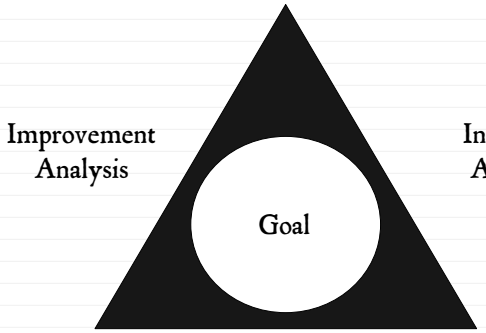
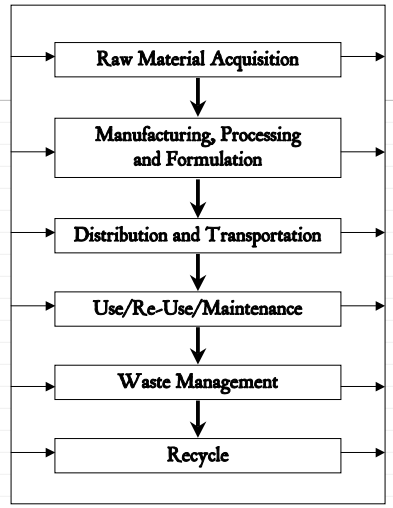
Valuation of Life Cycle Inventories
The EPS System

ESD.123; 2006

Life Cycle Analysis: Three stage Process
SETAC Life Cycle Framework





Inputs

Raw Materials

Energy

Outputs

Airborne Emissions

Water Effluents

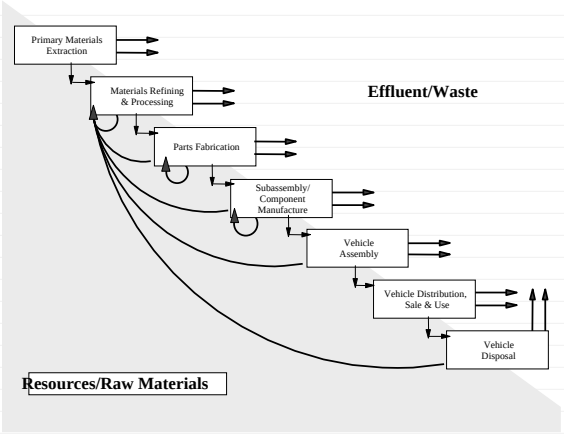
Other Environmental Releases

Usable Products

Solid Wastes

Life Cycle Inventory

Complex When Dealing With A Real Problem



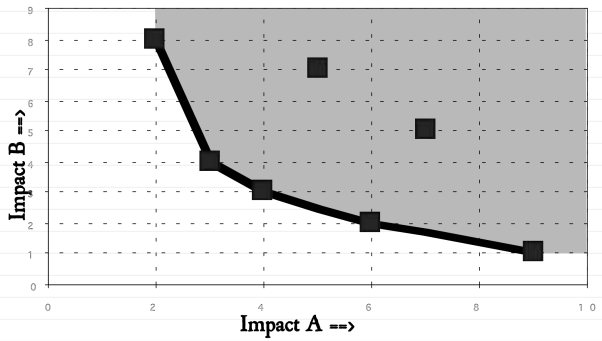
Inventory Analysis Goals

- To Establish Baseline Information for Specific Products or Activities
- To Rank the Relative Contributions from Specific Stages in Life Cycle
- To Understand Relative Environmental Burdens of Competing Products or Activities
- To Use as Guide for :
  - Process and Product Evaluation by Designers
  - Information and Assessment for Consumers
  - Guidelines and Indications for Government
- Issue of Valuation for Improvement Analysis

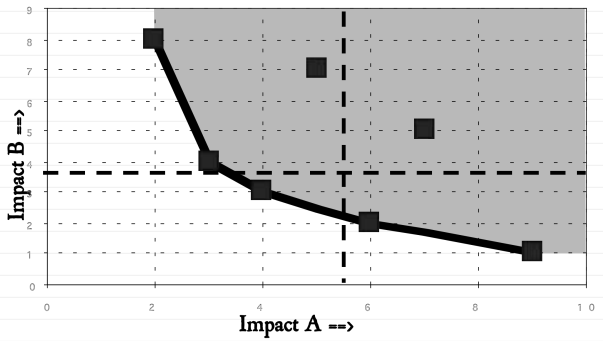
Improvement Analysis

- Based on Pertinent Metrics, Make Decisions to Improve Environment
- How to Decide Between Two "Evils:"
  - Product A, w/ 1,000 kg of CO_2 emissions? => Global Warming
  - Product B, w/ 3,000 kg of CO_2 emissions? => Global Warming
  - Product C, w/ 1,000 kg of SO_2 emissions => Acid Rain
- Valuation: Balance of Trade-Offs Between
  - Environmental
  - Economic
  - Technological / Engineering

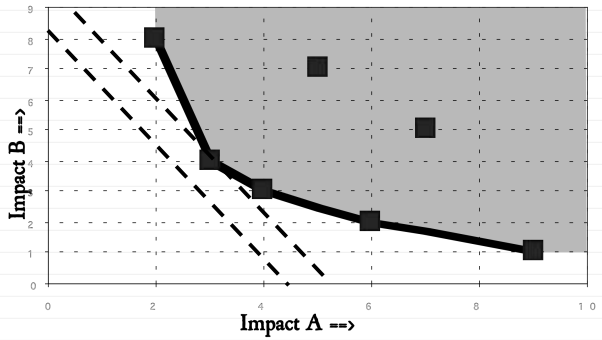
Improvement Analysis & Valuation



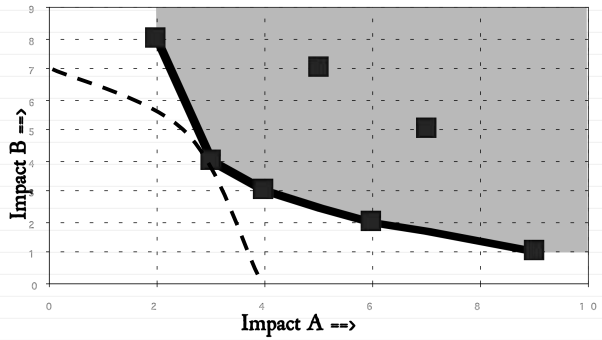
Screening



Indexing



More Complex Valuations



Impact Assessment

- Attempt to describe environmental consequences of the activity being studied
  - Accomplished by translating inventory into consequence (or impact)
- Aggregation of inventory information into fewer metrics
- Mechanics complex (and controversial)

Issues - 1

- Translating "emissions" into "impact"
  - CO_2 release → increased thermal absorption
    → raises terrestrial temperature
  - So what?
    higher temps → increase desertification
    → increase glacial melting
    → increase ocean temperature
    → ...
- Cause and effect chains; necessary, but lengthy
  - Recall issues of scoping in inventory, leading to....

Issues - 2

- Which effects to track?
- ISO establishes 3 broad categories of concern
  - Resource use
  - Human health
  - Ecological consequences
- Objections
  - Complete list?
  - Double counting?

Impact Assessment

- Impact category definition
  - Which impacts are of concern
  - How to go from emissions to impacts
- Classification
  - Categorize impacts according to key environmental stressors (e.g. "global warming potential," etc.
- Characterization (or quantification)
  - What's the size of the impact?
- Valuation
  - Rank or aggregate for comparative assessment

Lots of approaches

- In the end, all trying to do the same thing

  inventory of emissions → consequences of emissions

- Do it yourself?

- Or rely on others to do it for you.....

Environmental Priorities Strategy: EPS

- System Objectives
  - Introduce Environmentally Sound Product Development
  - Establish Common Database for Life Cycle Inventories
  - Develop PC-Based Tools for Eco- Product Design
  - Delineate Environmental Effects throughout Product Life
  - Inform & Educate Industrial Target Groups

Features of Environmental Priority Strategies

- Based on Swedish Parliament's Safeguard Subjects:
  - Biodiversity
  - Production (reproduction of biological organisms)
  - Human Health
  - Resources
  - Aesthetics
- "Environmental Burden" Determined For Activities & Processes

Features of Environmental Priority Strategies

- System Designed to Allow "Objective" Decisionmaking
- Monetization Reduces Complex Data To One Numerical Value
- "Environmental Load" Assigned To Each Resource, Emission & Activity On A Per Unit Mass Basis
- Load Applied For Each Element Of LCA Inventory & Summed

Institutional Features of EPS

- Scientific Analysis of Effects of Emissions
  - Done at Chalmers Institute
- Inventory Work To Be Done By Individual Firms
- Values From Various Sources

EPS Basic Principle

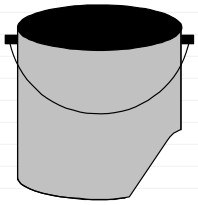
Environmental Load Index x Quantity = Environmental Load Value

Units for ELI: Environmental Load Units / quantity
= ELU / kg or ELU/part or ELU/ m^2

Units for ELV: Environmental Load Units
= ELU

Case I: Polypropene Bucket

- Weight: 0.7 kg
- Material: Polypropene
  - Environmental Load Index: 0.68 ELU / kg
- Process: Injection Molding
  - Environmental Load Index: 0.08 ELU / kg



EPS Calculation of ELV for Bucket

Materials & Processes	ELV = ELI * Quantity
Material: Polypropene	0.68 ELU/kg * **0.7 kg** = 0.48 ELU
Process: Injection Molding	0.08 ELU/kg * **0.7 kg** = 0.06 ELU
Total Environmental Load Value:	0.48 ELU + 0.06 ELU = 0.54 ELU

Defined Safeguard Subjects

- Biodiversity
- Human Health
- Production
- Resources
- Aesthetic Values

"Unit Effects" for Safeguard Subjects

- Human Health: Unit Effects for CO_2
  - Excess mortality due to increased temperature in tropics
  - Temperature increase leads to flooding and therefore accidental deaths
  - Global warming leads to increased desertifcation; less food; more starvation

"Value Factors" for Unit Effects

- F_1 Relative Cost to Reduce 1 kg Emission
- F_2 Extent of Affected Area
- F_3 Regularity of the Problem
- F_4 Duration of Effect
- F_5 Significance of 1 kg Substance wrt Total

EPS Valuation Bases -- 1995

Biodiversity			
Impact	ELU of impact	sd factor	Notes
Extinction of medium sized animals and plants	1.0E+15	10	10 ELU per person per year; 1E+09 persons; 1E+05 years
General and global impact on diodiversity	5.0E+11	5	100 ELU per person; 5E+09 persons

Biological Production			
Impact	ELU of impact	sd factor	Notes
1 kg of crop seed	0.2	2	economic value
1 kg of wood	0.025	2	economic value
1 kg of meat or fish	1	3	economic value
1 kg of fresh water	0.003	4	economic value in areas with water deficiency

EPS Valuation Bases - 1995 (continued)

Energy			
Impact	ELU per impact	sd factor	Notes
1 MJ renewable electrical	0.02	2	economic value
1 MJ renewable thermal	0.01	2	economic value

Human Health			
Impact	ELU per impact	sd factor	Notes
1 excess death	1,000,000	10	normalized from
1 man-yr painful morbidity	100,000	10	several studies
1 man-yr other morbidity	10,000	10	
1 man-yr severe nuisance	1,000	10	
1 man-yr moderate nuisance	100	10	

EPS Valuation Bases - 2000

1	**Impact Category - Human health**	**Category indicat**	**Indicator unit**	**Weighting facto** **Un**
1	Life expectancy	YOLL	Person-years	85000
2	Severe morbidity	Severe morbidity	Person-years	100000
3	Morbidity	Morbidity	Person-years	10000
4	Severe nuisance	Severe nuisance	Person-years	10000
5	Nuisance	Nuisance	Person-years	100
2	**Impact Category - Ecosystem proc**	**Category indicat**	**Indicator unit**	**Weighting facto** **Un**
1	Crop growth capacity	Crop	kg	0.15
2	Wood growth capacity	Wood	kg	0.04
3	Fish and meat production capacity	Fish and meat	kg	1
4	Soil acidification	Base cat-ion capa	mole H+ -equivale	0.01
5	Production capacity for irrigation wat	Irrigation water	kg	0.003
6	Production capacity for drinking wate	Drinking water	kg	0.03

EPS Valuation Bases - 2000

	Impact Category - Abiotic stock re	Category indicat	Indicator unit	Weighting facto	U
1	Depletion of oil reserves	Fossil oil	kg	0.506	
2	Depletion of coal reserves	Fossil coal	kg	0.0498	
3	Depletion of natural gas reserves	Natural gas	kg	1.1	
4	Depletion of Ag reserves	Ag reserves	kg of element	54000	
5	Depletion of Al reserves	Al reserves	kg of element	0.439	
6	Depletion of Ar reserves	Ar reserves	kg of element	0	
7	Depletion of As reserves	As reserves	kg of element	1490	
8	Depletion of Au reserves	Au reserves	kg of element	1190000	
9	Depletion of B reserves	B reserves	kg of element	0.05	
10	Depletion of Ba reserves	Ba reserves	kg of element	4.45	
11	Depletion of Bi reserves	Bi reserves	kg of element	24100	

EPS Valuation Bases - 2000

74	Depletion of Tm reserves	Tm reserves	kg of element	9900	
75	Depletion of U reserves	U reserves	kg of element	1190	
76	Depletion of V reserves	V reserves	kg of element	56	
77	Depletion of W reserves	W reserves	kg of element	2120	
78	Depletion of Y reserves	Y reserves	kg of element	143	
79	Depletion of Yb reserves	Yb reserves	kg of element	1980	
80	Depletion of Zn reserves	Zn reserves	kg of element	57.1	
81	Depletion of Zr reserves	Zr reserves	kg of element	12.5	
4	Impact Category - Biodiversity	Category indicat	Indicator unit	Weighting facto	Un
1	Species extinction	NEX	dimensionless	1.1E+11	

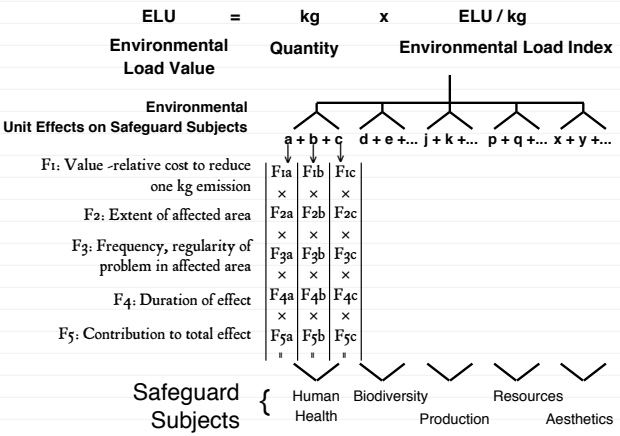
Environmental Load Index:

$$ELI = \sum_{k=1,5} \sum_{j=1,n} \prod_{i=1,5} F_{ijk}$$

k: safeguard subjects; j: unit effects; i: value factors

Units for ELI: Environmental Load Units / quantity
= ELU / kg or ELU/part or ELU/ m²

EPS Concept



EPS Estimated Emission Indices for CO_2 ELI

Substance	Activity	Safegd Subject	Unit Effect	Impact Type	F1 Cost	F2 Extent	F3 Frequency	F4 Duration	F5 Contribution	ELI (ELU/KG)
CO2	air emiss	Health	Death: heat	Temp.	1E+06	-3E+06	1	100	2.9E-16	-0.087
	air emiss	Health	Death: flood	Temp.	1E+06	1E+04	1	100	2.9E-16	0.00029
	air emiss	Health	Death: starv	Temp.	1E+06	1E+05	1	100	2.9E-16	0.0029
	air emiss	Health	Starvation	Temp.	1E+05	5E+07	1	100	2.9E-16	0.145
	air emiss	Biodiversity	Decrease	Temp.	5E+11	1	2	100	2.9E-16	0.029
	air emiss	Production	^ wood	Temp.	2.5E-02	-7.2E+10	1	100	2.9E-16	-0.0000522
	air emiss	Production	^ crops	Temp.	2E-01	-2.3E+11	1	100	2.9E-16	-0.001334
	air emission	Production	V crops	Temp.	2E-01	1.2E+10	1	100	2.9E-16	0.0000696
									ELI =	0.0888734

Estimated Emission Indices: 2000 CO_2 ELI

	A	B	C	D	E	F	G	H	I	J	K
1	CO2										
2	1	Human health	1	Life expectancy	YOLL	85000	5.90E+06	100	1.26E-16	7.43E-08	6.32E-03
3	1	Human health	1	Life expectancy	YOLL	85000	5.40E+09	1	1.26E-16	6.80E-07	5.78E-02
4	1	Human health	1	Life expectancy	YOLL	85000	4.50E+07	1	1.26E-16	5.67E-09	4.82E-04
5	1	Human health	1	Life expectancy	YOLL	85000	2.63E+06	100	1.26E-16	3.31E-08	2.81E-03
6	1	Human health	2	Severe morbidi	Severe r	100000	2.50E+09	1	1.26E-16	3.15E-07	3.15E-02
7	1	Human health	2	Severe morbidi	Severe r	100000	3.00E+08	1	1.26E-16	3.78E-08	3.78E-03
8	1	Human health	3	Morbidity	Morbidity	10000	2.50E+09	1	1.26E-16	3.15E-07	3.15E-03
9	1	Human health	3	Morbidity	Morbidity	10000	2.70E+09	1	1.26E-16	3.40E-07	3.40E-03
10	2	Ecosystem product	1	Crop growth ca	Crop	0.15	6.00E+12	1	1.26E-16	7.56E-04	1.13E-04
11	2	Ecosystem product	2	Wood growth c	Wood	0.04	-9.20E+12	1	1.26E-16	-1.16E-03	-4.64E-05
12	2	Ecosystem product	2	Wood growth c	Wood	0.04	-3.12E+12	100	1.26E-16	-3.93E-02	-1.57E-03
13	4	Biodiversity	1	Species extinct	NEX	1E+11	1.00E+00	100	1.26E-16	1.26E-14	1.39E-03
14											1.09E-01 /kg

ELU s for Processes

For Process: ELU = {ELI} * {Inventory} * {Quantity}

- Matrix Multiplication
  - –ELI Dimensions: 1 x n
    - –*With n emissions, resources used*
  - –Inventory Dimensions: n x m
    - –*With m subprocesses represented*
  - –Quantity dimension - Scalar
    - –*Input by User*

Summing Subprocesses: ELU(process) = Σ ELU(subs)

Environmental Load Value For Steel Grill Opening Panel

Material/ Product	Process/ Activity	Environmental Load Unit	Quantity	Environmental Load Value
Production Galv. Steel	Manufact	0.98 ELU/kg	9.0 kg	8.82 ELU
	Stamping	0.06 ELU/kg	9.0 kg	0.54 ELU
	SpotWeld	0.004 ELU/spot	48 spots	0.19 ELU
	Painting	0.01 ELU/m^2	0.6 m^2	0.01 ELU
Steel Scrap	Recycled Material	-0.92 ELU/kg	3.0 kg	-2.76 ELU
Product Use Fuel /Petrol	Manufact/ Combustion	0.82 ELU/kg	48 kg	39.36 ELU
Disposal Galv. Steel	Material	-0.92 ELU/kg	6.0 kg	-5.53 ELU
			TOTAL:	**40.64 ELU**

Environmental Load Value: GMT Composite Grill Panel

Material/ Product	Process/ Activity	Environmental Load Unit	Quantity	Environmental Load Value
Production				
GMT- Comp	Manufact	0.58 ELU/kg	4.0 kg	2.32 ELU
	Pressing	0.03 ELU/kg	4.0 kg	0.12 ELU
	Painting			
GMT- Comp	Recycld Matl	-0.58 ELU/kg	0.3 kg	-0.17 ELU
Product Use				
Fuel /Petrol	Manufact/ Combustion	0.82 ELU/kg	29.6 kg	24.27 ELU
Disposal				
GMT- Comp	Energy Reuse	-0.21 ELU/kg	3.7 kg	-0.78 ELU
			TOTAL:	**25.76 ELU**

Limitations of EPS

- Monetary Value of Each Resource and Emission Determined By:
  - Market Prices
  - Government Allocations
  - Contingent Valuation
- Money As A Measure of Value
  - Implies Construction of Linear Value Function
  - Each Unit Effect Adds Linearly to Final ELI
    - *Independent of Size of Each Unit Effect*

Basic Valuations - EPS

ELI-96.WK1

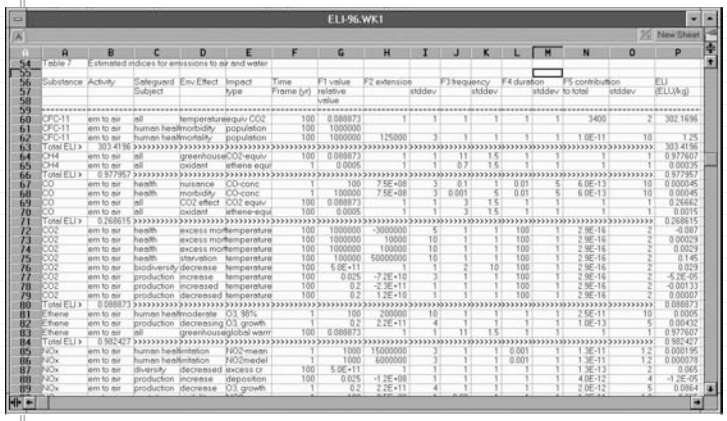
	A	B	C	D	E	F	G	H	I
1	Valuations		Valuations set up withing the EPS system - propagating throughout						
2									
3	Biodiversity	Impact			ELU		sdNotes		
4			Extinction of medium		1.0E+15		10 10 ELU / person / yr		
5			sized animals and plants				1E+09 persons, 1E+05 years		
6									
7			General and global		5.0E+11		5 100 ELU / person		
8			impact on biodiversity				5+E09 persons		
9									
10	Production	Impact			ELU		sdNotes		
11			1 kg crop seed		0.2		2		
12			1 kg of meat or fish		1		3 economic value		
13			1 kg of wood		0.025		2		
14			1 kg of freshwater		0.003		4 in areas with water deficiency		
15									
16	Energy	Impact			ELU		sdNotes		
17			1 MJ renewable electrical		0.02		2		
18			1 MJ renewable thermal		0.01		2		
19									
20	Health	Impact			ELU		sdNotes		
21			1 excess death		1000000		10 normalized		
22			1 man-yr painful morbidity		100000		10		
23			1 man-yr other morbidity		10000		10		
24			1 man-yr severe nuisance		1000		10		
25			1 man-yr moderate nuisan		100		10		
26									

Resource Consumption ELI Table

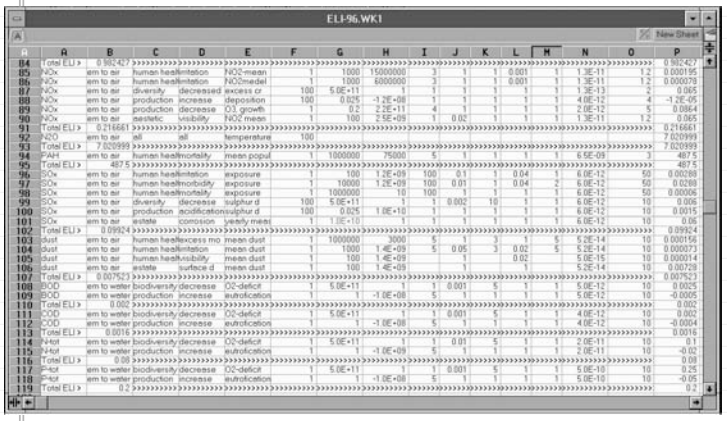
ELI-96.WK1

	A	B	C	D	E	F	G	H	I	J	K
28	Table 6	Estimated indices for fossil fuel and metal resources									
29			Safeguard	Environmental		Value of					
30	Activity		Subject	Effect	Impact	effect-ELU	Extension	stddev	Contributionstddev		Index
31											
32	Fossil gas	restauring	estate	all	Land use						0.4
33	Oil	restauring	estate	all	Land use	0.2	2	1.5	1	1	0.4
34	Coal	restauring	estate	all	Land use	0.025	4	1.5	1	1	0.1
35											
36	Ag	Alternative	resource	all	all	0.025	875000	2	1	1	21875
37	Al	Alternative	resource	all	all	0.025	3.571429	2	1	1	0.089286
38	Au	Alternative	resource	all	all	0.025	35000000	2	1	1	875000
39	Co	Alternative	resource	all	all	0.025	3043.478	2	1	1	76.08695
40	Cr	Alternative	resource	all	all	0.025	350	2	1	1	8.75
41	Cu	Alternative	resource	all	all	0.025	1206.897	2	1	1	30.17243
42	Fe	Alternative	resource	all	all	0.025	3.5	2	1	1	0.0875
43	Mn	Alternative	resource	all	all	0.025	38.88889	2	1	1	0.972222
44	Mo	Alternative	resource	all	all	0.025	58333.33	2	1	1	1458.333
45	Ni	Alternative	resource	all	all	0.025	972.2222	2	1	1	24.30556
46	Pb	Alternative	resource	all	all	0.025	7000	2	1	1	175
47	Pt	Alternative	resource	all	all	0.025	14000000	2	1	1	350000
48	Rh	Alternative	resource	all	all	0.025	70000000	2	1	1	1750000
49	Sn	Alternative	resource	all	all	0.025	46666.67	2	1	1	1166.667
50	Ti	Alternative	resource	all	all	0.025	15.90909	2	1	1	0.397727
51	V	Alternative	resource	all	all	0.025	466.6667	2	1	1	11.66667
52	Zn	Alternative	resource	all	all	0.025	853.6585	2	1	1	21.34146
53											

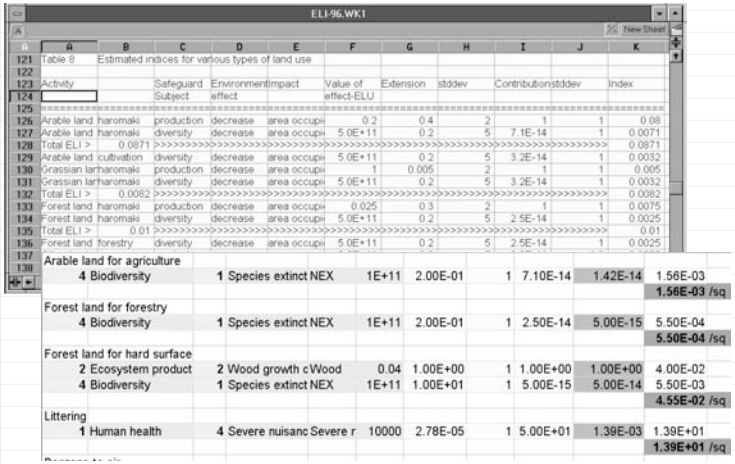
Air and Water ELIs (part 1)



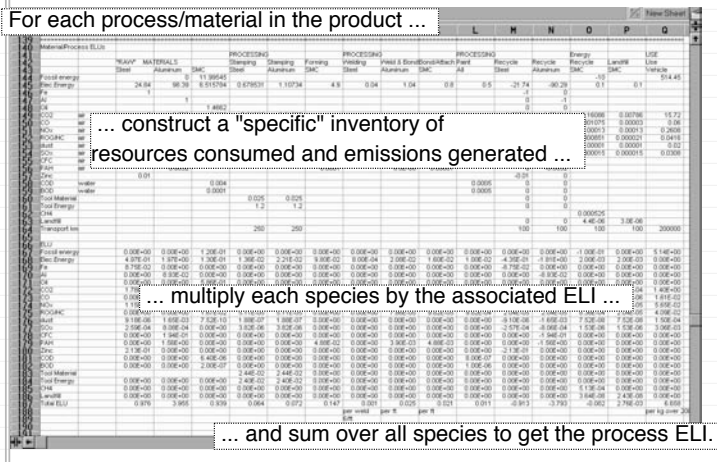
Air and Water ELIs (part 2)



Land ELIs



Using EPS - Step 1 & 2



Using EPS - Step 3 (or 1): Describe The Process Steps For Each Alternative

ELI-96.WK1

	W	X	Y	Z	AA	AB	AC	AD	AE
1	Example Comparison								
2									
3									
4				Material	ELI				
5			Process	Affected	Value	Units			
6		Raw Matls	Extract/Refine	Steel	0.976	ELU/kg			
7		|	Extract/Refine	Al	3.955	ELU/kg			
8		|	Extract/Refine	SMC	0.939	ELU/kg			
9		Manufacture	Stamping	Steel	0.064	ELU/kg			
10		|	Stamping	Al	0.072	ELU/kg			
11		|	Forming	SMC	0.147	ELU/kg			
12		|	Welding	Steel	0.001	ELU/weld	(6 welds/ft)		
13		|	Weld & Bond	Al	0.025	ELU/ft			
14		|	Bond/Attach	SMC	0.021	ELU/ft			
15		|	Paint	All	0.011	ELU/m2			
16		Disposal	Recycle	Steel	-0.913	ELU/kg			
17		|	Recycle	Aluminium	-3.793	ELU/kg			
18		|	Recycle	SMC	-0.082	ELU/kg			
19		|	Landfill	SMC	2.76E-03	ELU/kg			
20		Use	Use	Vehicle	6.658	ELU/kg vehicle transported 200,000 km			
21									
22									

Using EPS - Final Comparison

Find the mass of material used in each step (or the relevant rate of use) ...

... multiply by the process ELI ...

... and add to get the environmental loads.

	AB	AC	AD	AE
23	Steel Inner	SMC Inner	SMC Inner	
24	Steel Outer	Steel outer	Aluminum Outer	
25	Inner	6	6	6
26	Outer	10	10	6
27	Raw Matls Extract/Refine Steel			
28	| Extract/Refine Al			23.73
29	| Extract/Refine SMC		5.63	5.63
30	Manufacture Stamping Steel	1.15	0.64	
31	| Stamping Al			
32	| Forming SMC		0.88	
33	| Welding Steel	0.05		
34	| Weld & Bond Al			
35	| Bond/Attach SMC		0.21	0.21
36	| Paint All	0.01	0.01	0.01
37	Disposal Recycle Steel	-16.44	-9.13	
38	| Recycle Aluminum			-22.76
39	| Recycle SMC		-0.49	-0.49
40	| Landfill SMC		0.02	0.02
41	Use Use Vehicle	119.85	106.53	79.80
42				
43	Total	122.18	114.54	88.06
44	Net use	2.33	8.01	8.16
45	If incin	2.33	7.50	7.65