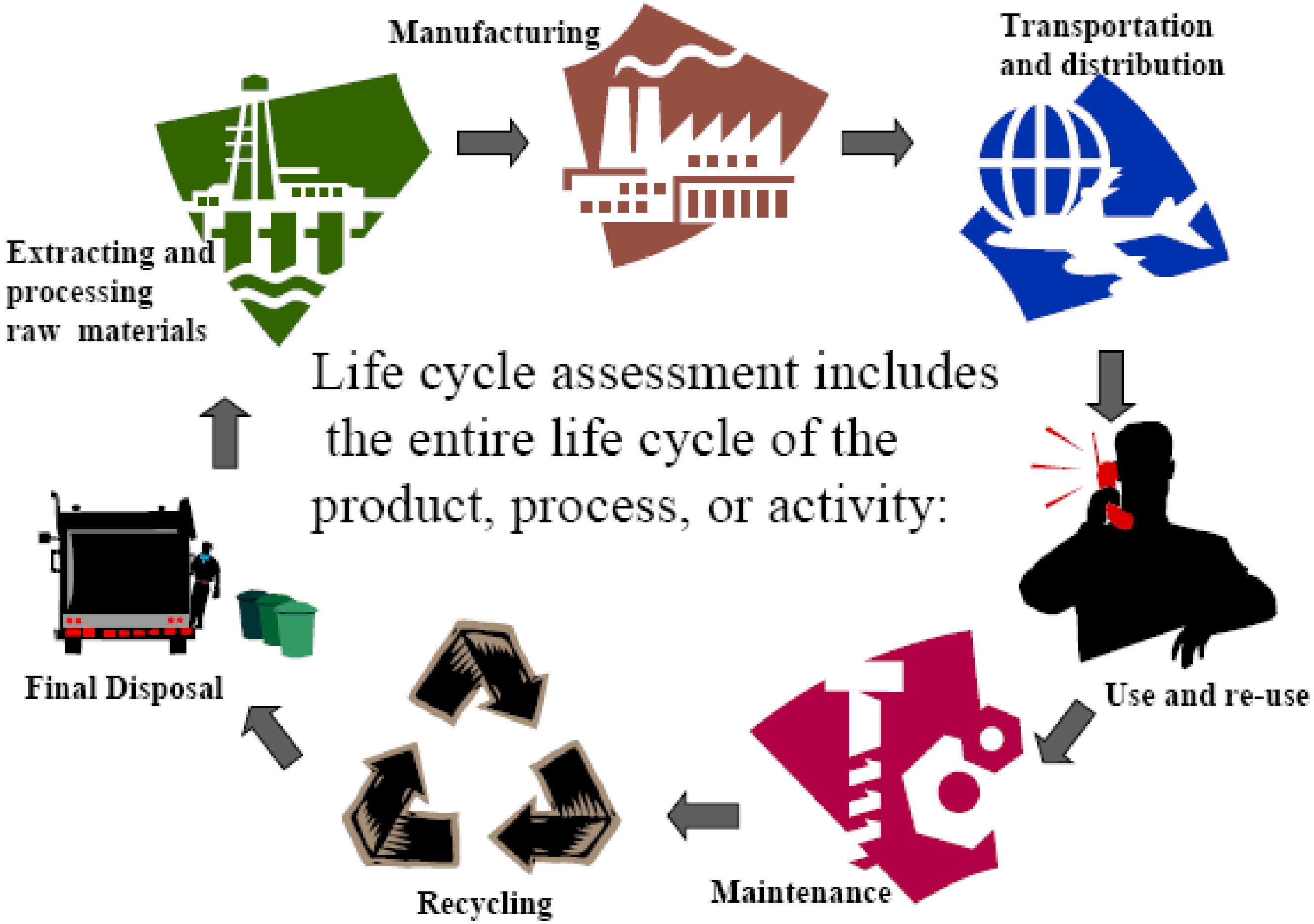
Gown

Biocide-coated Gown

What is a Life Cycle Assessment?

Life Cycle Assessment (LCA) is an environmental management tool.

LCA is a tabulation of all **water, resource, and energy consumption and emissions** generated from a product/process during manufacture, use, and disposal, from cradle to grave.

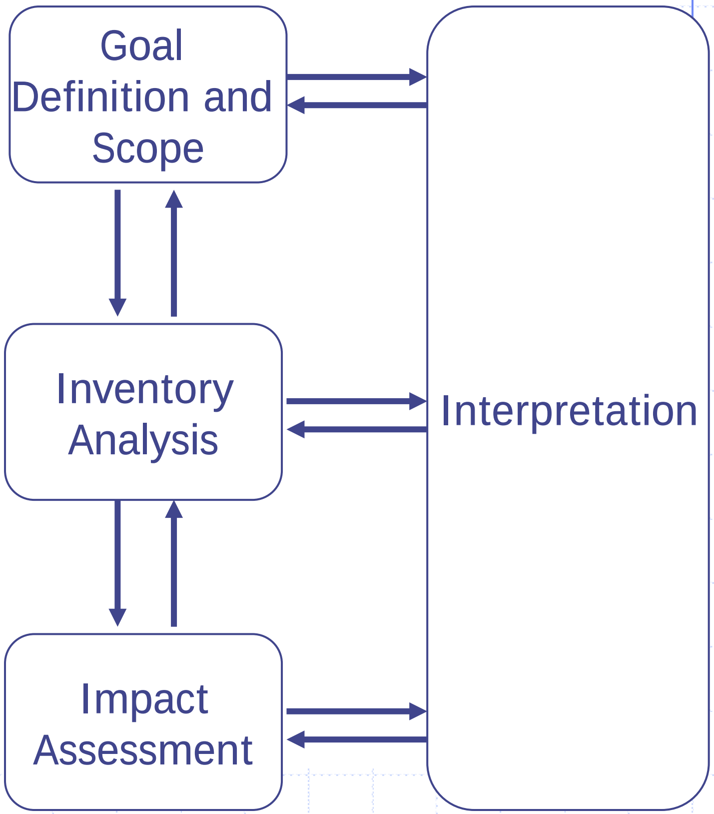


LCA Uses

- **Manufacturing improvement**
- **Corporate sustainability policies**
- **Beneficial reuse options**
- **Green purchasing**
- **International or US labeling – Ecolabel or Energy Star**
- **CO_2 trading credits**

Life Cycle Assessment Phases

- 4 Phases
  - **Goal & Scope Definition**
    - **Define and describe the product**
    - **Identify the functional unit, boundaries**
  - **Inventory Analysis**
    - **Energy consumption**
    - **Raw material and water usage**
    - **Emissions**
  - **Impact Assessment**
    - **Assess human and ecological impacts**
  - **Interpretation (Decision-making)**



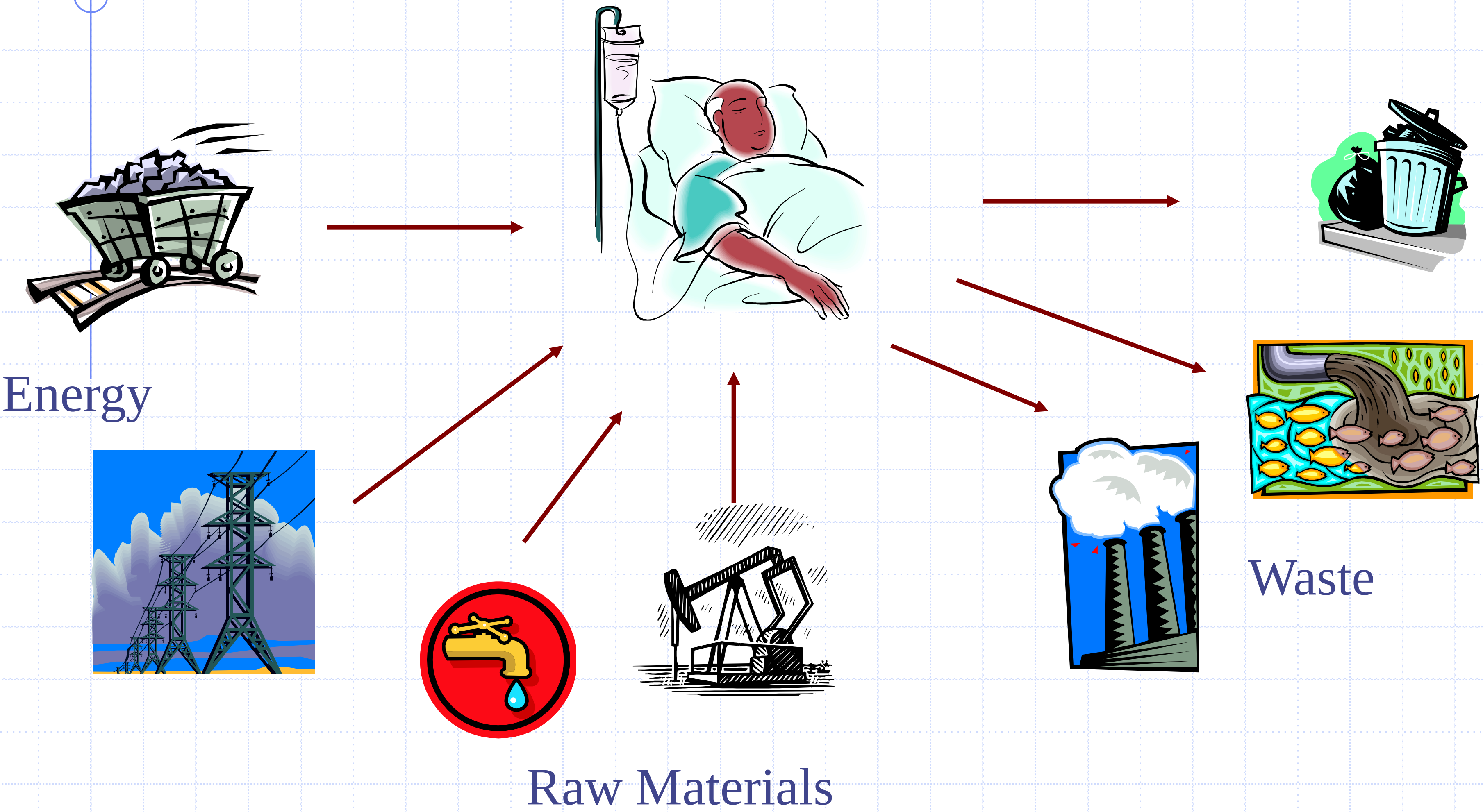
- LCA is iterative. Scope or other parts may need to be modified as more information is collected.

Source: ISO 14040

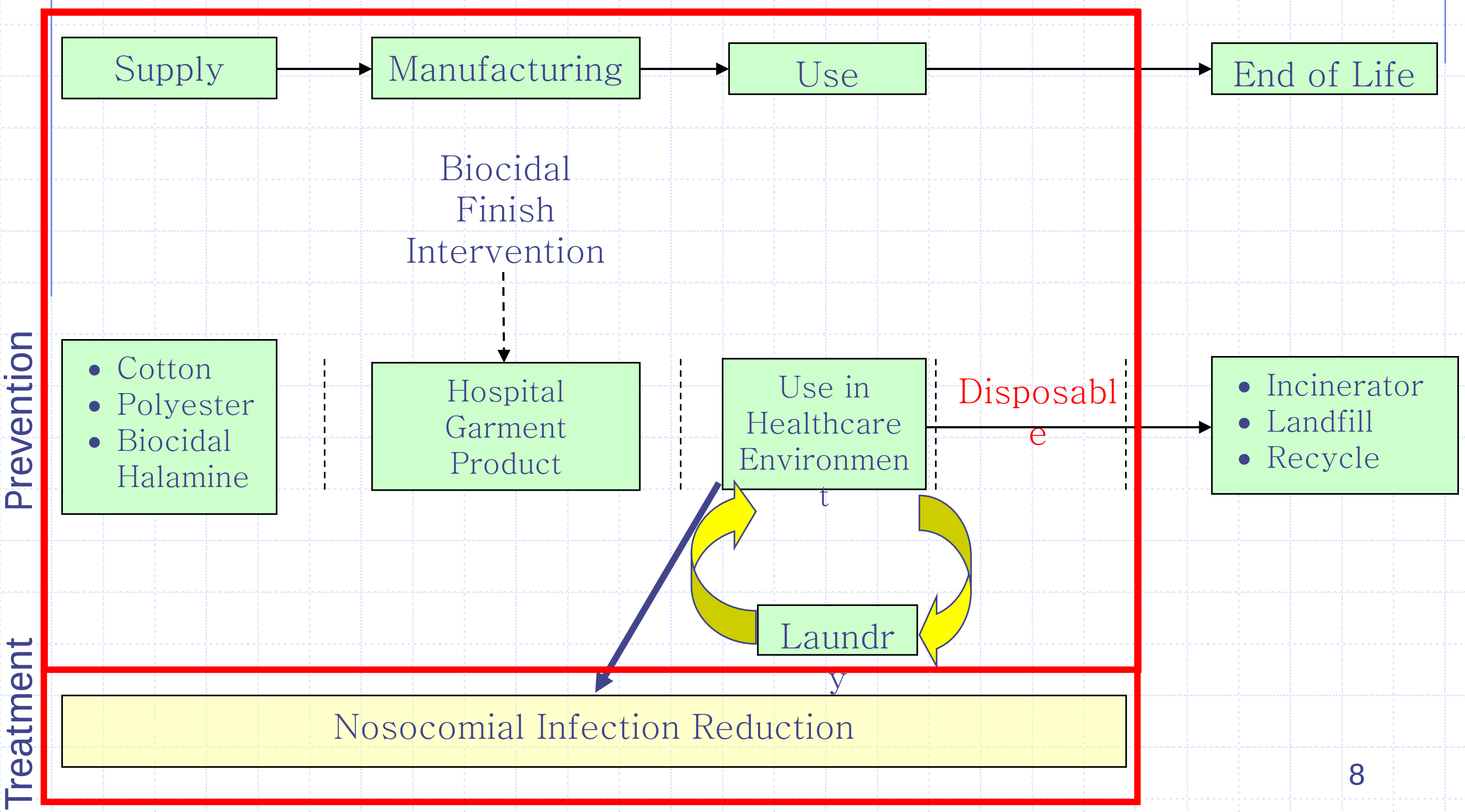
Methodology

- Research and Collect Data
- Generate Detailed Process Flow Diagram (mass flows and process conditions)
- Calculate Mass & Energy Balances (Excel)
- Generate LCI Report (MS Word)
- Review Process
- Repeat for all Chemicals in Supply Chain

Biocidal Hospital Patient Gown



Project Scope



Comparison of Disposable and Reusable Gowns (Functional Unit)

75 Disposable Patient Gowns

Polypropylene SMS Fabric

Reusable Patient Gown (used 75 times)

55% Cotton, 45% Polyester

Disposable & Reusable Comparison

Disposable Gown Chemical Tree

Level 1	Level 2	Level 3	Level 4	Level 5	Level 6
Disposable Gown	Polypropylene SMS Fabric	Polypropylene	Propylene	Naphtha	Oil

Reusable Gown Chemical Tree

Level 1	Level 2	Level 3	Level 4	Level 5-11	Level 12
Reusable Gown	Cotton Polyester Fabric	Cotton Polyester Yarn	Cotton	94 gtgs	Natural Resources: Air, Coal, Cotton Seed, Crude Oil, Natural gas, Phosphate rock, Salt rock, Sand, Sylvinite ore, Water
			PET	40 gtgs	
		DMDMH	Dimethyl hydantoin	45 gtgs	
			Formaldehyde	7 gtgs	
			Sodium hydroxide	4 gtgs	

Reusable Gown Chemical Tree

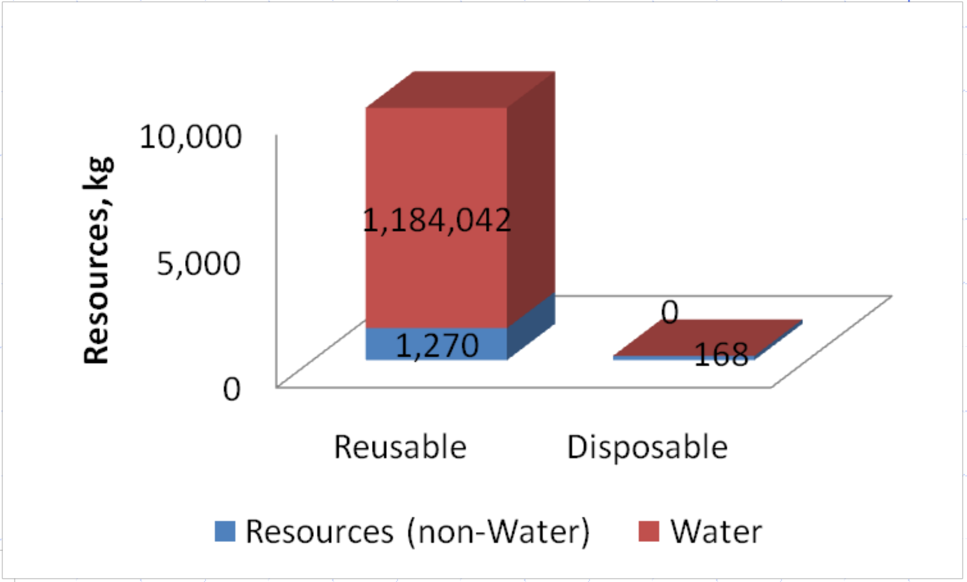
Level 1	Level 2	Level 3	Level 4	Level 5	Level 6	Level 7	Level 8	Level 9	Level 10	Level 11	Level 12
Reusable Gown	CotPoly Fabric Biocide	CottonPoly Yarn	Cotton	Cotton Seed	Cotton Seed (Untreated)						
				K in fertilizer	Potassium chloride	Sylvinite ore	sylvinite ore (in ground)				
				N in fertilizer	**Ammonia**	Natural gas	Natural gas (unprocessed)				
						Nitrogen from air	Air (untreated)				
						Oxygen from air	Air (untreated)				
						Water for rxn	Water (untreated)				
					N in DAP	DAP	**Ammonia**	Natural gas	Natural gas (unprocessed)		
								Nitrogen from air	Air (untreated)		
								Oxygen from air	Air (untreated)		
								Water for rxn	Water (untreated)		
							Phosphoric acid	**Phosphate rock**	Phosphate rock (in ground)		
									Sand		
									Water for rxn	Water (untreated)	
								Sulfuric acid	**Sulfur trioxide**	**Oxygen from air**	Air (untreated)
										Sulfur	oil (in ground)
										Water for rxn	Water (untreated)
									Water for rxn	Water (untreated)	
								Water for rxn	Water (untreated)		
					Urea	**Ammonia**	Natural gas	Natural gas (unprocessed)			
							Nitrogen from air	Air (untreated)			
							Oxygen from air	Air (untreated)			
							Water for rxn	Water (untreated)			
						Carbon dioxide	Natural gas	Natural gas (unprocessed)			
							Nitrogen from air	Air (untreated)			
							Oxygen from air	Air (untreated)			
							Water for rxn	Water (untreated)			
				P in fertilizer	**P in DAP**	DAP	**Ammonia**	Natural gas	Natural gas (unprocessed)		
								Nitrogen from air	Air (untreated)		
								Oxygen from air	Air (untreated)		
								Water for rxn	Water (untreated)		
							Phosphoric acid	**Phosphate rock**	Phosphate rock (in ground)		
									Sand		
									Water for rxn	Water (untreated)	
								Sulfuric acid	**Sulfur trioxide**	**Oxygen from air**	Air (untreated)
										Sulfur	oil (in ground)
										Water for rxn	Water (untreated)
									Water for rxn	Water (untreated)	
								Water for rxn	Water (untreated)		
			PET	**Ethylene glycol**	Ethylene oxide	**Ethylene**	Naphtha	oil (in ground)			
						Oxygen	Air (untreated)				
					Water for rxn	Water (untreated)					
				p-benzenedicarboxylic acid	Acetic acid	**Carbon monoxide**	**Carbon dioxide**	Natural gas	Natural gas (unprocessed)		
								Nitrogen from air	Air (untreated)		
								Oxygen from air	Air (untreated)		
								Water for rxn	Water (untreated)		
							Natural gas	Natural gas (unprocessed)			
							Water for rxn	Water (untreated)			
						Methanol	Natural gas	Natural gas (unprocessed)			
							Water for rxn	Water (untreated)			
					Oxygen from air	Air (untreated)					
					p-Xylene	**Toluene**	**pyrolysis gas**	Naphtha	oil (in ground)		
							reformate, from naphtha	Naphtha	oil (in ground)		
			Water for rxn	Water (untreated)							
		Dimethyloldimethyl hydantoin	Dimethyl hydantoin	**Acetone**	**Benzene**	**pyrolysis gas**	Naphtha	oil (in ground)			
						reformate, from naphtha	Naphtha	oil (in ground)			
					Oxygen	Air (untreated)					
					Propylene	Naphtha	oil (in ground)				
				Ammonia	Natural gas	Natural gas (unprocessed)					
					Nitrogen from air	Air (untreated)					
					Oxygen from air	Air (untreated)					
					Water for rxn	Water (untreated)					
				Carbon dioxide	Natural gas	Natural gas (unprocessed)					
					Nitrogen from air	Air (untreated)					
					Oxygen from air	Air (untreated)					
					Water for rxn	Water (untreated)					
				Hydrogen cyanide	**Ammonia**	Natural gas	Natural gas (unprocessed)				
						Nitrogen from air	Air (untreated)				
						Oxygen from air	Air (untreated)				
						Water for rxn	Water (untreated)				
					Natural gas	Natural gas (unprocessed)					
					Oxygen from air	Air (untreated)					
			Formaldehyde	**Methanol**	Natural gas	Natural gas (unprocessed)					
					Water for rxn	Water (untreated)					
				Oxygen from air	Air (untreated)						
			Sodium hydroxide	Sodium chloride	Salt rock						
				Water for rxn	Water (untreated)						

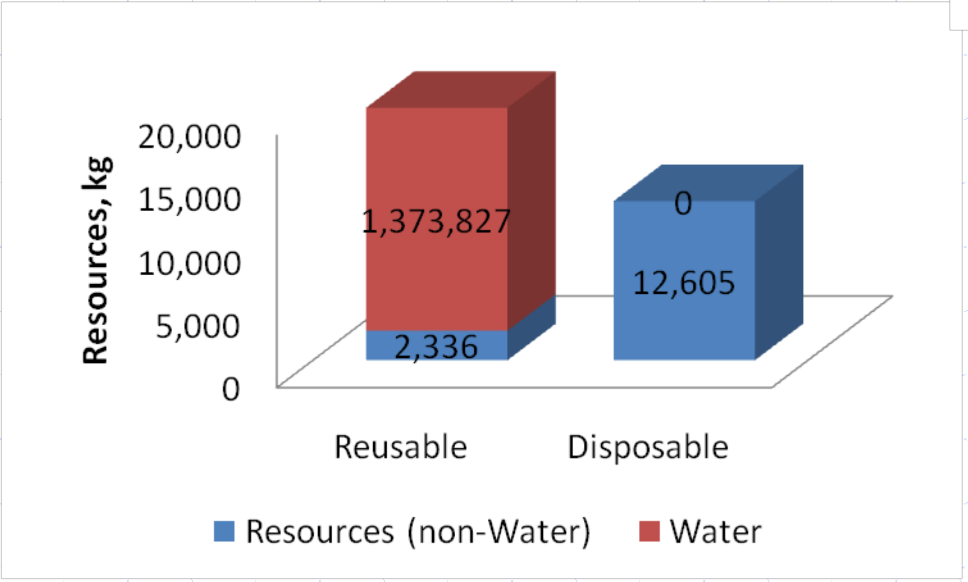
Disposable & Reusable Comparison

	PP SMS Fabric	Reusable Fabric
# GTG chemicals in CTG	5	200
# Unique GTG chemicals in CTG	5	47
# Unit Operations (in GTG)	29	24
Mass Intensity (inputs/product)	1.02	1.78
E-factor (waste/product)	0.02	0.80

Natural Resources

Cradle-to-Gate, per 1000 Gowns **Manufactured**

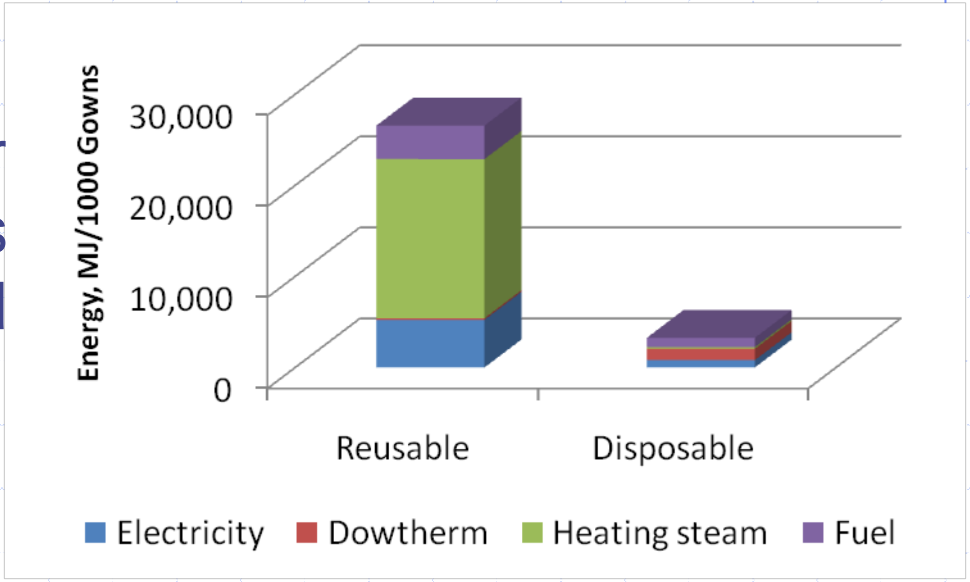


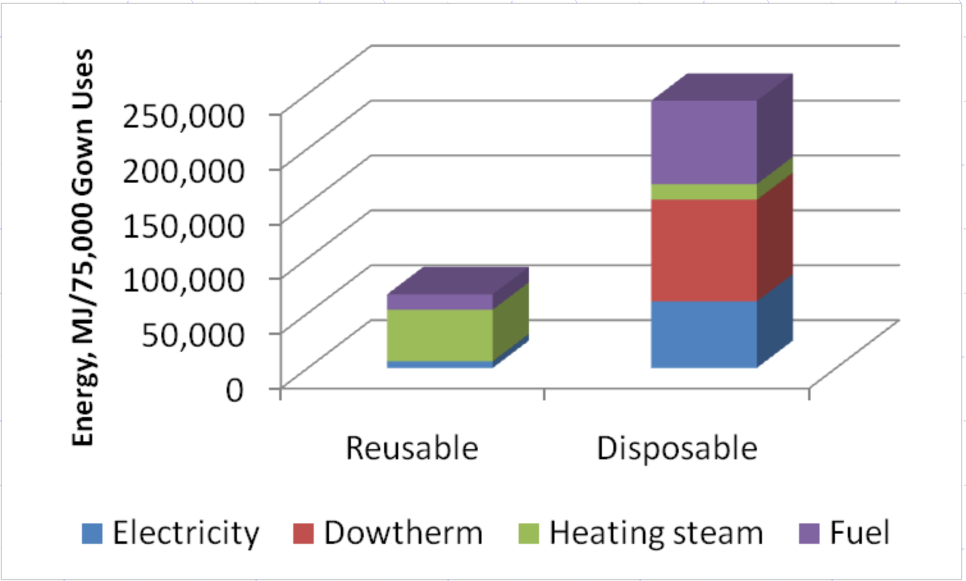


Cradle-to-Use, per 75,000 **Gown Uses**

Energy Comparison

Cradle-to-Gate, per 1000 Gowns **Manufactured**

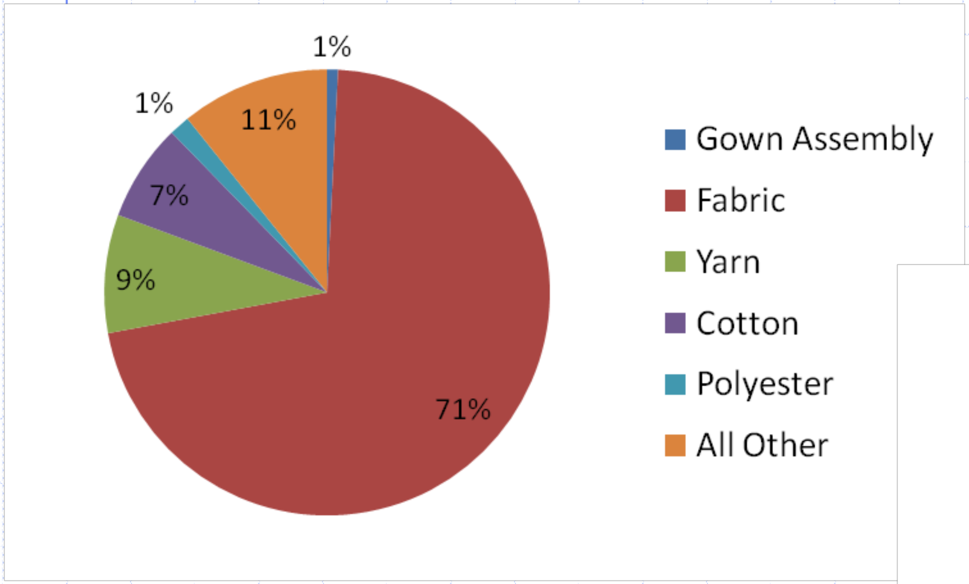




Cradle-to-Use, per 75,000 **Gown Uses**

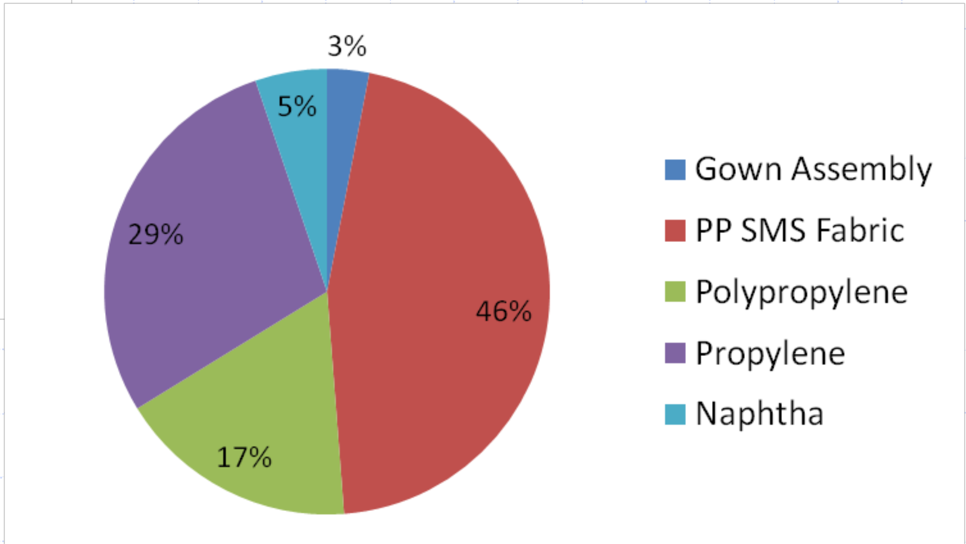
Energy Comparison

Reusable Gown



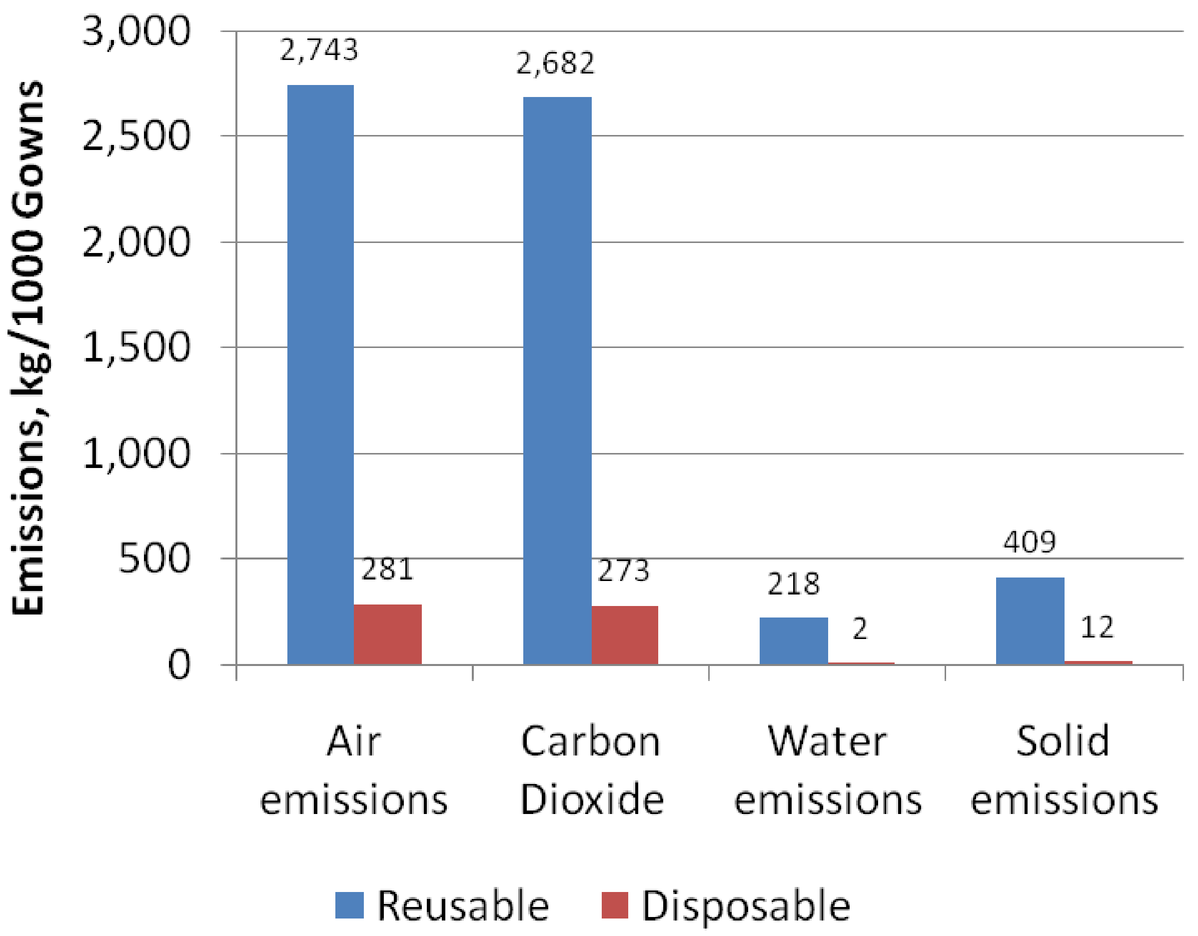
27,315 MJ/1000 Gowns

Disposable Gown

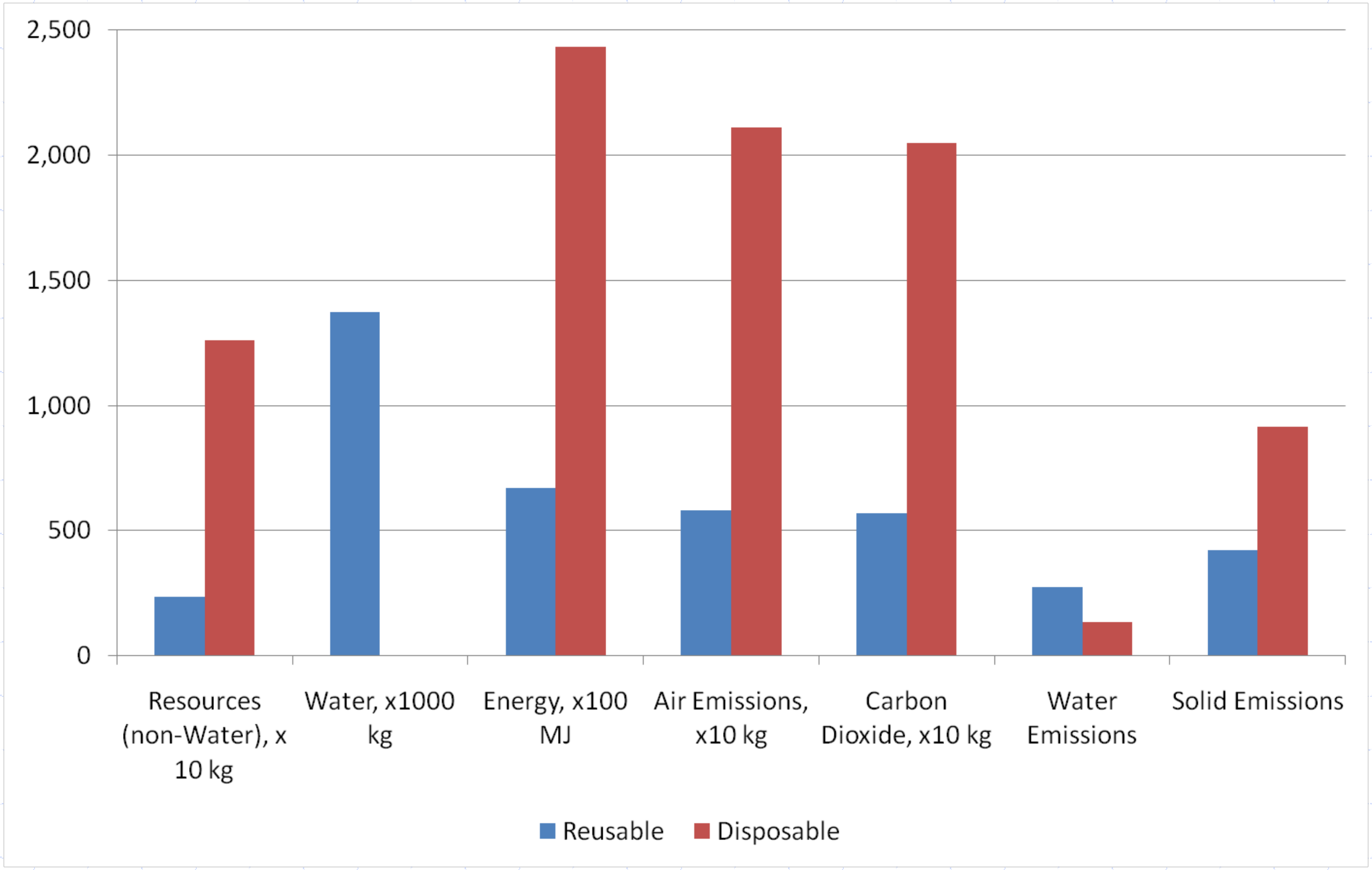


3,013 MJ/1000 Gowns

Emissions (per 1000 gowns)



Cradle-to-Use Comparison
(75,000 Gown Uses including Laundry)



Conclusions

- The reusable gown production consumes 9 times more energy and 7 times more resources than the disposable gown (CTG).
- Fabric production is the largest energy consumer for both reusable and disposable gowns.
- Comparing 75 disposable gowns to 1 reusable gown shows that the reusable gown including laundering has a smaller environmental footprint, except for water use during crop irrigation.
- Reusable gown must be re-used10 times to equal the energy use of an equivalent number of disposable gown uses

Acknowledgements

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- J&J Industries
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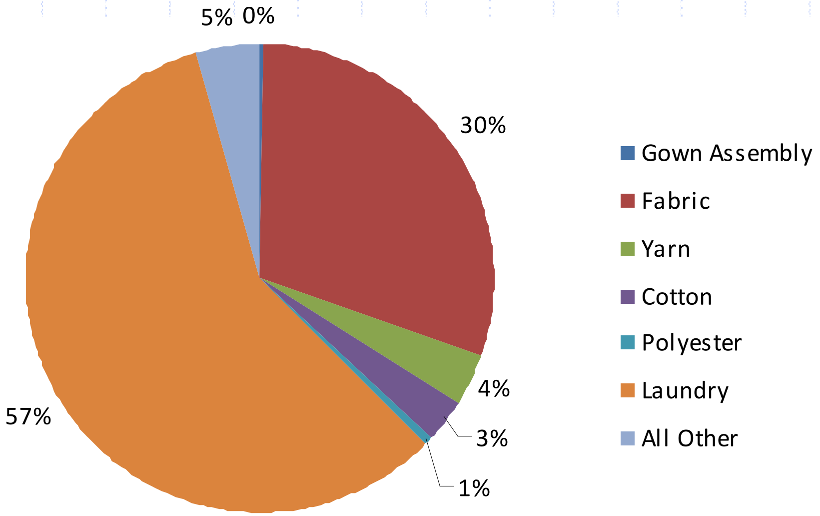
Thank You!

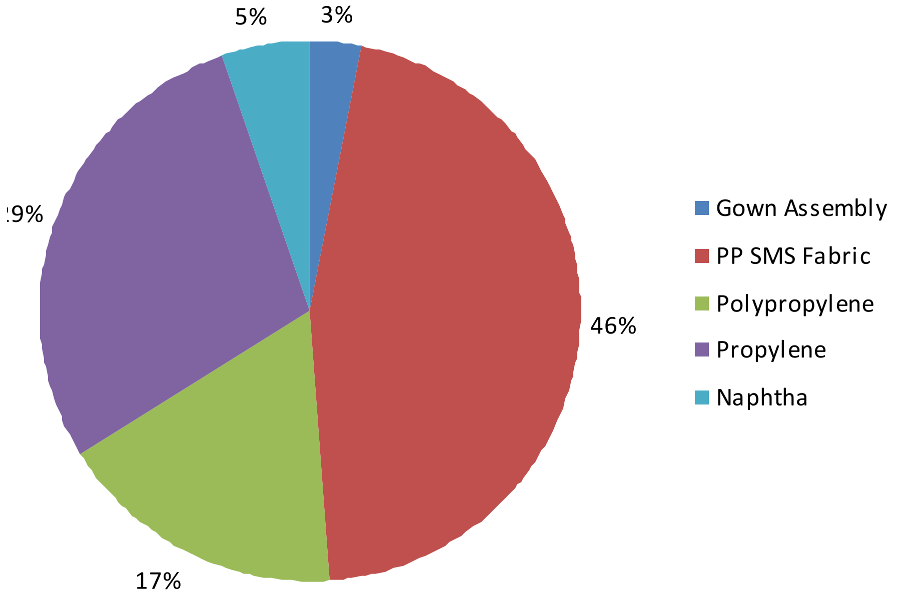
Questions?

Energy Comparison - CTU

Reusable Gown



Disposable Gown



Comparison with other Databases

Case Study: Ammonia GTG

Parameter	Process-based	BUWAL 250	Boustead	PEMS	EFMA
Natural gas, kg	446 810	467	760[a]	760[a]	458
Water, kg	1200 12000	920	11176[b]	11000[b]	1500
Ammonia, kg	1000	1000	1000	1000	1000
CO_2, kg	1179	1156	c	c	1150-1300
Total energy, MJ	13300	6000	11600	11600	8000-10000

a. Includes energy input

b. Including cooling water

c. Counted as emission

Effect of Pigment on Gown LCI

	Gown w/ Color	Gown w/o Color	Difference	Dye Effect
Raw Materials, kg	3,202	2,801	401	13%
Energy, MJ	50,764	50,212	553	1%
Air Emissions, kg	4,759	4,687	72	2%
Water Emissions, kg	40	30	10	24%
Solid Emissions, kg	205	204	2	1%

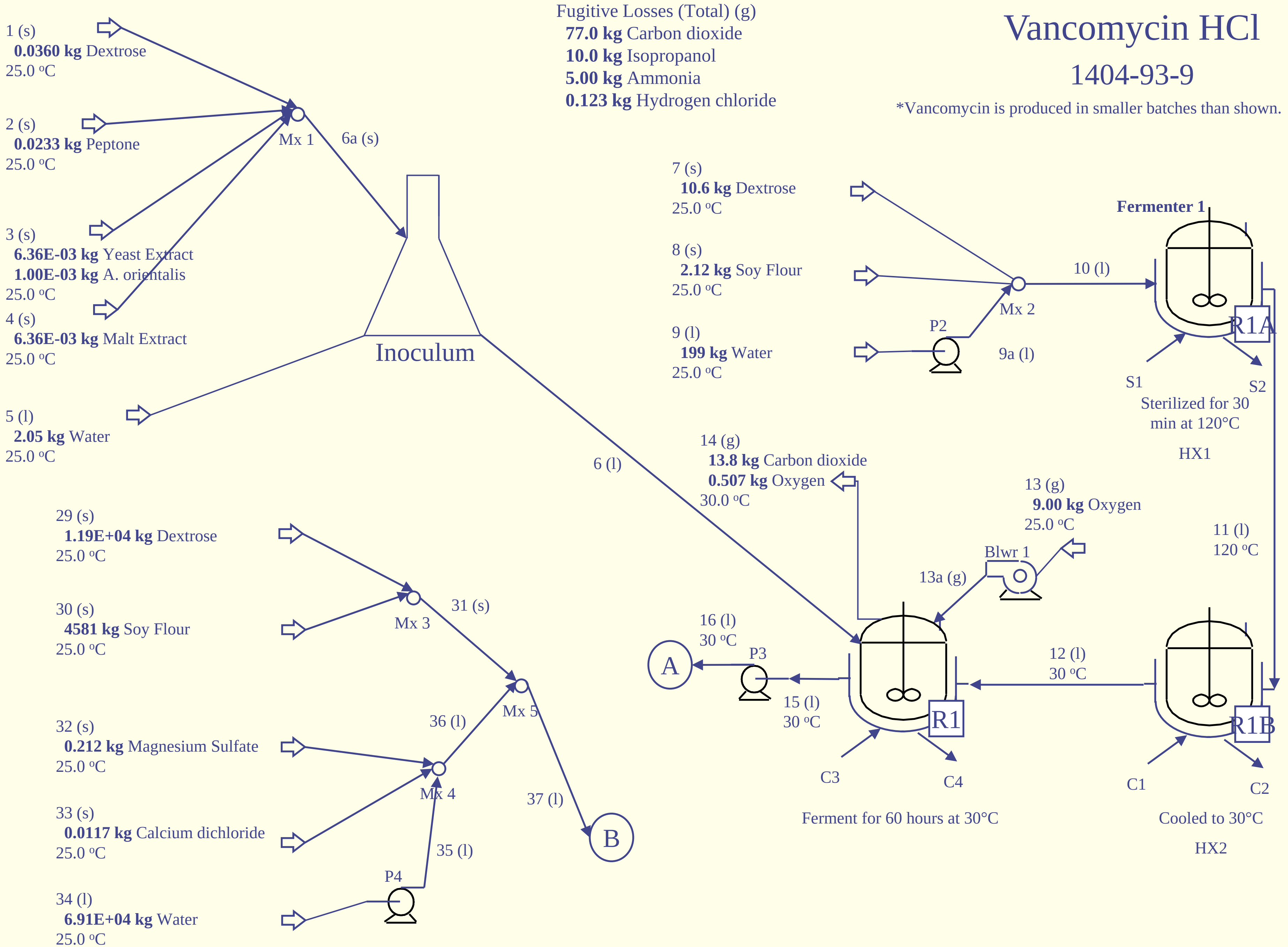
Life Cycle Assessment History

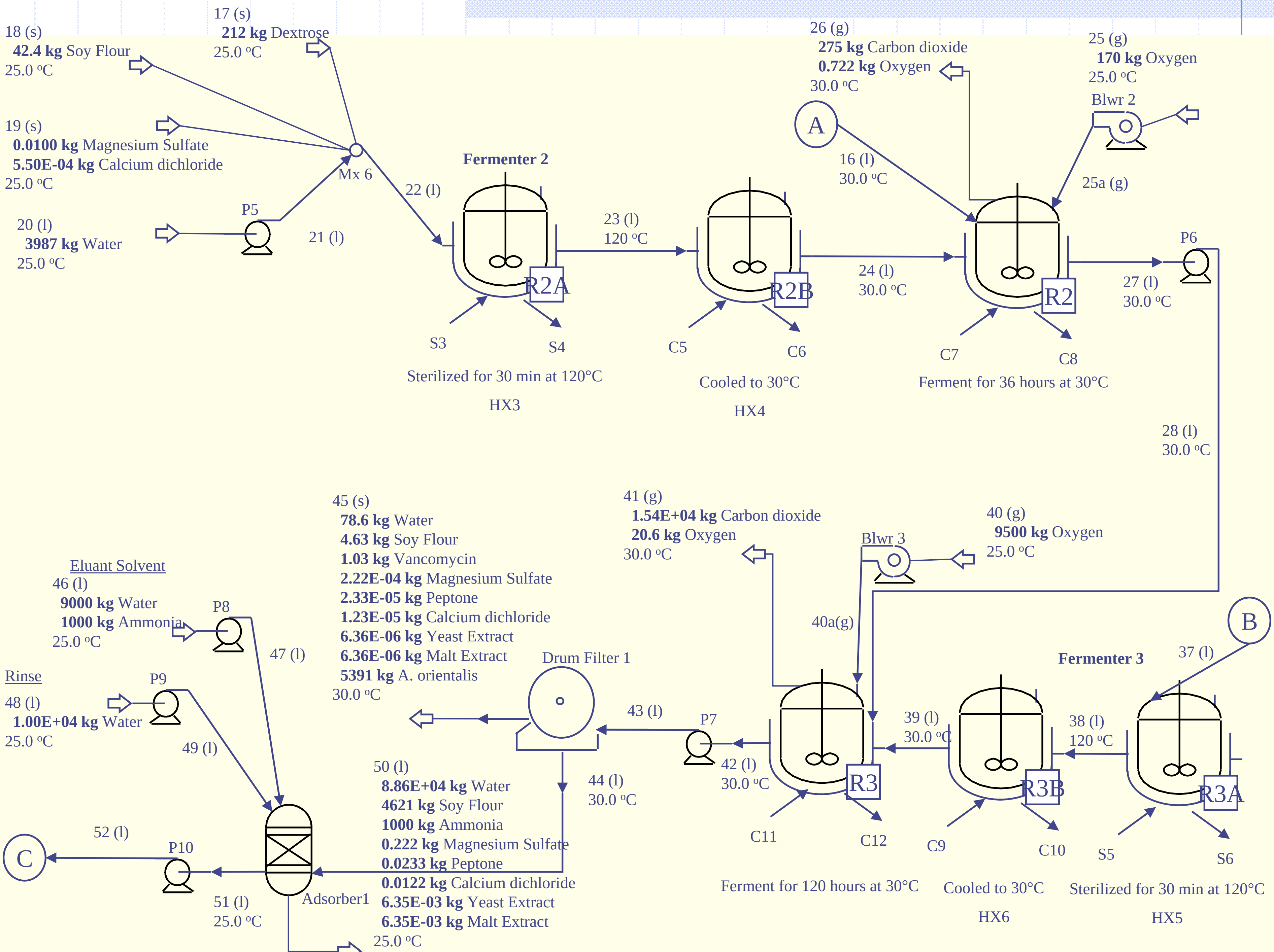
- Began in 1963, Harold Smith reported cumulative energy requirements for production of chemical intermediates at World Energy Conference
- In 1969, Coca-Cola studied alternative beverage containers.
- Resource and Environmental Profile Analysis (REPA) or Ecobalance (in Europe) done by private consulting firms
- In the 1980s and early 1990s, numerous REPAs with contradicting results and no commonality
- In 1990, REPA by Franklin & Assoc finds disposable diapers preferable.
- In 1991, REPA by Lehrberger & Jones finds cloth diapers preferable
- In 1992, REPA by A.D. Little finds disposable diapers preferable.
- During the 1990s, SETAC (Society of Environmental Toxicology and Chemistry) and ISO (International Organization for Standardization) worked together to develop ISO 14000 standards for the life cycle assessment.
- In 2006, ISO updates Standards 14040 and 14044

Vancomycin HCl

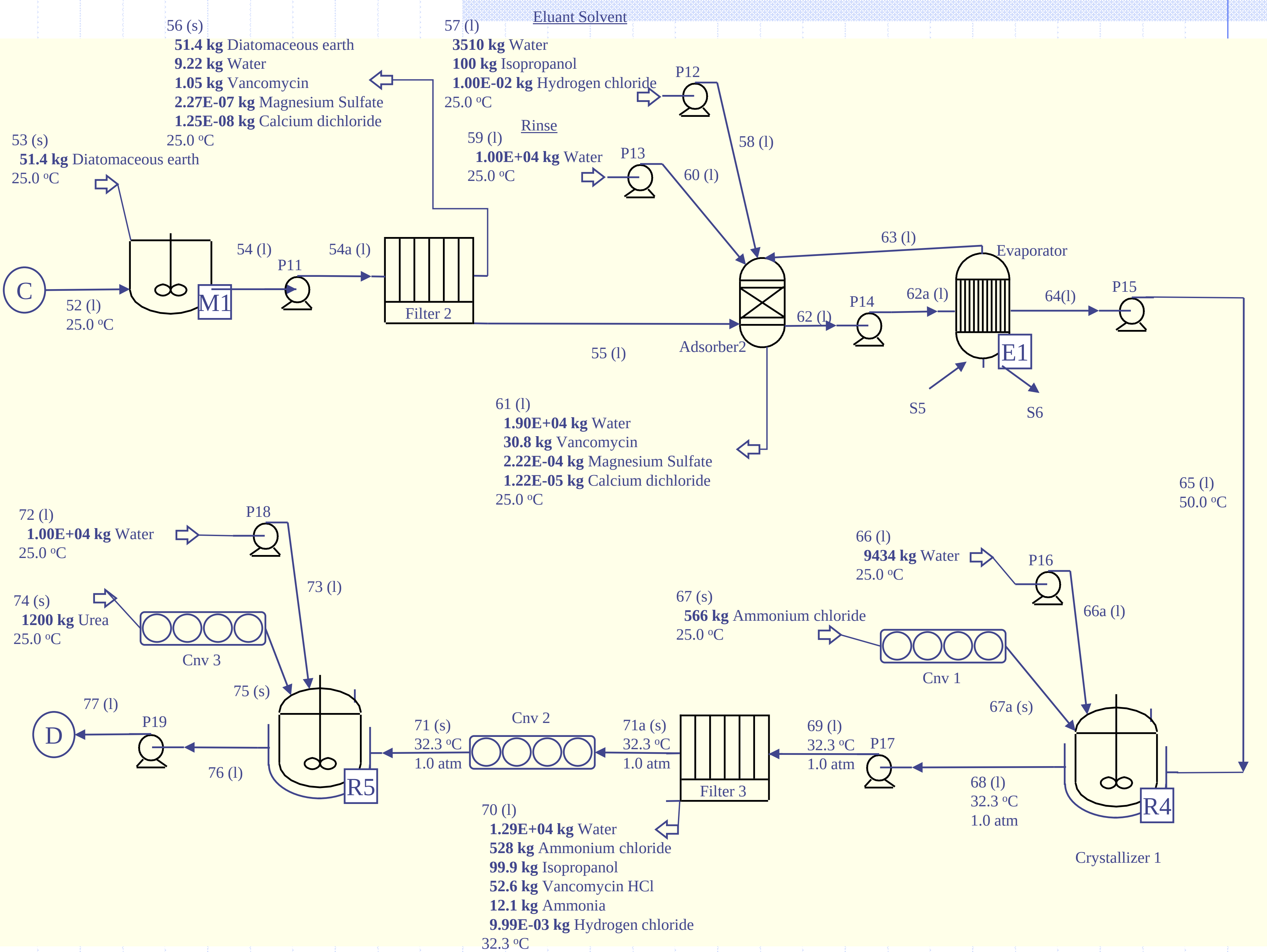
1404-93-9

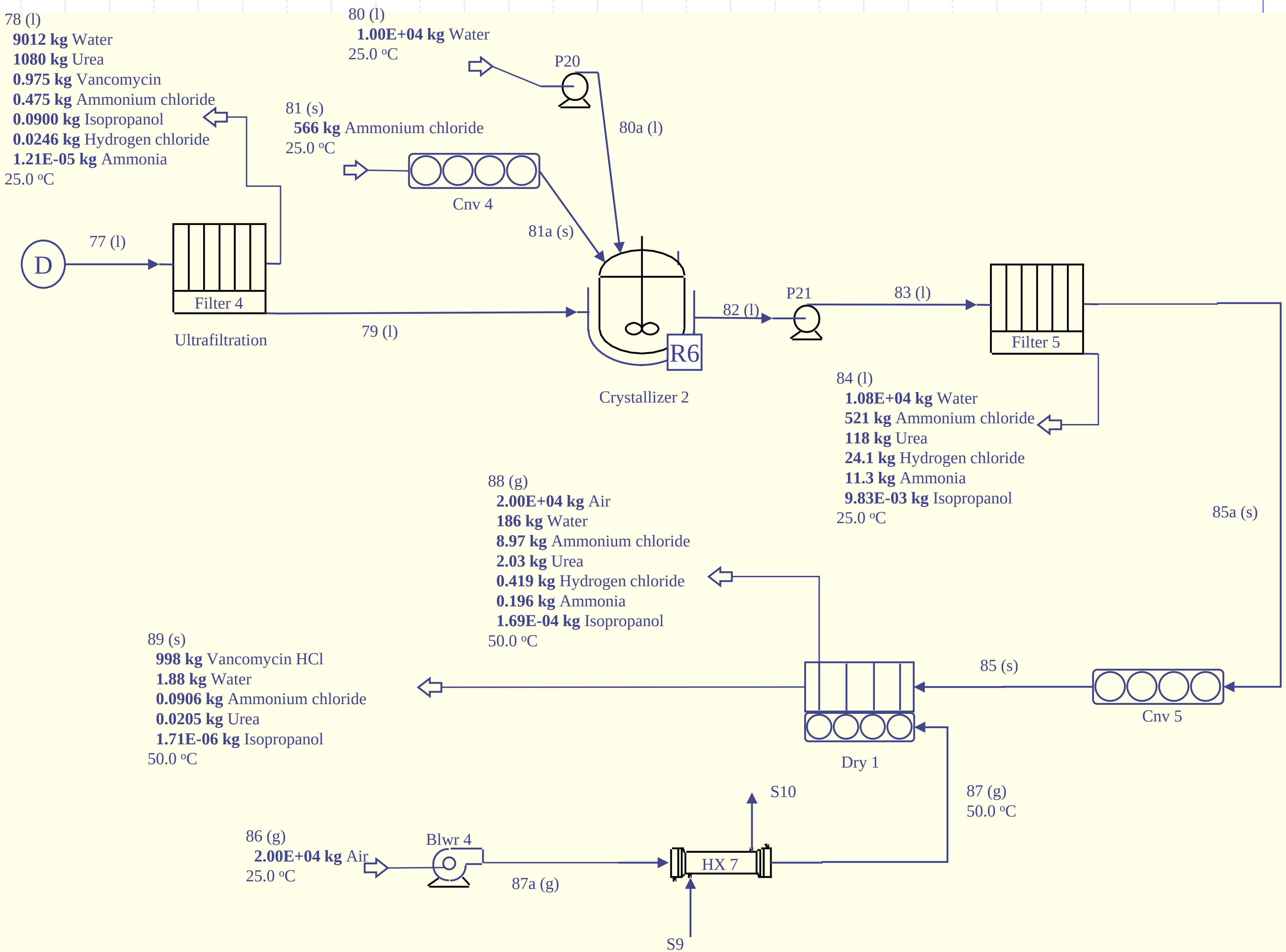
*Vancomycin is produced in smaller batches than shown.





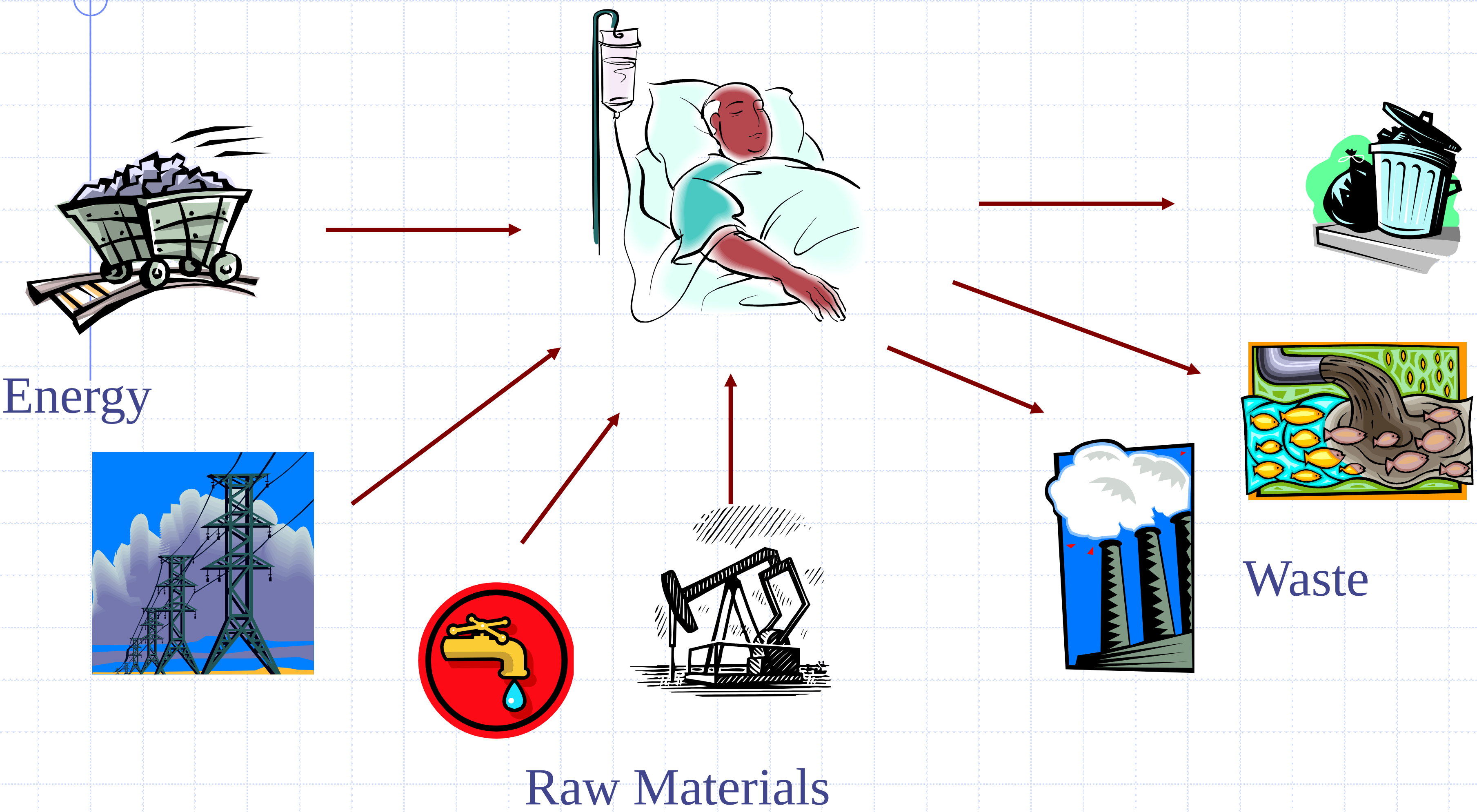
18 (s)
42.4 kg Soy Flour
25.0 °C
17 (s)
212 kg Dextrose
25.0 °C
19 (s)
0.0100 kg Magnesium Sulfate
5.50E-04 kg Calcium dichloride
25.0 °C
20 (l)
3987 kg Water
25.0 °C
P5
Mx 6
21 (l)
22 (l)
Fermenter 2
23 (l)
120 °C
R2A
S3
S4
Sterilized for 30 min at 120°C
HX3
R2B
C5
C6
Cooled to 30°C
HX4
24 (l)
30.0 °C
26 (g)
275 kg Carbon dioxide
0.722 kg Oxygen
30.0 °C
A
16 (l)
30.0 °C
25 (g)
170 kg Oxygen
25.0 °C
Blwr 2
25a (g)
R2
C7
C8
Ferment for 36 hours at 30°C
P6
27 (l)
30.0 °C
28 (l)
30.0 °C
45 (s)
78.6 kg Water
4.63 kg Soy Flour
1.03 kg Vancomycin
2.22E-04 kg Magnesium Sulfate
2.33E-05 kg Peptone
1.23E-05 kg Calcium dichloride
6.36E-06 kg Yeast Extract
6.36E-06 kg Malt Extract
5391 kg A. orientalis
30.0 °C
41 (g)
1.54E+04 kg Carbon dioxide
20.6 kg Oxygen
30.0 °C
40 (g)
9500 kg Oxygen
25.0 °C
Blwr 3
40a(g)
B
37 (l)
Fermenter 3
Eluant Solvent
46 (l)
9000 kg Water
1000 kg Ammonia
25.0 °C
P8
47 (l)
Rinse
48 (l)
1.00E+04 kg Water
25.0 °C
P9
49 (l)
Drum Filter 1
43 (l)
P7
42 (l)
30.0 °C
44 (l)
30.0 °C
39 (l)
30.0 °C
38 (l)
120 °C
R3
R3B
R3A
C11
C12
C9
C10
S5
S6
Ferment for 120 hours at 30°C
Cooled to 30°C
HX6
Sterilized for 30 min at 120°C
HX5
50 (l)
8.86E+04 kg Water
4621 kg Soy Flour
1000 kg Ammonia
0.222 kg Magnesium Sulfate
0.0233 kg Peptone
0.0122 kg Calcium dichloride
6.35E-03 kg Yeast Extract
6.35E-03 kg Malt Extract
25.0 °C
C
52 (l)
P10
51 (l)
25.0 °C
Adsorber1


Eluant Solvent
56 (s)
51.4 kg Diatomaceous earth
9.22 kg Water
1.05 kg Vancomycin
2.27E-07 kg Magnesium Sulfate
1.25E-08 kg Calcium dichloride
25.0 °C
57 (l)
3510 kg Water
100 kg Isopropanol
1.00E-02 kg Hydrogen chloride
25.0 °C
P12
58 (l)
53 (s)
51.4 kg Diatomaceous earth
25.0 °C
Rinse
59 (l)
1.00E+04 kg Water
25.0 °C
P13
60 (l)
63 (l)
Evaporator
C
52 (l)
25.0 °C
M1
54 (l)
P11
54a (l)
Filter 2
55 (l)
Adsorber2
62 (l)
P14
62a (l)
E1
64(l)
P15
S5
S6
61 (l)
1.90E+04 kg Water
30.8 kg Vancomycin
2.22E-04 kg Magnesium Sulfate
1.22E-05 kg Calcium dichloride
25.0 °C
65 (l)
50.0 °C
72 (l)
1.00E+04 kg Water
25.0 °C
P18
73 (l)
74 (s)
1200 kg Urea
25.0 °C
Cnv 3
75 (s)
66 (l)
9434 kg Water
25.0 °C
P16
66a (l)
67 (s)
566 kg Ammonium chloride
25.0 °C
Cnv 1
67a (s)
77 (l)
D
P19
76 (l)
R5
71 (s)
32.3 °C
1.0 atm
Cnv 2
71a (s)
32.3 °C
1.0 atm
Filter 3
69 (l)
32.3 °C
1.0 atm
P17
68 (l)
32.3 °C
1.0 atm
R4
Crystallizer 1
70 (l)
1.29E+04 kg Water
528 kg Ammonium chloride
99.9 kg Isopropanol
52.6 kg Vancomycin HCl
12.1 kg Ammonia
9.99E-03 kg Hydrogen chloride
32.3 °C



78 (l)
9012 kg Water
1080 kg Urea
0.975 kg Vancomycin
0.475 kg Ammonium chloride
0.0900 kg Isopropanol
0.0246 kg Hydrogen chloride
1.21E-05 kg Ammonia
25.0 ºC
80 (l)
1.00E+04 kg Water
25.0 ºC
P20
81 (s)
566 kg Ammonium chloride
25.0 ºC
80a (l)
Cnv 4
81a (s)
D
77 (l)
Filter 4
Ultrafiltration
79 (l)
R6
Crystallizer 2
82 (l)
P21
83 (l)
Filter 5
84 (l)
1.08E+04 kg Water
521 kg Ammonium chloride
118 kg Urea
24.1 kg Hydrogen chloride
11.3 kg Ammonia
9.83E-03 kg Isopropanol
25.0 ºC
85a (s)
88 (g)
2.00E+04 kg Air
186 kg Water
8.97 kg Ammonium chloride
2.03 kg Urea
0.419 kg Hydrogen chloride
0.196 kg Ammonia
1.69E-04 kg Isopropanol
50.0 ºC
89 (s)
998 kg Vancomycin HCl
1.88 kg Water
0.0906 kg Ammonium chloride
0.0205 kg Urea
1.71E-06 kg Isopropanol
50.0 ºC
85 (s)
Cnv 5
Dry 1
S10
87 (g)
50.0 ºC
86 (g)
2.00E+04 kg Air
25.0 ºC
Blwr 4
HX 7
87a (g)
S9

Biocidal Hospital Patient Gown



Life Cycle Inventory

- Backbone of the Life Cycle Assessment
- Quantifies the full range of environmental impacts of a product over its complete life
- Goals are technical clarity and accuracy, transparency, ability to be modified, and streamlining with technical accuracy
- Need
  - Inputs
  - Outputs/products
  - Chemical or material losses
  - Energy requirements

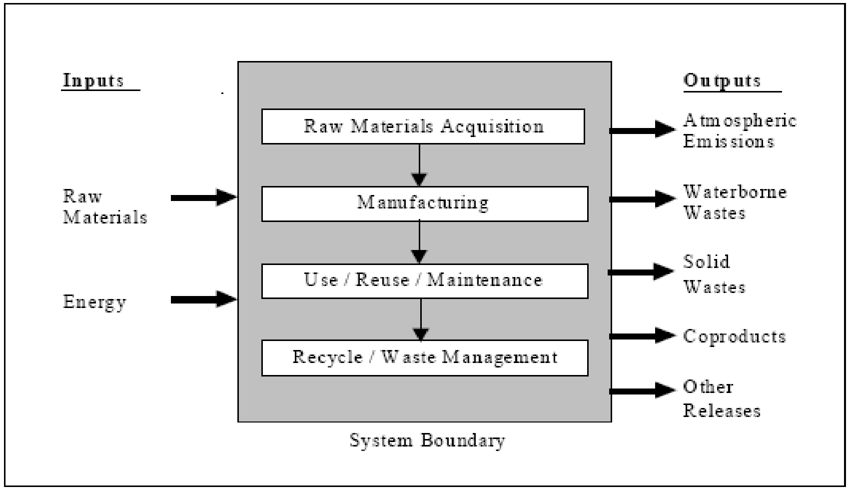


Exhibit 1-1. Life Cycle Stages (Source: EPA,1993)

LCI Data

- Scientific literature, chemical encyclopedias, patents, published studies, industry and government records
- Chemical engineering design method
  - Goals of quality and complex systems and increased speed
  - Use procedures and data from actual manufacturing plants and rules of thumb taught to all engineers
  - Highest transparency

Methodology

$$\text{Cradle-to-Gate Life Cycle Inventory} = \sum (\text{Gate-to-Gate Inventory})_i$$

i = each chemical or process going back to the cradle that made the product (functional unit) being studied

- Capital processes (construction, decommissioning) not included
- Human labor not included
- One manufacturing process per chemical
- Heuristics written for unit operations
- Transportation of chemicals added to each gate-to-gate inventory
- Industry data averaged (when available)

Jimenez-Gonzalez, C.; Kim, S.; Overcash, M. *Int. J. LCA*. **2000**, *3*, 153-159.