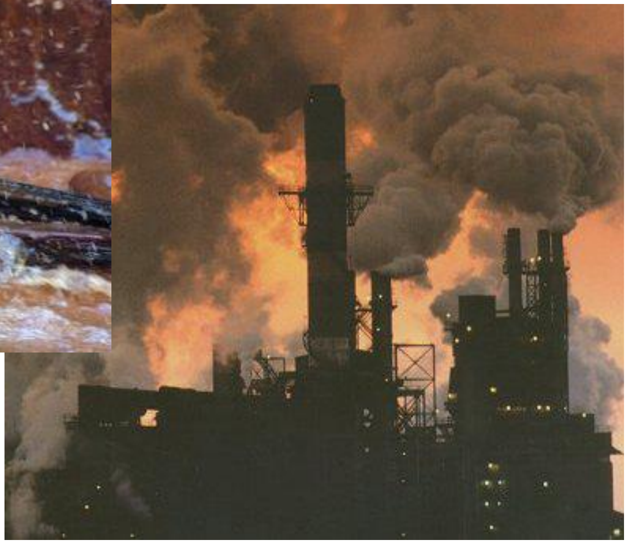
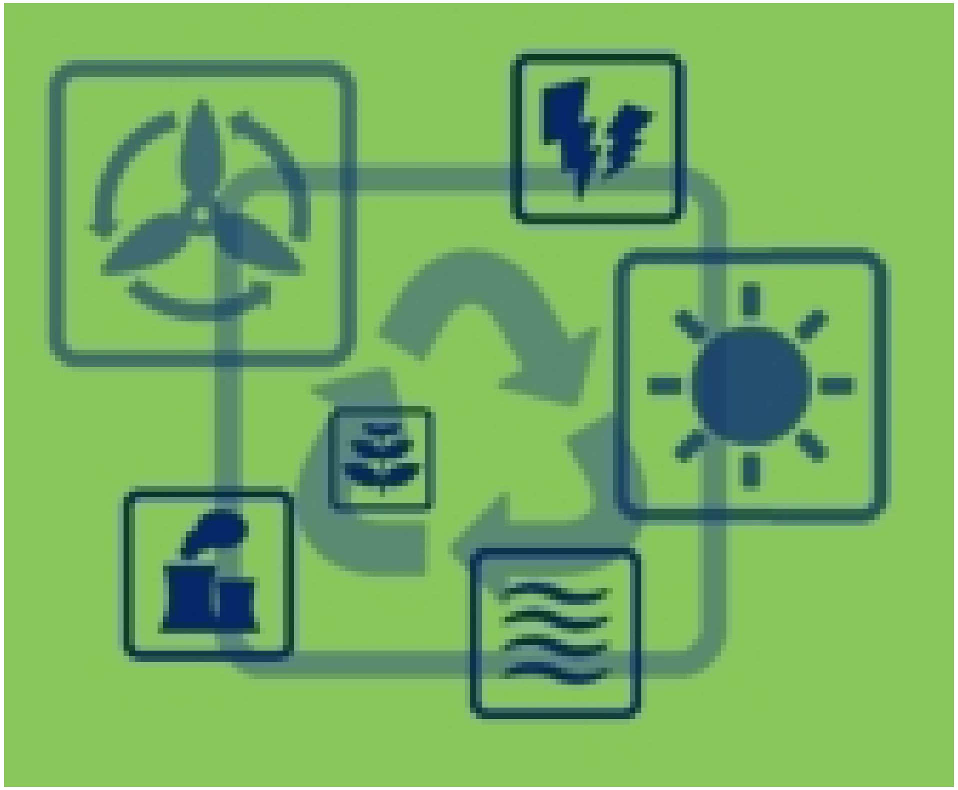
Manufacturing Systems Engineering
Sustainable Manufacturing



HYUNSOO LEE




International Journal of
Sustainable Engineering
Editor-in-Chief: Shahin Rahimifard,
Loughborough University, UK
Taylor & Francis

Today's References

- Professor, Hart

  - http://www.ce.utexas.edu/prof/hart/333T/documents/SustainableEngineering.pdf

- Wikipedia, and so on

Sustainable Engineering

- Traditional Engineering Vs. sustainable Engineering

- In "Traditional / Conventional" Engineering
  - Human exposed to toxics in food, air, water and soil
  - Rising demand for energy for transport, manufacturing, heating & cooling
  - Depletion of non-renewable resources (Petroleum, metals, phosphorus)
  - Excessive demand for water for homes, agriculture and industry
  - Rising demand for land for housing, food production and economical activities (Production, retail, transportation)
  - Ecosystem damage and habitat loss due to pollutant discharger
  - Impact on global climate

Conventional Engineering

Low ⟷ High

Low:

1. Energy Conservation
2. Recycling
3. Reusing

High:

1. Emission of Toxicity
2. Emission of carbon
3. Pollution
4. Usage of non-renewable energy
5. Ecosystem damage and habitat loss
6. Impact on global climate

Sustainable Engineering

Low ⟷ High

Low

1. Emission of Toxicity
2. Emission of carbon
3. Pollution
4. Usage of non-renewable energy
5. Ecosystem damage and habitat loss
6. Impact on global climate

High

1. Energy Conservation
2. Recycling
3. Reusing

Sustainable Engineering

- Another viewpoint

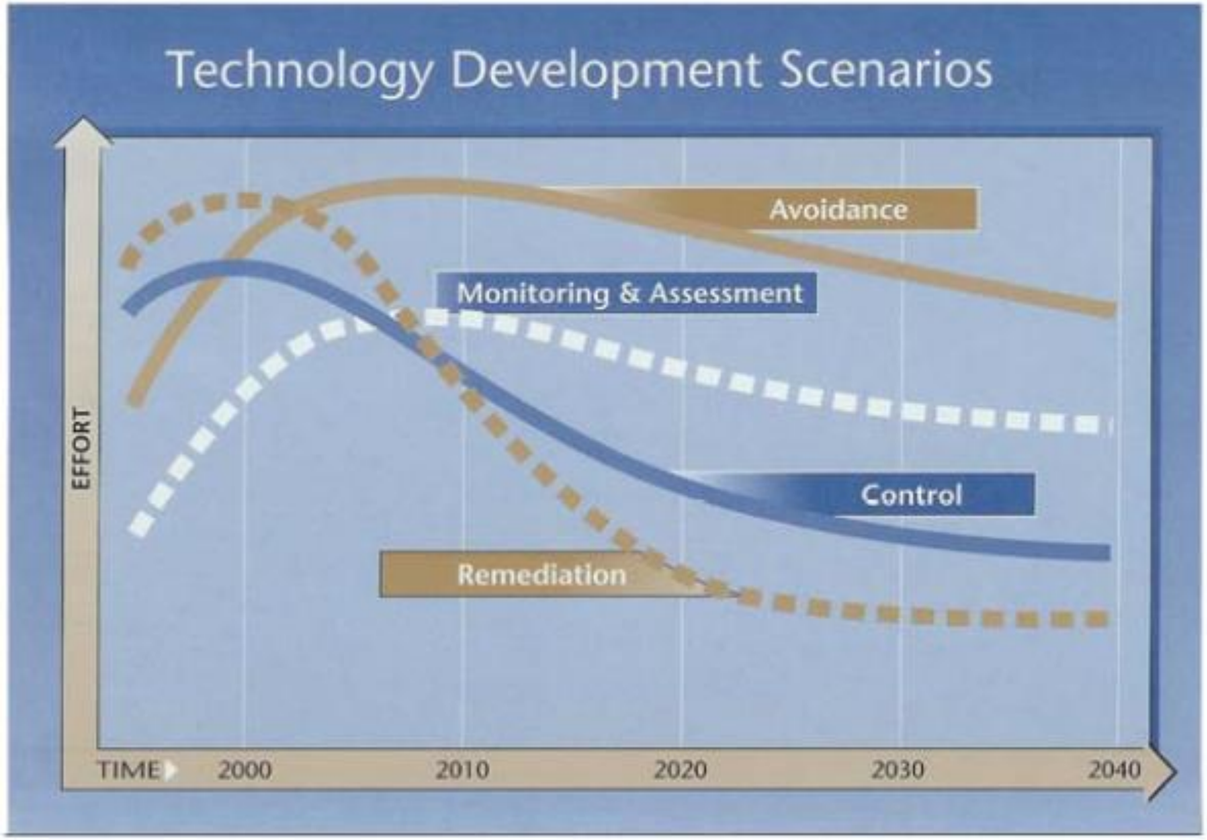
Conventional Engineering	Sustainable Engineering
Consider "Object"	Consider "System"
Focuses on technical issues	Integrated technical issues & non-technical issues
Solve the immediate problem (Now)	Solve problem for the indefinite future
Considers the local context (User)	Consider the global context (Planet)
Assumes others will deal with politics, ethics & societal issues	Acknowledges the needs for engineers to interacts with experts in other disciplines related to the problem

Sustainable Engineering

- Stage of sustainable solution

Sustainable Engineering

- Control



Sustainable Engineering

- Definition
  - There is no fixed definition
  - The 12 principles of Green Engineering

    [Anastas & Zimmerman, Environmental Science & Technology, 2003]
  - The process of using energy and resources at a rate that does not compromise the natural environment or the ability of future generations to meet their own needs

    [*Wikipedia*]
  - What's your definition?

The 12 principles of Green Engineering

- Anastas & Zimmerman
  - 1. Apply green chemistry
  - 2. Prevent rather than treat consequences
  - 3. Design for separation
  - 4. Maximize mass, energy, space and time efficiency
  - 5. “out-pulled” rather than “input-pushed”
  - 6. View complexity as an investment rather than a complication
  - 7. Durability than obsolescence
  - 8. Meet need without excess
  - 9. Minimize material diversity
  - 10. Integrate local material and energy flows
  - 11. design for commercial “after-life”
  - 12. Renewable and readily available

Example : Tire design

Wall Street Journal, 10 September 2008, page A1

Conventional Engineering :
"Functionality"
-"Resists sand abrasion and heat"

Sustainable Engineering :
"Functionality" + "Sustainability"
-"where will all the rubber for tire?"
- "where will tires go at the end of usage?"

Topics in Sustainable Engineering

- IJSE
  - Engineering design for sustainable development
  - Sustainable technology innovation
  - Life-cycle engineering
  - Energy conservation and low-carbon manufacturing
  - Sustainable power engineering and renewable energy technology
  - Waste minimization, remanufacturing, reuse and recycling technology
  - Sustainable material development
  - Sustainable packaging solution
  - Sustainable process engineering
  - Sustainable supply chain management
  - Sustainable transport engineering

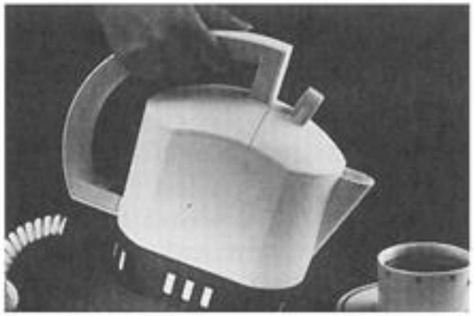
Tools for S.E.

- Some tools
  - Design for Environment (DfE)
  - Life-cycle Assessment (LCA)
  - Eco-industrial parks (EIPs)
  - Pollution Prevention (P2)
  - …….

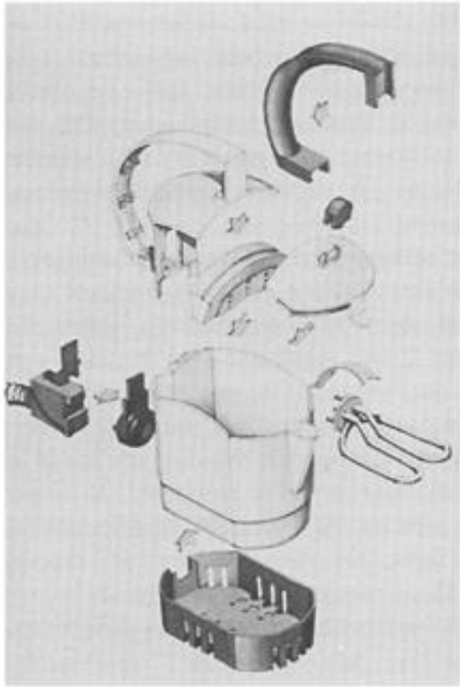
  - Industrial Engineering techniques → ?

DfE

- Design for Environment



Tea kettle designed for disassembly by Polymer Solutions, Inc., for Great British Kettles Ltd.
(From Graedel & Allenby, *Industrial Ecology*, 1995, page 270)



Consideration :

1. Less material
2. Less material variety
3. Recycled materials
4. Recyclable materials
5. Ease of disassembly
6. Less energy consumption
7. Longevity
8. modularity

LCA (1)

- Life-Cycle Assessment (3Steps approach)
  - Step 1. Define System / product boundaries
    - Determine product life, functional unit, system boundaries
  - Step 2. Make BOM
    - BOM
  - Step 3. Calculate estimate impacts
    - Calculate and compare impacts of the product's components

LCA (2)

- Button Vs. Zipper

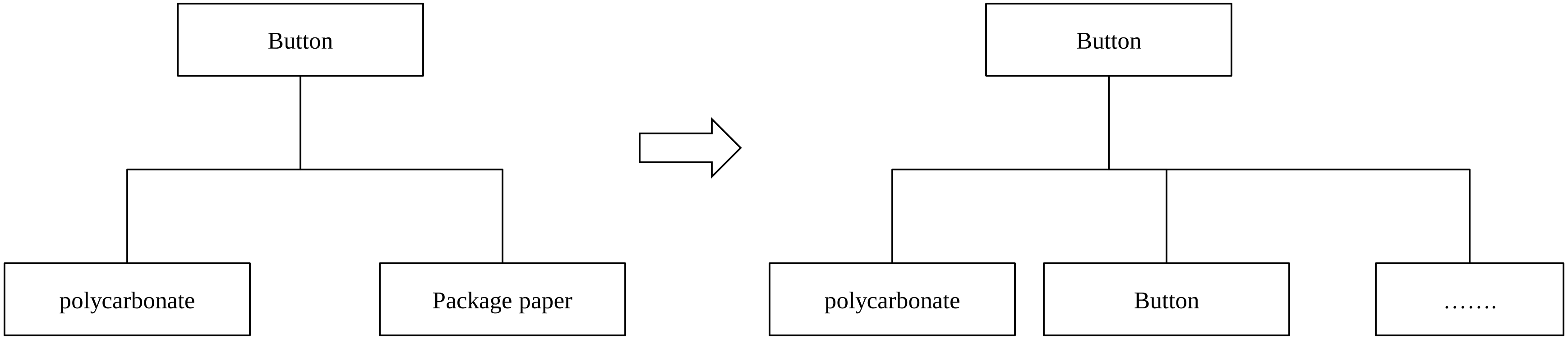
LCA (3)

- Button
  - Polycarbonate buttons used in a jacket (= 12 buttons)
  - Worn 150 hrs / yr
  - 6 years life

- Step 1 : System Boundaries
  - Life time → 150 hrs/yr * 6 yr = 900 hrs
  - Functional unit → impacts / 100 hrs worn

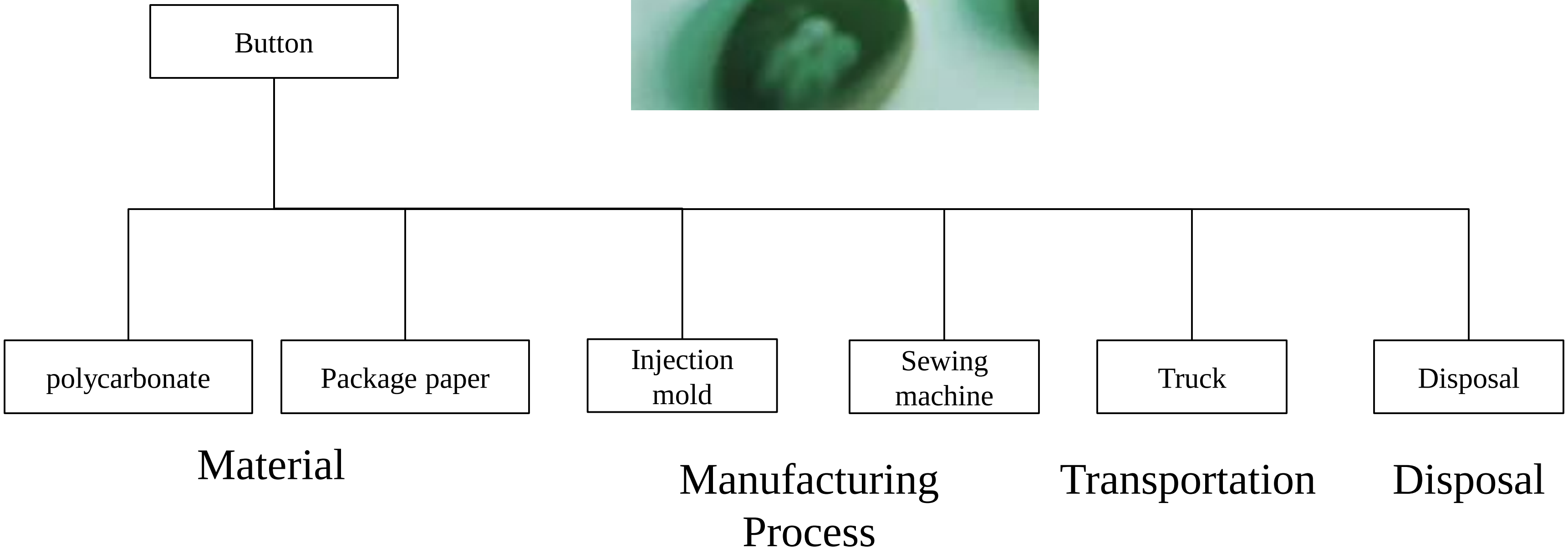
LCA (4)

- Step 2 : BOM
  - 12 plastic button



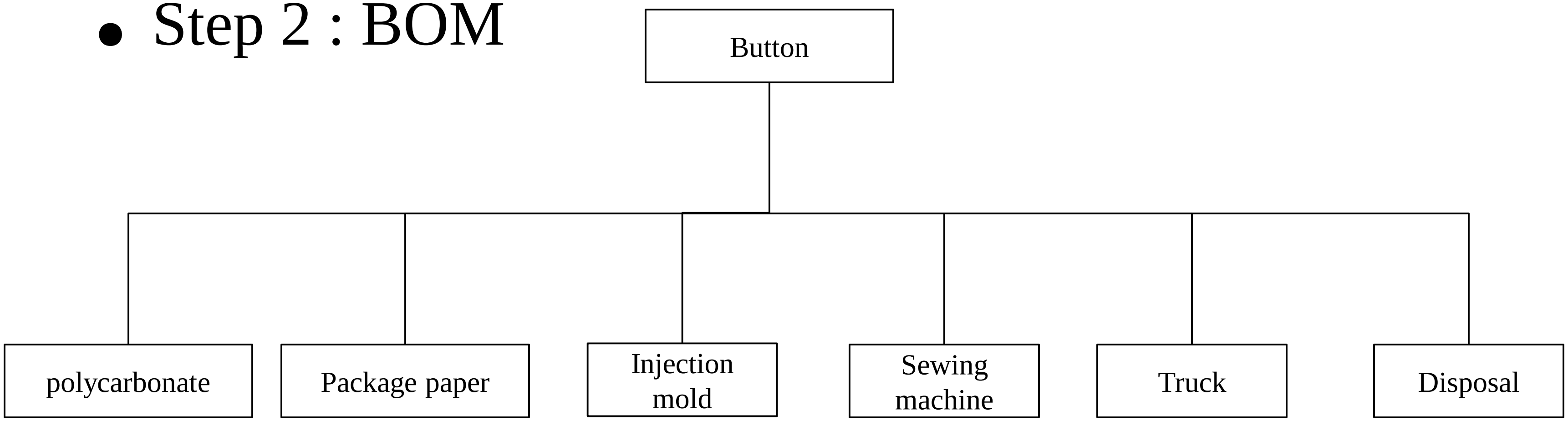
LCA (5)

- Step 2 : BOM
  - 12 plastic button



LCA (6)

- Step 2 : BOM



Weight	Weight	Weight	Electricity	Weight- Distance	Weight
0.05lb	0.025lb	0.05lb	0.042 kw-hr	0.056 ton-mi	N/A

120V * 5Amp / 1000 w/kw * 5 min / 60 min / hr

0.075lb * 1500 mi / 2000 lbs/ton

Charts of Okala millipoints

Material or Process	*Unit*	**Okala millipoints**	*Description*
POLYMERS			
ABS	lb.	47	acrylonitrile butadiene styrene
HDPE polythylene	lb.	25	high density
HDPE polythylene secondary	lb.	13	high density, 100% recycled
LDPE$_7$ polythylene	lb.	36	low density film
LDPE$_7$ polythylene secondary	lb.	35	low density film, 100% recycled
PET bottle grade	lb.	82	polytethylene terephthalate
PET bottle grade secondary	lb.	50	polytethylene t., 100% recycled
EPS expanded polystyrene	lb.	62	foam (packing material)
EPS secondary	lb.	50	100% recycled
HIPS high impact polystyrene	lb.	40	
HIPS secondary	lb.	30	100% recycled
PS polystyrene secondary	lb.	24	general purpose 100% recycled
PS polystyrene	lb.	40	general purpose
PA polyamide, nylon	lb.	99	6.6, no glass fibers
PC polycarbonate	lb.	180	
PP polypropylene	lb.	58	
PP polypropylene secondary	lb.	49	100% recycled, from bottle caps
PVC flexible polyvinyl chloride	lb.	41	with plasticizer, no stabilizer
PVC rigid polyvinyl chloride	lb.	33	pipes, without additives
pvdC, teflon	lb.	160	polyvinylidene chloride
PUR flexible polyurethane	lb.	270	cushion foam, pentane blown
PUR rigid polyurethane	lb.	340	foam insulation or in dashboards
natural rubber	lb.	avoid	uncertified tropical
natural rubber certified	lb.	6.4	certified sustainable
EPDM elastomer	lb.	140	ethylene propylene terpolymer
SBR elastomer	lb.	35	styrene butadiene rubber
SAN elastomer	lb.	45	styrene acrylonitrile
POLYMER FORMING			
blow extrusion, PE film	lb.	0.77	in addition to production
blow mold	lb.	9.9	from HDPE milk bottles
extrusion	lb.	3.7	from extrusion of HDPE pipe
injection mold, most plastics	lb.	11	in addition to production
injection mold PET	lb.	2.1	in addition to production
thermoform (vacuum)	lb.	4.4	from sheet PVC form
METALS			
cast iron, grey	lb.	18	
steel	lb.	29	typical steel (20% recycled)
steel, secondary	lb.	20	100% recycled
stainless steel	lb.	130	X10CrNiMoNb, typical
aluminum	lb.	140	
aluminum	lb.	24	from cans, 100% recycled
chromium	lb.	720	
copper	lb.	160	40% recycled typical
lead	lb.	670	50% recycled typical
magnesium	lb.	98	
nickel	lb.	300	
palladium	lb.	530,000	
platinum	lb.	1,100,000	
tin	lb.	54	
zinc	lb.	81	
METAL PROCESSING			
aluminum extrusion	lb.	26	energy required
aluminum continuous weld	ft.	120	joining 2 aluminum plates
aluminum MIG arc welding	ft.	70	per 6 mm butt-weld, sans emissions
aluminum machining	lb.	1.7	energy required
aluminum anodizing	ft^2	6.9	
steel machining	lb.	1.2	per lb. removed
steel deep drawing, cold	lb.	1.4	exclude non-deformed parts
steel cutting	in^2	0.036	per square inch cutting surface
steel turning	lb.	1.2	energy required
steel electrode welding	ft.	23	3 mm weld, energy required
brazing	lb.	230	cadmium free
chrome plating, electrolytic	ft^2	18	micron, doubled sided
nickel plating, electrolytic	ft^2	23	6 micron, double sided
zinc galvanizing, electrolytic	ft^2	22	per square foot, double sided
zinc coating	lb.	96	
OTHER MATERIALS			
brown cardboard	lb.	14	corrugated, wood fiber, sulphates
cardboard secondary	lb.	9	100% recycled, wood
white paper	lb.	27	sulphates, wood fiber, bleached
white paper secondary	lb.	12	100% recycled, wood, bleached
glass clear	lb.	9.8	
glass clear secondary	lb.	6.9	100% recycled
ceramic, porcelain	lb.	3.1	for bathroom fixtures
concrete, not reinforced	lb.	2.6	includes sand
cement, portland ash	lb.	3.8	
sand	lb.	0.18	
plywood, pine	lb.	16	urea formaldehyde bond
pine, solid	lb.	5.5	
oak, solid	lb.	11	
tropical wood	lb.	avoid	avoid unless certified sustainable
paint, oil based	lb.	280	liquid (not dry) weight
varnish, alkyd	lb.	78	liquid (not dry) weight
carbon black	lb.	40	common black pigment
gasoline, unleaded	gal.	59	pre-combustion
fuel oil	gal.	69	pre-combustion

LCA (7)

- Calculate button impacts

Input	Amount	x	Factor (millipoints/unit)	=	Impact (millipoints)
Polycarbonate	0.050 lb.		180 /lb.		9.00
Paper	0.025 lb.		27 /lb.		0.68
total weight	0.075 lb.				
Injection Molding	0.050 lb.		11 /lb.		0.55
Electricity: Sewing	0.050 kW-Hr		20 /kW-Hr		1.00
Transport: Truck	0.056 ton-mi.		9.7 /ton-mi.		0.55
Landfill:					
PC	0.050 lb.		1.6 /lb.		0.08
Paper	0.025 lb.		5.3 /lb.		0.13
			Total Impacts/Life		11.99

$$\text{Button impacts} \times \frac{\text{Functional time}}{\text{Lifetime}} = \mathbf{11.99} \times \frac{100\text{ hr}}{900\text{ hr}} = 1.33$$

$$= \frac{\mathbf{1.33\ millipoints}}{\mathbf{100\ hours\ worn}}$$

LCA (8)

- Zipper

- Step 1: Lifetime, functional unit, system boundary
  - Functional Unit: 190 hr/yr x 4 yrs = 760 hrs
  - Functional unit: impacts/100 hrs worn
  - System boundary: excludes jacket, thread, washing
- Step 2: Bill of materials
  - Materials:
    - zinc (0.025 lb), copper (0.043 lb), cotton tape (0.044 lb), package paper (0.039 lb)
  - Manufacturing: metal machining (0.068 lb)
  - Electricity: sewing (120 V x 5 A ÷ 1000 W/kW x 0.05 hr = 0.03 kW-hr)
  - Transport: truck (0.151 lb x 1500 mi ÷ 2,000 lb/ton = 0.113 ton-mi)
  - Disposal: landfill

LCA (9)

- Zipper

Input	Amount	x	Factor	=	Impact
			millipoints/unit		millipoints
zinc	0.025 lb.		81 /lb.		2.03
copper	0.043 lb.		160 /lb.		6.88
cotton	0.044 lb.		140 /lb.		6.16
paper	0.039 lb.		27 /lb.		1.05
total weight	0.151 lb.				
Metal machining	0.068 lb.		1.2 /lb.		0.08
Electricity: Sewing	0.030 kW-Hr		20 /kW-Hr		0.60
Transport: Truck	0.113 ton-mi.		9.7 /ton-mi.		1.10
Landfill:					
zinc	0.025 lb.		0.25 /lb. (est.)		0.01
copper	0.043 lb.		0.25 /lb. (est.)		0.01
cotton	0.044 lb.		0 /lb. (est.)		0.00
paper	0.039 lb.		5.3 /lb.		0.21
			Total Impacts/Life		18.13
functional unit time	100 hrs		lifetime (hrs) 760		2.39

Example of the LCA process

BUTTONS

ZIPPER

We compare the impacts of 12 buttons verses a zipper on a jacket to demonstrate how the assessments are performed.

STEP 1 > Define lifetime, functional unit & system boundary

The jacket with the zipper is worn more often, and it wears out faster.

	Buttons		Zipper
Lifetime Buttons	150hr/yr x 6yr = 900hr	**Lifetime Zipper**	190hr/yr x 4yr = 760hr
Functional unit	impacts/100 hrs worn	**Functional unit**	ditto
System boundary	excludes jacket, thread, washing	**System boundary**	ditto

STEP 2 > Make bill-of-materials

Next compile the bill-of-materials for the fasteners:

PLASTIC BUTTONS

Materials	polycarbonate(PC)	0.050 lb
	package paper	0.025 lb
Manufacturing	injection mold	0.050 lb
Electricity	sewing machine	0.042 kw-hr
Transport	truck	0.067 ton-mi
Disposal	landfill	

BRASS* ZIPPER

Materials	zinc	0.025 lb
	copper	0.043 lb
	cotton tape	0.044 lb
	package paper	0.039 lb
Manufacturing	machining	0.068 lb
Electricity	sewing machine	0.063 kw-hr
Transport	truck	0.103 ton-mi
Disposal	landfill	

*Brass is made of 63% copper, 37% zinc

STEP 3 > Calculate estimated impacts

INPUT	AMOUNT X	OKALA03 FACTOR =	IMPACTS (Okala03 millipoints)
PC	0.050 lb	180/lb	9.00
paper	0.025 lb	27/lb	0.68
inj. mold	0.050 lb	11/lb	0.57
sewing	0.042 kw-hr	20/kw-hr	0.83
truck	0.067 ton-mi	9.7/t.-mi	0.65
landfill PC	0.050 lb	1.6/lb	0.08
landfill paper	0.025 lb	5.3/lb	0.13

TOTAL IMPACTS/LIFE BUTTONS: 11.94

INPUT	AMOUNT X	OKALA03 FACTOR =	IMPACTS (Okala03 millipoints)
zinc	0.025 lb	81/lb	4.05
copper	0.043 lb	160/lb	6.88
cotton	0.044 lb	140/lb	6.18
paper	0.039 lb	27/lb	1.05
machine	0.068 lb	1.2/lb	0.08
sewing	0.026 kw-hr	20/kw-hr	0.52
truck	0.103 ton-mi.	9.7/t. -mi	0.99
landfill zinc	0.025 lb	0.25/lb (est.)	0.006
landfill copper	0.043 lb	0.25/lb (est.)	0.01
landfill paper	0.039 lb	5.3/lb	0.21

TOTAL IMPACTS/LIFE ZIPPER: 19.976

Next, we calculate the impacts per functional unit and round to two significant figures:

$$\text{button impacts} \times \frac{\text{functional unit time}}{\text{lifetime}} = 11.94 \times \frac{100\text{ hr}}{900\text{ hr}} = 1.3267 = \frac{\textbf{1.3 Okala03 millipoints}}{\text{100 hours buttons are worn}}$$

$$\text{zipper impacts} \times \frac{\text{functional unit time}}{\text{lifetime}} = 19.976 \times \frac{100\text{ hr}}{760\text{ hr}} = 2.6284 = \frac{\textbf{2.6 Okala03 millipoints}}{\text{100 hours zipper is worn}}$$

Another example (1)

- Which is better?

Metal Utensils

Plastic Utensils

Biodegradable Utensils

Another example (2)

- Spoon case
    - Metal: 0.25 millipoints/use
    - Plastic: ~0.94 millipoints/use
    - Biodegradable: 0.86 millipoints/use

Metal WINS!!

LCA (10)

- Conclusion
- Problem
  - Criteria → 1
  - If multi-criteria exist
    - Environmental impact
    - Functionality
    - Design

Next Week

- What we discussed
  - Sustainable engineering
  - DfE / LCA

- What we will discuss
  - Multi-criteria Decision making for MSE
  - Modeling & Simulation
  - Semi-conductor Manufacturing Systems