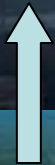


Intro to Life Cycle Analysis

2.83/2.813

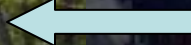
Manufacturing



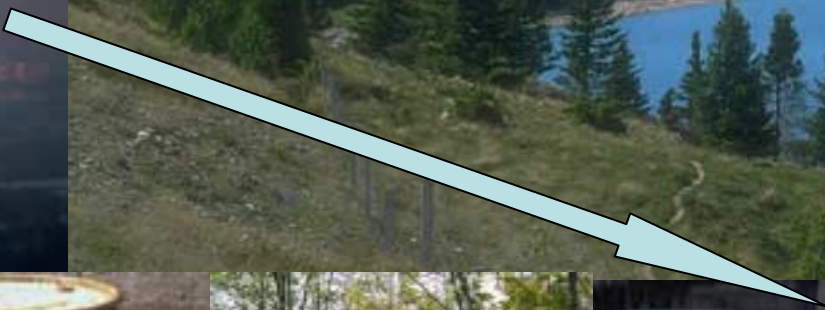
Mining



End of Life



Use Phase



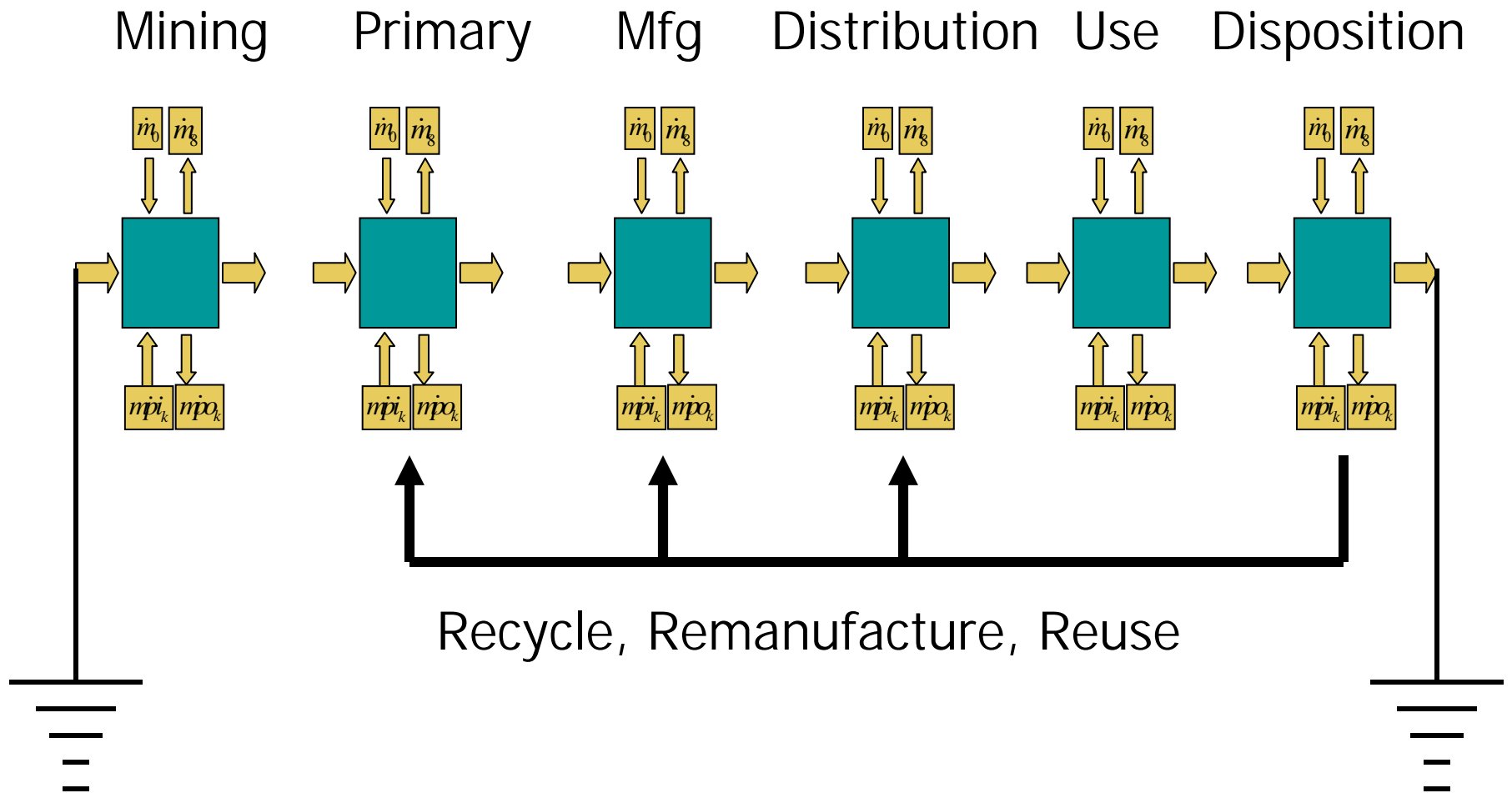
References

1. Allen and Shonnard, Ch 13 “*Life Cycle Concepts...*”
2. Hendrickson, Lave and Matthews, Chapters (1), 2, and 5, 6 & App. I
3. Leontief, Input/Output Economics, pp19 – 24 (handout)
4. CMU I/O Website: Environmental Input–Output LCA: <http://www.eiolca.net/>
5. Sullivan et al LCI of Family Sedan

Outline

1. Streamlined Life Cycle Analysis
2. Process Level LCA
3. Input/Output LCA
4. Case Study: Automobiles
5. Other Examples (critique)

Life Cycle Analysis



Life Cycle Inventory

- $LCA = LCI + \text{Impact Analysis}$
- i.e. counting the mercury emissions, and then accounting for their impact...
- Issues:
 - transport, exposure, sensitivity
 - aggregating impacts
 - weighting impacts

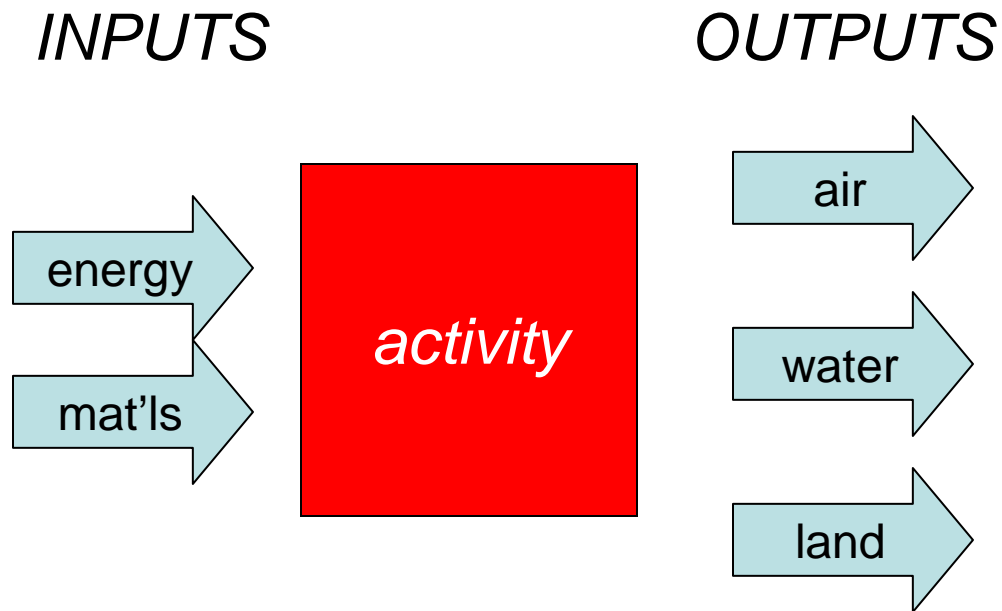
Life Cycle Perspective

- in theory boundaries start from earth as the **source**, and return to earth as the **sink**
- evaluation is often focused on a **product** or **service**
- tracking is of **materials**
- **time** stands still

Streamlined Life Cycle Assessment

- qualitative assessment
- value judgments by experts
- for each stage of the life cycle
- in broad categories of impact
- “first cut” at the problem
- See SLCA by T. Graedel 1998

Streamlined LCA



Issues:

- 1. qualitative Vs quantitative*
- 2. aggregation*

Evaluation Matrix for SLCA, M_{ij}

Life Cycle Stages	Materials Choice	Energy Use	Solid Residues	Liquid Residues	Gaseous Residues
<i>Extraction and Refining</i>	11	12	13	14	15
<i>Manufacturing</i>	21	22	23	24	25
<i>Product Delivery</i>	31	32	33	34	35
<i>Product Use</i>	41	42	43	44	45
<i>Refurbishment, Recycling, Disposal</i>	51	52	53	54	55

Scoring M_{21} (mat'ls used in mfg)

- $M_{21} = 0$ when product mfg requires relatively large amounts of restricted mat'ls (limited supply, toxic, radioactive) and alternatives are available.
- $M_{21} = 4$ when mat'ls used in mfg are completely closed loop and minimum inputs are required.

Automobile Example; Manufacturing Ratings 0-4 (best)

<i>Element Designation</i>		<i>Element Value & Explanation: 1950s Auto</i>		<i>Element Value & Explanation: 1990s Auto</i>	
<i>Matls. choice</i>	21	0	Chlorinated solvents, cyanide	3	Good materials choices, except for lead solder waste
<i>Energy use</i>	22	1	Energy use during manufacture is high	2	Energy use during manufacture is fairly high
<i>Solid residue</i>	23	2	Lots of metal scrap and packaging scrap produced	3	Some metal scrap and packaging scrap produced
<i>Liq. Residue</i>	24	2	Substantial liquid residues from cleaning and painting	3	Some liquid residues from cleaning and painting
<i>Gas residue</i>	25	1	Volatile hydrocarbons emitted from paint shop	3	Small amounts of volatile hydrocarbons emitted

taken from Graedel 1998

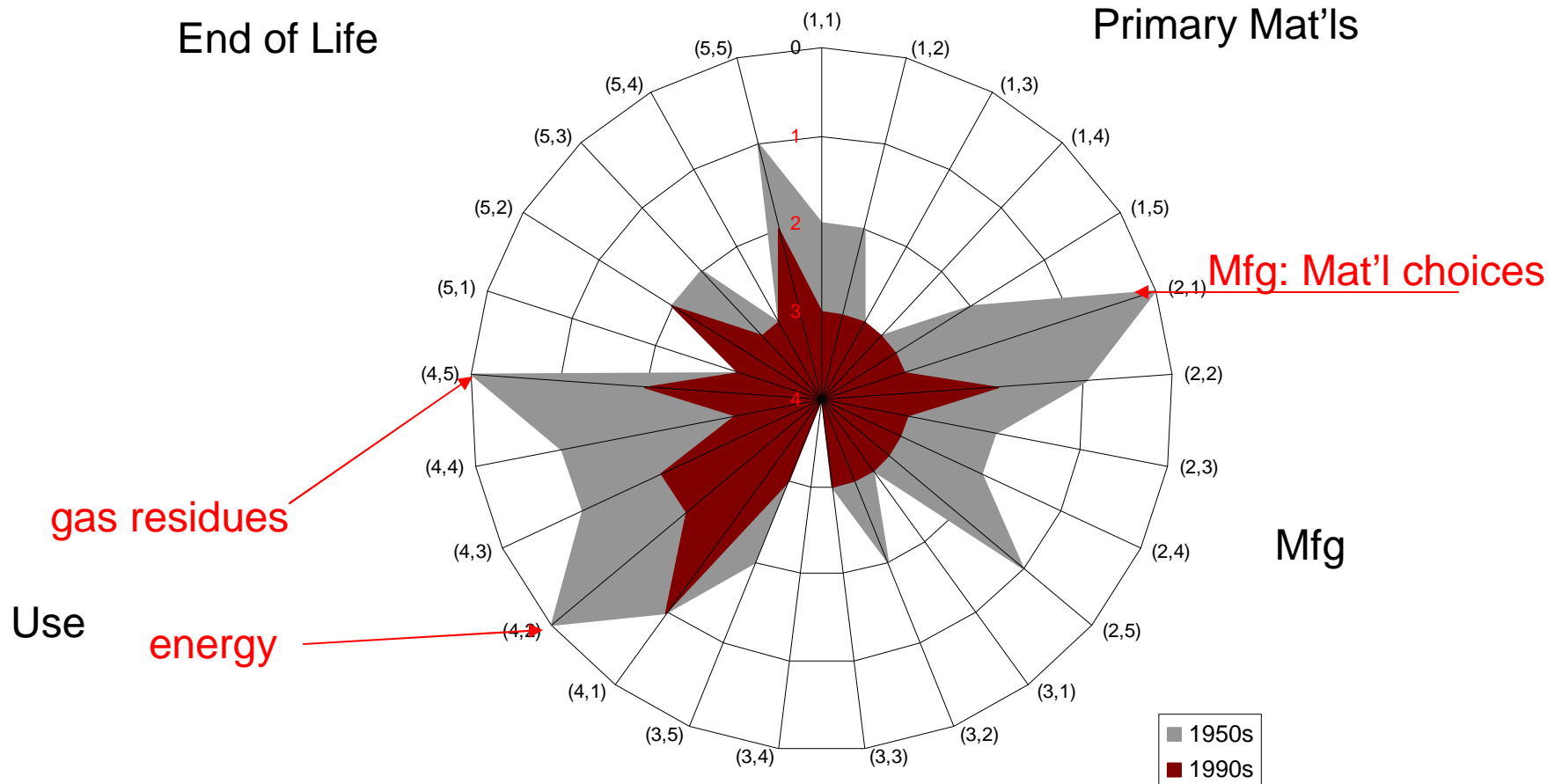
*Product Assessment Matrix for the
Generic 1950s Automobile [Graedel 1998]*

Life Cycle Stage	Environmental Stressor					Total
	Materials Choice	Energy Use	Solid Residues	Liquid Residues	Gaseous Residues	
Premanufacture	2	2	3	3	2	12/20
Product Manufacture	0	1	2	2	1	6/20
Product Delivery	3	2	3	4	2	14/20
Product Use	1	0	1	1	0	3/20
Refurbishment, Recycling, Disposal	3	2	2	3	1	11/20
Total	9/20	7/20	11/20	13/20	6/20	46/100

*Product Assessment Matrix for the
Generic 1990s Automobile [Graedel 1998]*

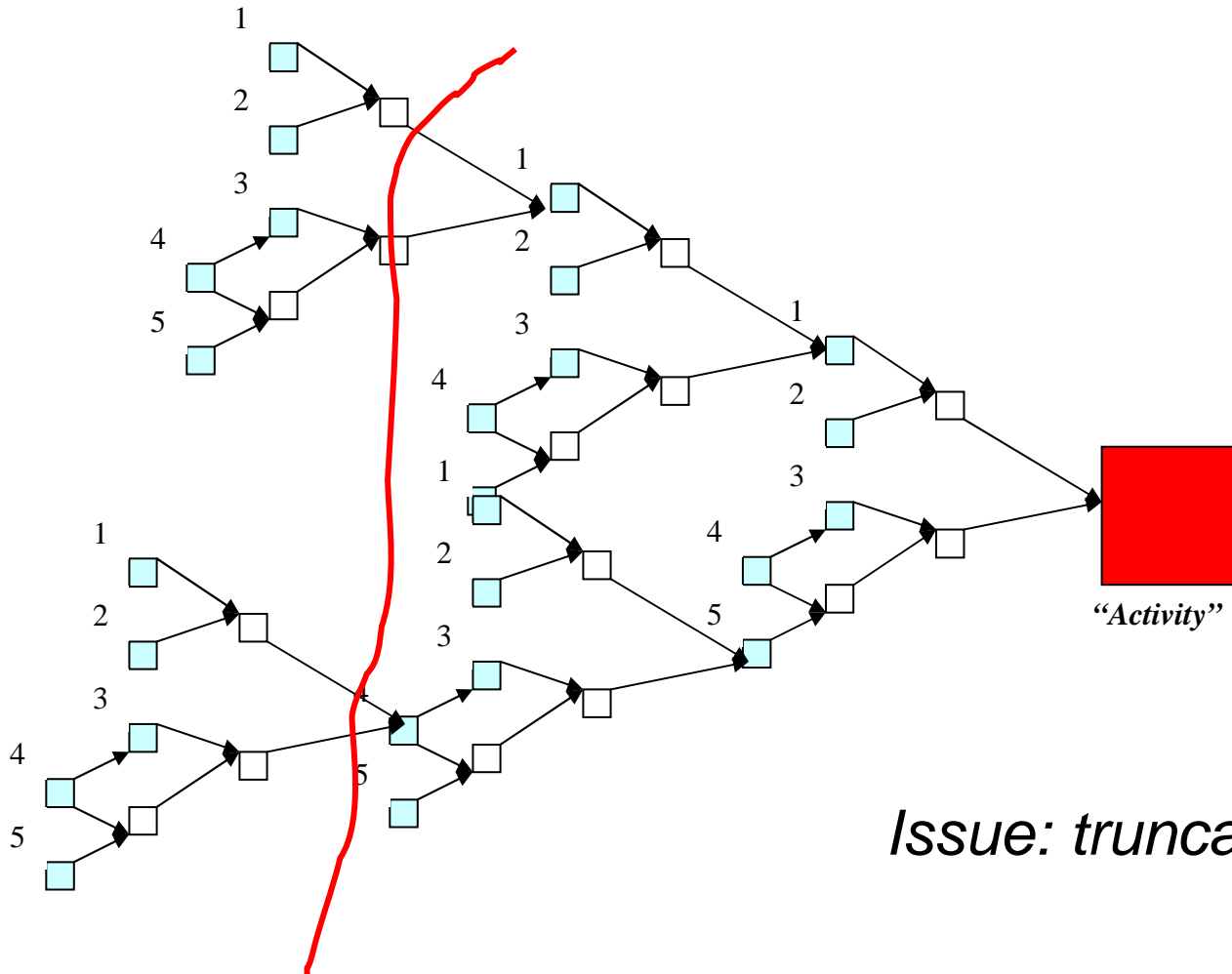
Life Cycle Stage	Environmental Stressor					Total
	Materials Choice	Energy Use	Solid Residues	Liquid Residues	Gaseous Residues	
Premanufacture	3	3	3	3	3	15/20
Product Manufacture	3	2	3	3	3	14/20
Product Delivery	3	3	3	4	3	16/20
Product Use	1	2	2	3	2	10/20
Refurbishment, Recycling, Disposal	3	2	3	3	2	13/20
Total	13/20	12/20	14/20	16/20	13/20	68/100

Target plot of the estimated SLCA impacts for generic automobiles for the 1950s and 1990s

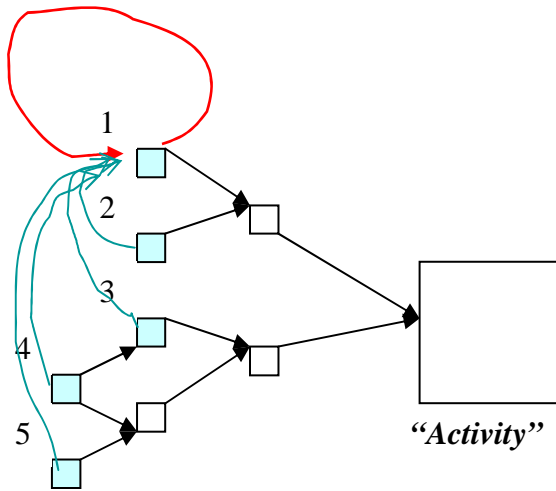


distribution [Graedel 1998]

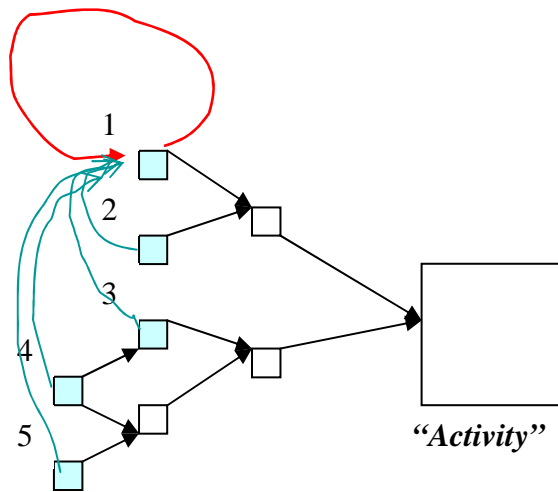
Process Level LCA



Demand Vs Production



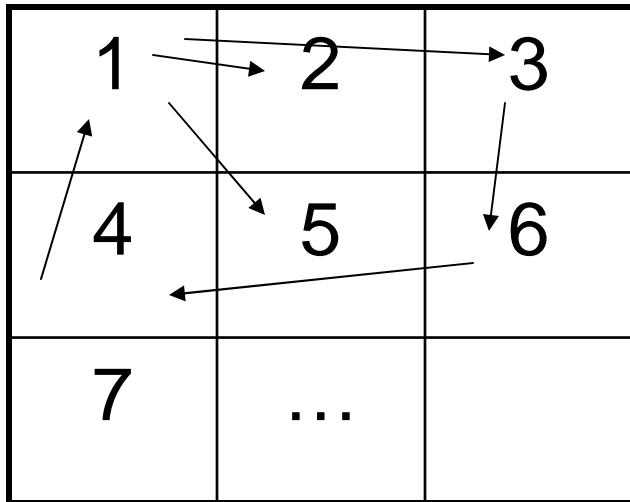
Demand Vs Production



- f = “demand for 1” by the “Activity”
- x = quantity of 1 produced to meet the demand
- $x - \alpha x = f$
- $x = f / (1 - \alpha)$

Because of interactions, “1” has to produce more “x” than “f” furthermore, 2, 3, 4, ... have to produce to support “1”

Input/Output Analysis



- f_1 = “demand for 1” by the “Activity 1”
- x_i = quantity of “i” produced to meet the demand for “1”

Physically we can think of subdividing the economy in sectors that interact with each other. The sectors include all activities so there are no truncation errors, however to be manageable we can only handle a few hundred sectors, therefore each sector will actually include a lot of different activities. “Aggregation errors”

Simplified input-output table for a three-sector economy

Table 2.1 from Leontief, Oxford Press '86

From:	to	Sector 1: Agriculture	Sector 2: Manufacture	Sector 3: House- Holds	Total Output
Sector 1: Agriculture		25	20	55	100 bushels of wheat
Sector 2: Manufacture		14	6	30	50 yards of cloth
Sector 3: Households		80	180	40	300 man- years of labor

Rewrite as table in dollars

	Ag	Mfg.	House (demand)	Total (pro- duction)
Ag	x_{11}	x_{12}	f_1	x_1
Mfg	x_{21}	x_{22}	f_2	x_2

In matrix form

$$(x_1 - x_{11}) - x_{12} = f_1$$

$$-x_{21} + (x_2 - x_{22}) = f_2$$

or using coefficients $a_{ij} = x_{ij}/x_j$

$$(1 - a_{11})x_1 - a_{12}x_2 = f_1$$

$$-a_{21}x_1 + (1 - a_{22})x_2 = f_2$$

or $[I - a] \{x\} = \{f\}$

$$[I - a] \{x\} = \{f\}$$

$$\{x\} = [I - a]^{-1} \{f\}$$

$$\{e\} = [R] \{x\}$$

$$\{e\} = [R] [I - a]^{-1} \{f\}$$

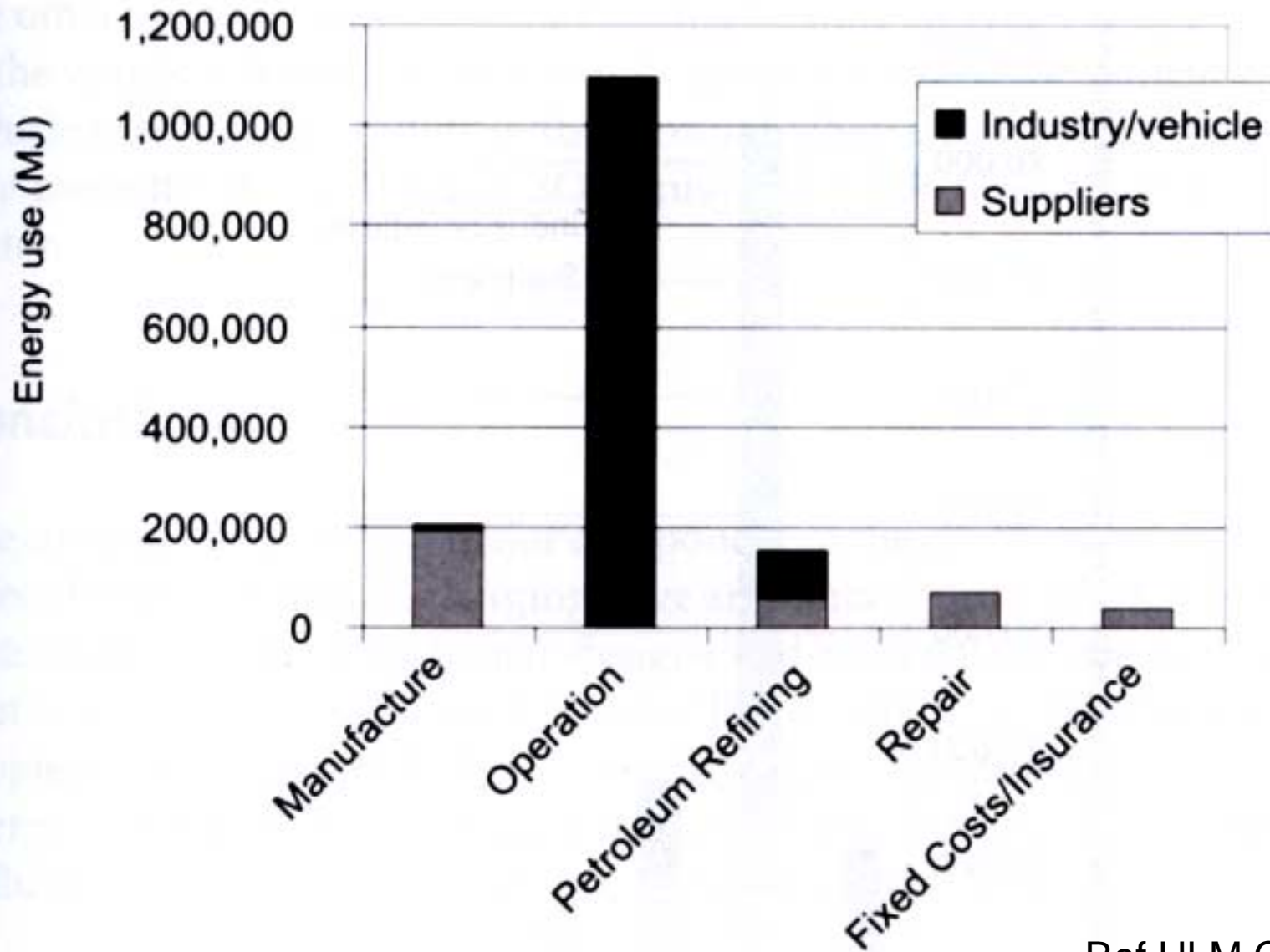
where [R] is a matrix with diagonal elements (impact/dollar) and {e} = environmental impacts

CMU I/O website

<http://www.eiolca.net/>

Auto example (Ch 6 of HLM)

- Sector #336110: Automobile and light truck manufacturing
- $7.57 \text{ TJ/G\$} = 7.57 \text{ MJ/\$}$
- $7.57 \text{ MJ/\$} \times \$16,000 = 121 \text{ GJ}$
- $193,800 \text{ miles}/23.6 \text{ mpg} = 8212 \text{ gal}$
- Smil (p 16) 45 MJ/kg , 2.57 kg/gal
- $8212 \times 2.57 \times 25 = 950 \text{ MJ}$



Ref HLM Ch 6

FIGURE 6-3. Energy Use in the Automobile Life Cycle

Sullivan et al 1998

- “family sedan”
- 120,000 miles life time
- estimate from 644 parts
- 23 mpg
- total mass 1532 kg
- solvent based paints with controls



1. Material Production
2. Manufacturing
3. Use
4. Maintenance & Repair
5. End of Life

Inputs

Table 7: LCI of the Generic Vehicle (Raw Materials Use)

	Units	Generic Vehicle	Material Production	Manufacturing	Operation	Maintenance & Repair	End Of Life
Inflow							
(r) Bauxite (Al ₂ O ₃ , ore)	Kg	32	32	0.0026	0	0.021	0
(r) Bauxite Rich Soil	Kg	222	222	0	0	0	0
(r) Chromium (Cr, in ground)	Kg	0.91	0.91	0	0	0	0
(r) Coal (in ground)	Kg	2,509	1,033	618	748	100	11
(r) Copper (Cu, in ground)	Kg	23	23	0	0	0	0
(r) Ilmenite (FeO.TiO ₂ , in ground)	Kg	0.97	0.32	0.65	0	9.9 E-05	0
(r) Iron (Fe, in ground)	Kg	1,443	1,440	0.38	0	3.0	0.045
(r) Lead (Pb, in ground)	Kg	33	13	0.26	0	20	0
(r) Limestone (CaCO ₃ , in ground)	Kg	458	199	95	142	21	2.
(r) Manganese (Mn, in ground)	Kg	24	23	0	0	0.76	0
(r) Natural Gas (in ground)	Kg	1,810	491	216	1,027	73	2.2
(r) Oil (in ground)	Kg	16,486	631	87	15,562	171	35
(r) Olivine (in ground)	Kg	8.3	8.3	0	0	0.0032	0
(r) Perlite (SiO ₂ , in ground)	Kg	2.4	2.3	0.056	0	0	0
(r) Platinum (Pt, in ground)	Kg	0.0015	0.0015	0	0	0	0
(r) Pyrite (FeS ₂ , in ground)	Kg	13	13	0	0	4.3 E-05	0
(r) Rhodium (Rh, in ground)	Kg	2.9 E-04	2.9 E-04	0	0	0	0
(r) Sand (in ground)	Kg	179	140	0	0	12	27
(r) Sulfur (S)	Kg	0.1	0.08	0.022	0	4.0 E-05	0
(r) Tin (Sn, in ground)	Kg	0.48	0.067	0.41	0	0	0
(r) Tungsten (W, in ground)	Kg	0.012	0.011	0	0	6.8 E-04	0
(r) Uranium (U, in ground)*	Kg	0.039	0.01	0.0089	0.018	0.0019	2.5 E-04
(r) Zinc (Zn, in ground)	Kg	22	22	0	0	4.3 E-04	0
Cullet (from stock)	Kg	0.013	0	0.013	0	0	0
Iron Scrap	Kg	243	200	0.05	0	43	0
Natural Rubber	Kg	25	8.8	0	0	16	0
Raw Materials (alloying additives)	Kg	4.0	4.0	0	0	0	0
Raw Materials (Iron Casting Alloys)	Kg	12	12	0	0	0	0
Raw Materials (unspecified)	Kg	17	7.4	9.2	0	0.32	0
Steel Scrap	Kg	474	428	0	0	46	0
Water Used (total)	Liter	76,959	59,672	9,818	2,007	5,459	4.0

* From electricity production

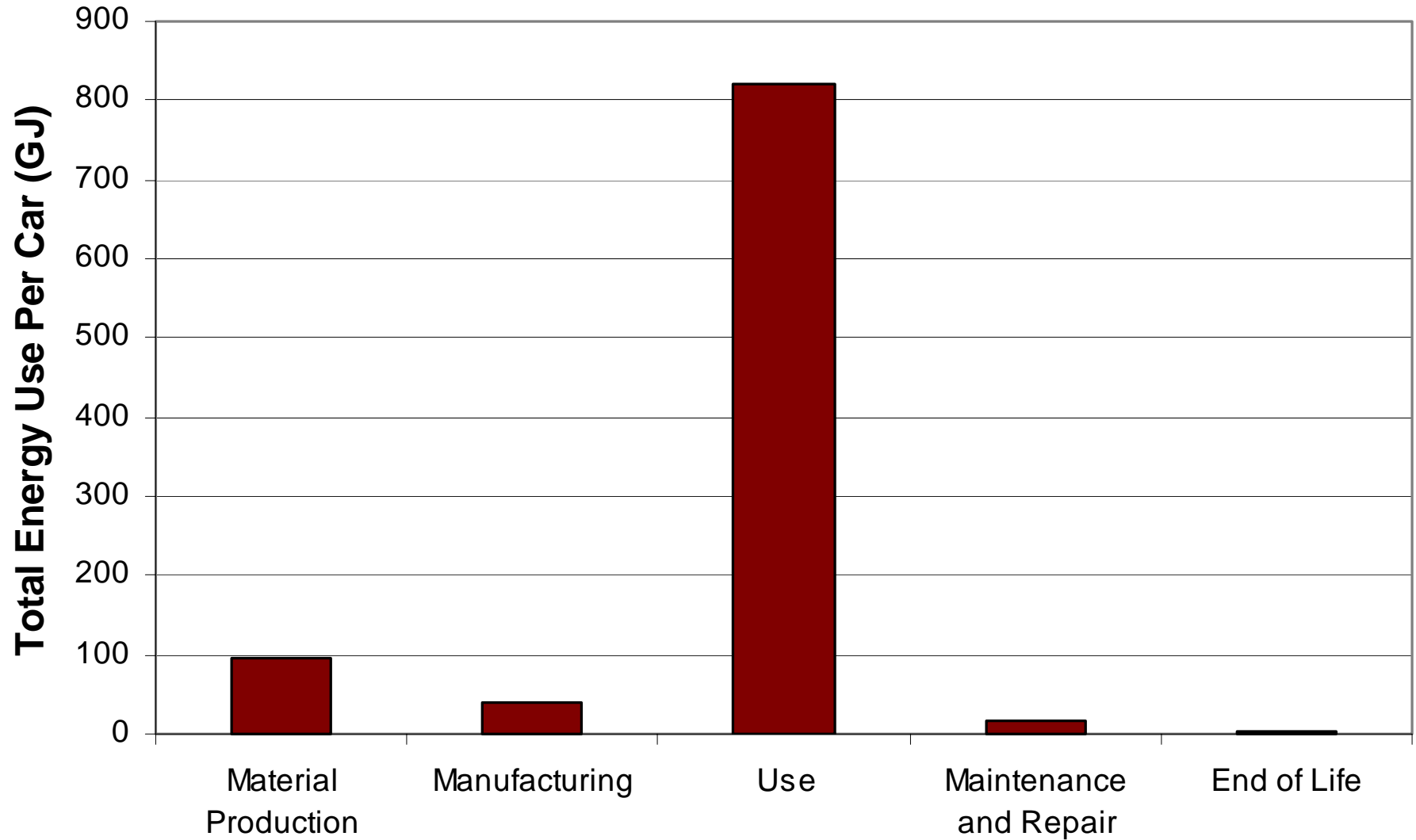
Output and Energy Use

Table 8: LCI of the Generic Vehicle (Outflows and Energy Use)

	Units	Generic Vehicle	Material Production	Manufacturing	Operation	Maintenance & Repair	End Of Life
Outflow							
(a) Carbon Dioxide (CO ₂ , fossil)	gm	59,092,200	4,439,850	2,562,160	51,331,400	615,481	143,273
(a) Carbon Monoxide (CO)	gm	1,942,230	63,813	5,914	1,832,728	39,088	683
(a) Hydrocarbons (except methane)	gm	256,640	12,627	7,349	234,520	1,974	170
(a) Hydrogen Chloride (HCl)	gm	725	278	10	402	29	5.7
(a) Hydrogen Fluoride (HF)	gm	113	59	1.1	50	2.0	0.71
(a) Lead (Pb)	gm	115	50	1.2	1.1	63	0.015
(a) Methane (CH ₄)	gm	65,806	11,773	5,534	44,500	3,854	144
(a) Nitrogen Oxides (NO _x as NO ₂)	gm	254,193	12,871	8,295	229,465	2,755	806
(a) Particulates (unspecified)	gm	53,526	26,470	8,235	16,525	2,050	247
(a) Sulfur Oxides (SO _x as SO ₂)	gm	133,326	30,491	14,917	83,180	4,424	315
(w) Ammonia (NH ₄ ⁺ , NH ₃ , as N)	gm	2,354	116	17	2,208	12	1.9
(w) Dissolved Matter (unspecified)	gm	7,686	4,527	1,118	982	1,041	17
(w) Heavy Metals (total)	gm	39	29	7.5	0	3.1	0.0013
(w) Oils (unspecified)	gm	7,611	130	516	6,918	39	7.4
(w) Other Organics (unspecified)	gm	80	77	0.43	0	2.5	2.2 E-04
(w) Phosphates (as P)	gm	15	7.2	7.8	0	0.42	1.6 E-05
(w) Suspended Matter (unspecified)	gm	74,321	2,779	2,450	68,522	512	58
Waste (municipal and industrial)	Kg	415	22	56	8.0 E-05	41	296
Waste (total)	Kg	4,213	2,440	386	783	277	326
Energy Reminder							
E (HHV) Feedstock Energy	MJ	28,016	18,574	953	308	8,182	0
E (HHV) Fossil Energy	MJ	967,367	90,741	38,414	819,791	16,274	2,147
E (HHV) Non-Fossil Energy	MJ	6,053	3,719	803	1,142	373	16
E (HHV) Process Energy	MJ	934,369	74,531	36,691	814,014	8,389	746
E (HHV) Total Energy	MJ	973,418	94,460	39,217	820,933	16,645	2,164
E (HHV) Transportation Energy	MJ	11,033	1,355	1,574	6,612	74	1,418
Electricity	MJ	10,577	2,468	6,769	0	1,203	136

Total Energy Use by Lifecycle Stage

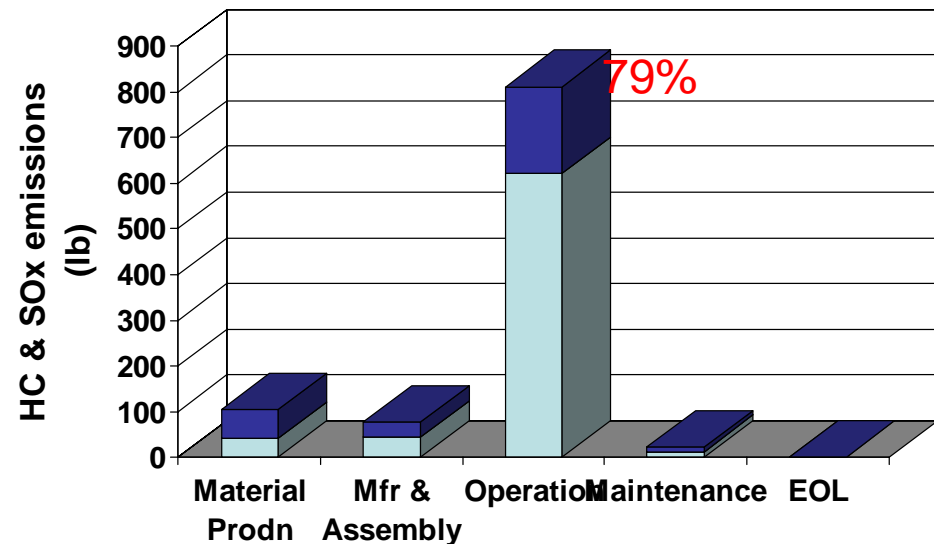
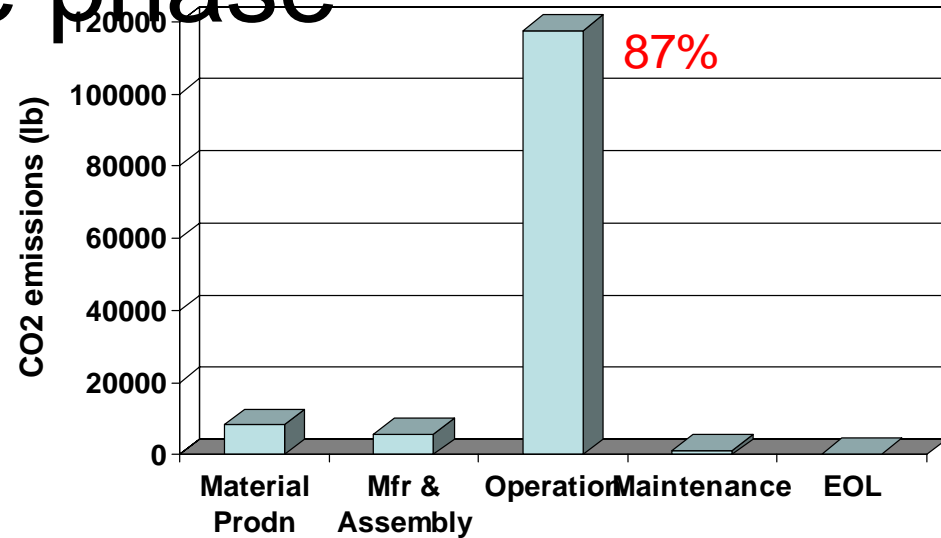
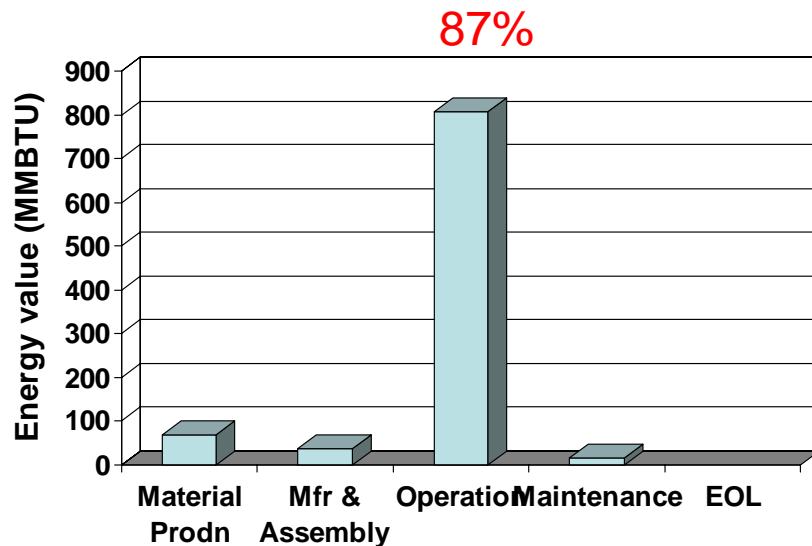
Total Energy 973 GJ/car



Lifecycle Stage

Sullivan 1998

A majority of the environmental burden of an auto occurs during the use phase



Source: Sullivan & Cobas-Flores (2001),
Full Vehicle LCAs: A Review, SAE 2001-01-3725

CMU Input/Output Model Vs. Sullivan's Process Model

emissions (gms) per vehicle	CMU I/O (1992 data)	Sullivan et al (1995 ref. vehicle)	% Difference from CMU
CO ₂	7,536,196	7,002,010	-7%
CH ₄	69,483	17,307	-75%
SO ₂	32,484	45,408	40%
CO	51,079	69,727	37%
NO ₂	31,937	21,166	-34%
VOC	12,008		
Lead	28	51	86%
PM10	5,582	34,705	522%

Results for all activities up to and including manufacturing

LCA software

http://www.life-cycle.org/LCA_soft.htm

- [Boustead Consulting Database and Software](#)
- [ECO-it](#): Eco-Indicator Tool for environmentally friendly design - PRé Consultants
- [EDIP](#) - Environmental design of industrial products - Danish EPA
- [EIOLCA](#) - Economic Input-Output LCA at Carnegie Mellon University
- [GaBi 4](#) - (Ganzheitlichen Bilanzierung - holistic balancing) - Five Winds International/University of Stuttgart (IKP)/PE Product Engineering
- [IDEMAT](#) - Delft University Clean Technology Institute Interduct Environmental Product Development
- [KCL-ECO 3.0](#) - KCL LCA software
- [LCAiT](#) - CIT EkoLogik (Chalmers Industriteknik)
- [SimaPro 6 for Windows](#) - PRé Consultants
- [TEAM\(TM\)](#) (Tools for Environmental Analysis and Management) - Ecobalance, Inc.
- [Umberto](#) - An advanced software tool for Life Cycle Assessment - Institut für Umweltinformatik

SIMAPRO 6.0



What is it?

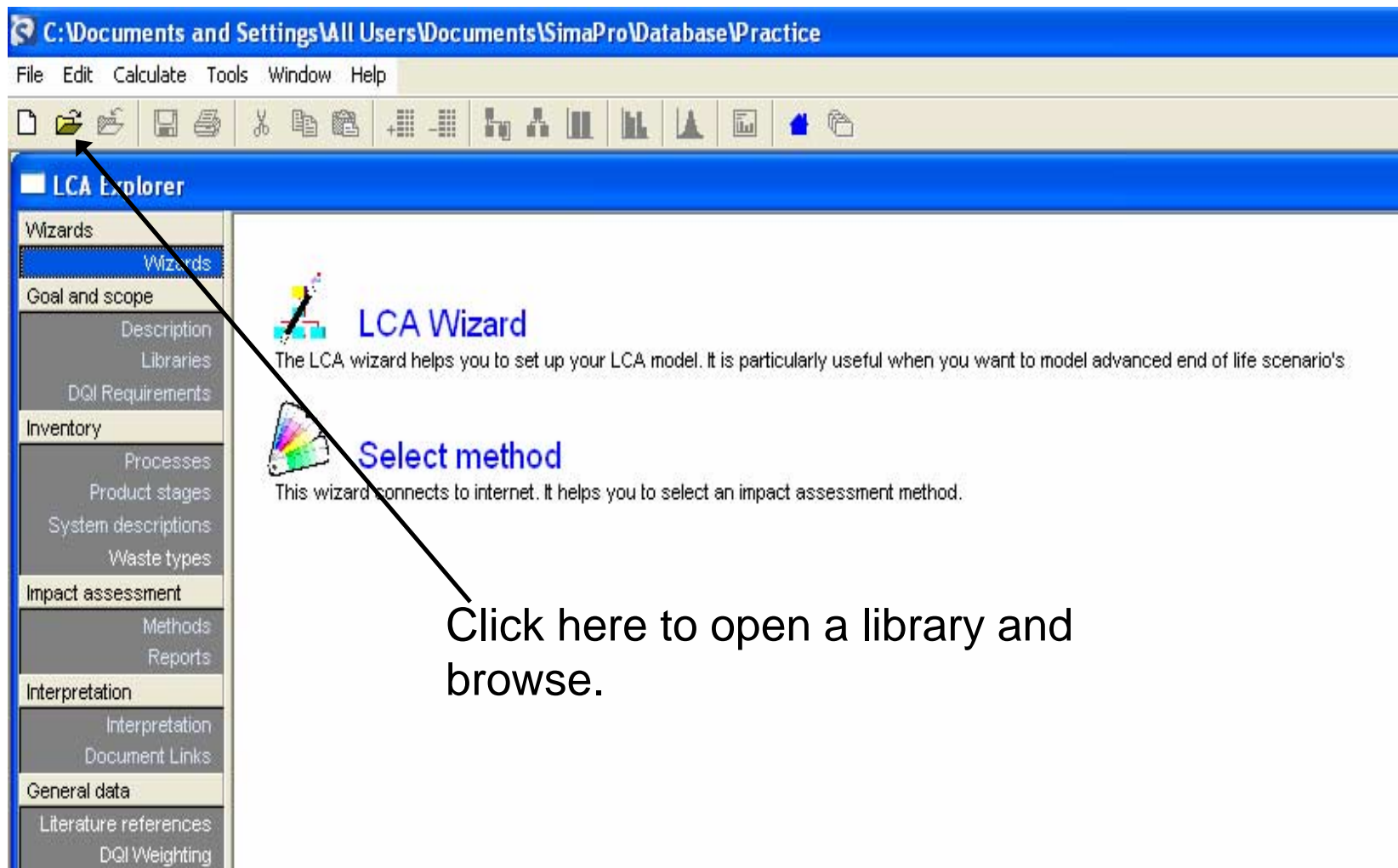
SIMAPRO is a compilation of LCI libraries together with LCA evaluation tools such as the Eco-indicator 99. Some of its libraries include:

- Buwal 250 (Swiss - EMPA)
- IDEMAT 2001 (Netherlands – Delft University of Technology)
- ETH-ESU (Swiss)
- USA Input Output Database 1998

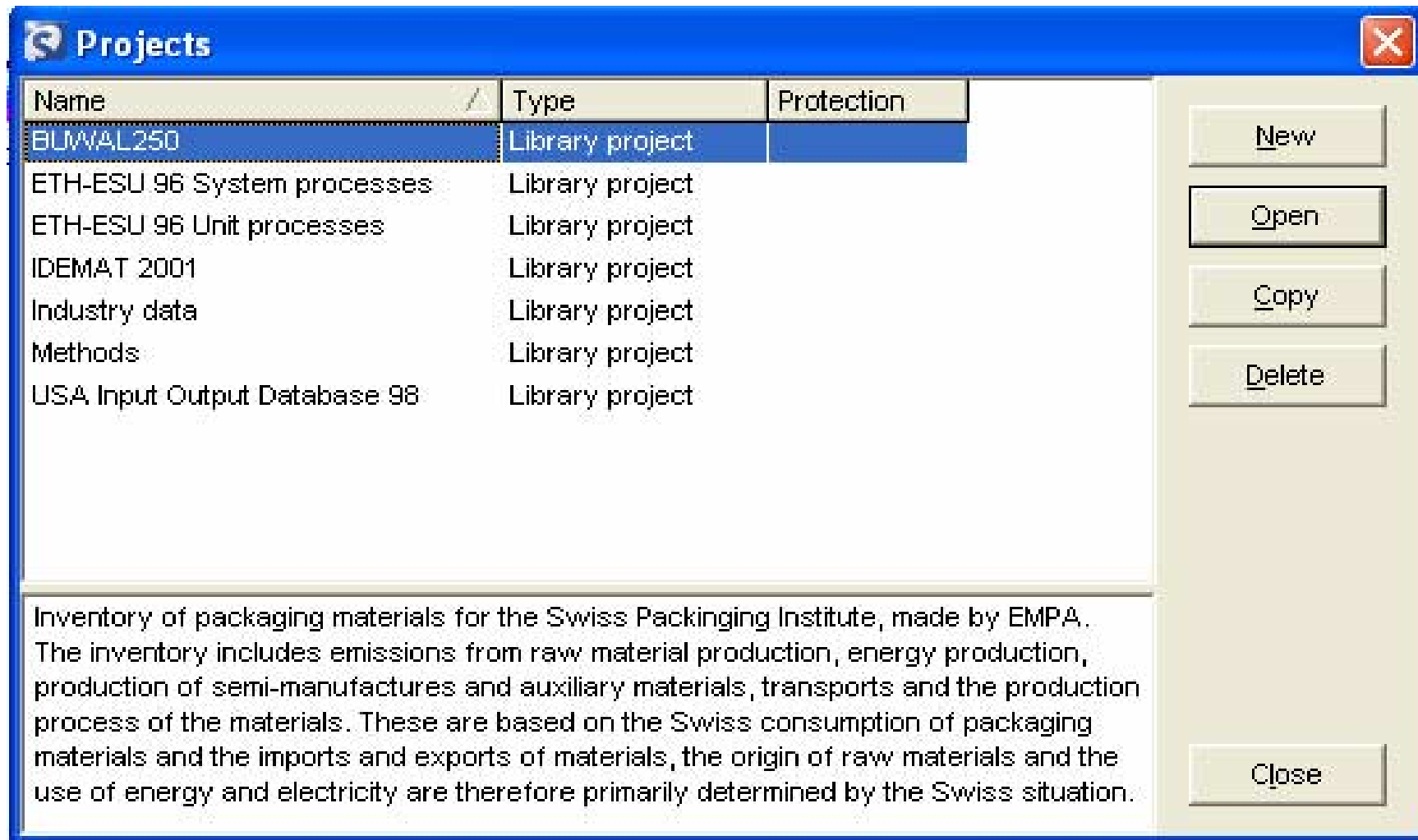
Aside from the latter one, all the other libraries contain process LCI's (the traditional bean counting way)

The Focus of this presentation is on Navigation. Please refer to the “Wood Example” tutorial online for instructions on creating a full LCA.

- 1) Open Simapro
- 2) This is the first screen you see:



Open a database



The screenshot shows a window titled "Projects" with a table of project entries. The "BLMVAL250" project is selected. To the right of the table are buttons for "New", "Open", "Copy", "Delete", and "Close". Below the table is a text area containing a description of the selected project.

Name	Type	Protection
BLMVAL250	Library project	
ETH-ESU 96 System processes	Library project	
ETH-ESU 96 Unit processes	Library project	
IDEMAT 2001	Library project	
Industry data	Library project	
Methods	Library project	
USA Input Output Database 98	Library project	

Inventory of packaging materials for the Swiss Packaging Institute, made by EMPA. The inventory includes emissions from raw material production, energy production, production of semi-manufactures and auxiliary materials, transports and the production process of the materials. These are based on the Swiss consumption of packaging materials and the imports and exports of materials, the origin of raw materials and the use of energy and electricity are therefore primarily determined by the Swiss situation.

Imagine we are interested in the LCI of a cardboard box

The screenshot shows the LCA Explorer interface. On the left is a navigation pane with categories like 'Wizards', 'Goal and scope', 'Description', 'Inventory', 'Processes', 'Impact assessment', 'Interpretation', and 'General data'. The 'Processes' category is selected, showing a tree view with 'Material', 'Energy', 'Transport', and 'Processing'. Under 'Processing', 'Cardboard' is highlighted. On the right is a table of processes. The row 'Production cardboard box I' is highlighted in yellow. Below the table is a list of checked options for the LCI, and a text box providing details about the production process.

Name	Unit	Waste type	Project	DQI
CC packaging production L	kg		BUWAL250	█
CC packaging production S	kg		BUWAL250	█
Production cardboard box I	kg		BUWAL250	█
Production cardboard box II	kg		BUWAL250	█

Click to obtain LCI (points to the 'Production cardboard box I' row)

Click to obtain tree diagram of LCI (points to the 'Cardboard' entry in the tree)

Double Click to obtain data on the LCI (points to the 'Production cardboard box I' row)

- ✓ Time period
- ✓ Geography
- ✓ Technology
- ✓ Representativeness
- ✓ Multiple output allocation
- ✓ Substitution allocation
- ✓ Waste treatment allocation
- ✓ Cut-off rules
- ✓ System boundary
- ✓ Boundary with nature

Production of cardboard boxes with off set printing (1000 kg). In this process 20% of the cardboard is lost, for a box of 1 kg 1.2 kg cardboard is needed. The data concern an average type of box, data are derived from 6 factories in Switzerland, materials are not specified in BUWAL 250/2. The inventory only includes processing data (printing, blanking and glueing plus auxiliary materials). The infrastructure is excluded. Waste treatment is not included.

286 items | 1 item selected

Data on the LCI – Input/Output Tab

C:\Documents and Settings\All Users\Documents\SimaProDatabase\Practice; BUWAL250 - [Edit processing process 'Production cardboard box I']

File Edit Calculate Tools Window Help

Documentation Input/output System description

Known outputs to technosphere. Products and co-products

Name	Amount	Unit	Quantity	Allocation %	Category	Comment
Production cardboard box I	1000	kg	Mass	100 %	Cardboard	
(Insert line here)						

Known outputs to technosphere. Avoided products

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
(Insert line here)							

Inputs

Known inputs from nature (resources)

Name	Sub-compartment	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
Ink		18.3	kg	Uniform		7.8	34.5	not traced ba average
Glue		5.2	kg	Uniform		0.9	10.6	not traced ba
Oil		0.2	kg	Undefined				not traced ba
Additives		7	kg	Undefined				not traced ba
Water, unspecified natural origin/kg	in water	2.5	kg	Undefined				
(Insert line here)								

Known inputs from technosphere (materials/fuels)

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
Paper wood-free C B250	52	kg	Undefined				average amount, paper type not in the inventory
LDPE B250	8.5	kg	Undefined				listed as unspecified plastics.
(Insert line here)							

Known inputs from technosphere (electricity/heat)

Name	Amount	Unit	Distribution	SD^2 or 2*SD	Min	Max	Comment
Heat diesel B250	90.8	MJ	Undefined				(2 kg, 45.4 MJ/kg)
Heat gas B250	5.03	MJ	Undefined				0.1 kg propane, 50.3 MJ/kg, avera
Electricity Swiss B250	325	kWh	Uniform		88	807	average

Data on the LCI – Documentation Tab



Documentation | Input/output | System description

Project	BUWAL250	Category	Processing
Created on	2/4/2003	Last update on	6/10/2004
Process type	System	Process identifier	BUWAL25006555300161
Name	Production of cardboard boxes with off set printing (1000 kg)		
Image			

Data Quality Indicators

Time period	1990-1994
Geography	Europe, Western
Technology	Average technology
Representativeness	Mixed data
Multiple output allocation	Not applicable
Substitution allocation	Not applicable
Cut-off rules	Unspecified
System boundary	Second order (material/energy flows including operations)
Boundary with nature	Not applicable
Infra. process	No
Date	4/1/1997
Record	PRé Consultants, Amersfoort, the Netherlands, RS
Generator	ETH Zürich, Institut für Verfahrens- und Kältetechnik (IVUK), Switzerland. EMPA, St. Gallen, Switzerland.

General reference and sources

Literature Reference

Comment

Data on the LCI – System Description Tab

C:\Documents and Settings\All Users\Documents\SimaProDatabase\Practice; BUWAL250 - [Edit processing process 'Production cardboard box I']

File Edit Calculate Tools Window Help

Documentation | Input/output | System description

System description	Comment
Buwal 250 general	

Description

The inventory table includes emissions from raw material production, energy production, production of semi-manufactures and auxiliary materials, transports and the production process of the materials. The system model is based on the Swiss consumption of packaging materials and the imports and exports of materials, the origin of raw materials and the use of energy and electricity are therefore primarily determined by the Swiss situation.

Sub-systems

Production of input materials, transports, production of electricity and thermal energy

Cut-off rules

Biogenous carbon dioxide emissions are not included in the inventory table, since these are assumed to be part of the sustainable use of the biogenous, renewable, resources. Emissions to soil are only included in connection with waste processing of the packaging materials after the consumption phase. For most other processes, except for a very few processing processes, they could not be registered as there were no emissions to soil reported.

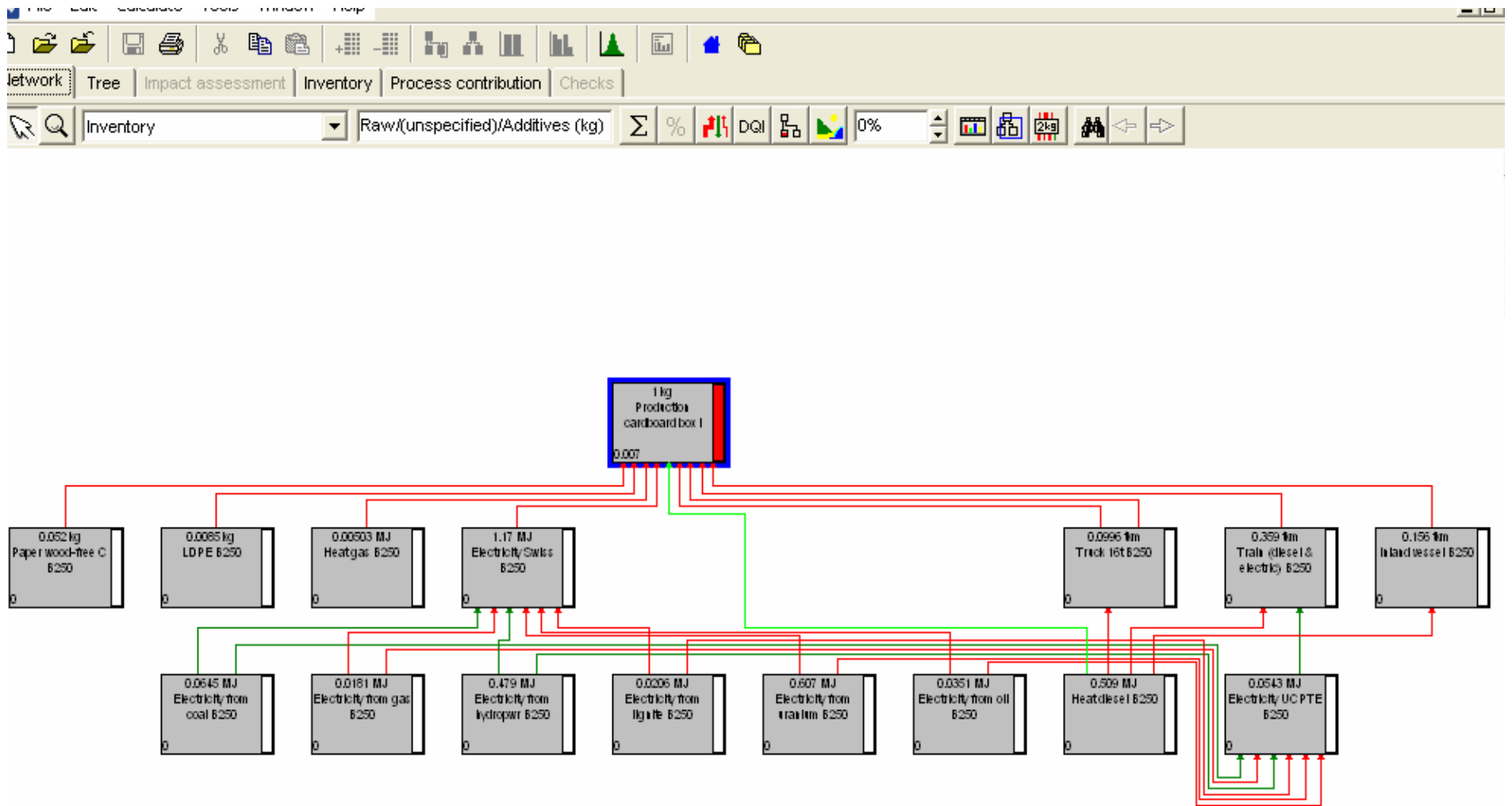
In general the production process is traced back to the raw material resources as far as possible. For some inputs, mainly chemicals and complex auxiliary materials, which are used in the production processes in smaller amounts, not enough data were available to trace the production of these materials back to the raw material resources. Since these materials are only used in small amounts, the effect of the omission in the final results will be small.

These input materials are listed as "not traced back" in the inventory tables. In the output, production waste and re-usable waste are listed. Since the amount of production waste is small, and the composition is unknown, no emissions from the processing of this waste are included in the inventory. For the re-usable wastes, which function as raw materials in another production process, no emissions from recycling processes of these materials are included in the inventory either.

Allocation rules

In general the environmental impacts of multi output processes have been allocated on a mass basis. In the output of the system co-products, which are explicitly mentioned, form an exception to this rule because these co-products leave the whole system defined and are not allocated to. In the inventory table these are listed as solids without emissions. Co-products (intermediate products), which have been balanced in single process steps, are allocated to and these are not mentioned in the total inventory input list. The output of re-usable waste has not been allocated any emissions, since it functions as a raw material in another product system.

LCI – Network Diagram



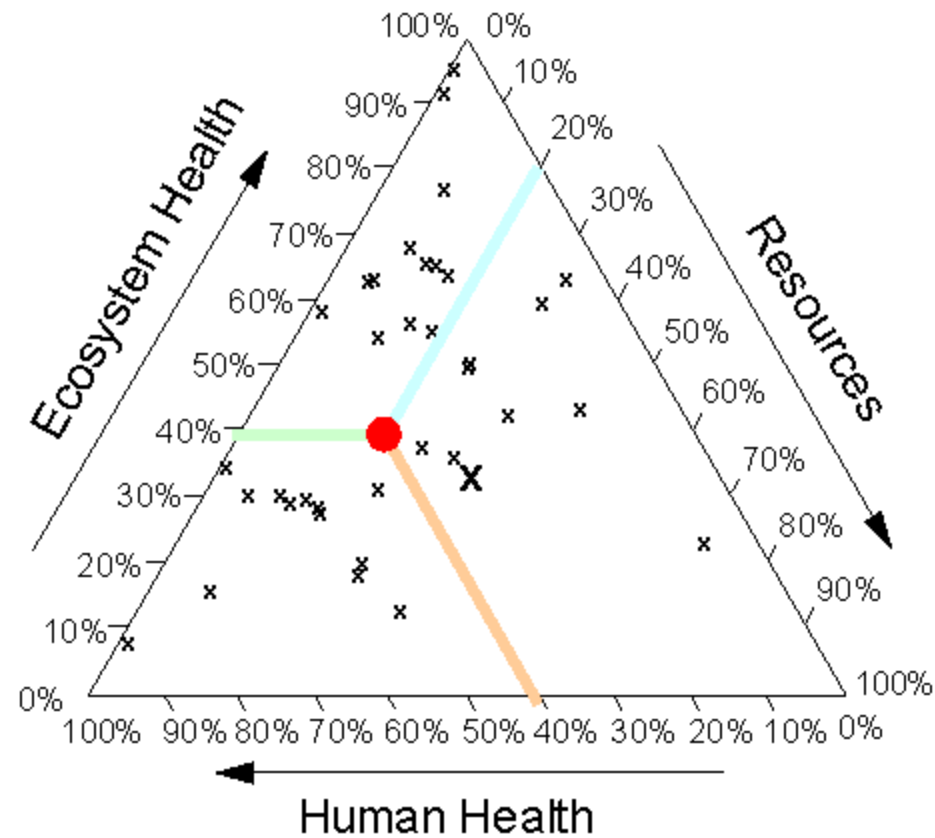
LCI - Inventory

No	Substance	Compartment	Unit	Total	Production cardboard box	Paper wood-free C B250
1	Additives	Raw	kg	0.007	0.007	x
2	Artificial fertilizer	Raw	kg	0.0000473	x	0.0000473
3	Bauxite, in ground	Raw	kg	0.00000343	x	0.000000879
4	Biomass	Raw	kg	0.000629	x	0.000629
5	Clay, unspecified, in ground	Raw	kg	0.013	x	0.013
6	Coal, 18 MJ per kg, in ground	Raw	kg	0.0146	x	0.0021
7	Coal, brown, 8 MJ per kg, in ground	Raw	kg	0.0112	x	0.00135
8	Complexing agent	Raw	kg	0.00000417	x	0.00000417
9	Defoamer	Raw	kg	0.0000158	x	0.0000158
10	Energy, potential, stock, in barrel	Raw	MJ	0.688	x	0.0567
11	Gas, natural, 35 MJ per m3, in ground	Raw	m3	0.00247	x	x
12	Gas, natural, 36.6 MJ per m3, in ground	Raw	m3	0.0154	x	0.0106
13	Gas, natural, feedstock, 35 MJ per m3	Raw	m3	0.0051	x	x
14	Glue	Raw	kg	0.0052	0.0052	x
15	Ink	Raw	kg	0.0183	0.0183	x
16	Iron ore, in ground	Raw	kg	0.000002	x	0.000000302
17	Limestone, in ground	Raw	kg	0.0232	x	0.0232
18	Magnesium sulfate	Raw	kg	0.0000251	x	0.0000251
19	Manure	Raw	kg	0.00506	x	0.00506
20	Oil	Raw	kg	0.0002	0.0002	x
21	Oil, crude, 42.6 MJ per kg, in ground	Raw	kg	0.0202	x	0.00254
22	Oil, crude, feedstock, 41 MJ per kg	Raw	kg	0.00561	x	0.0011
23	Pesticides	Raw	kg	0.00000407	x	0.00000407
24	Potatoes	Raw	kg	0.00105	x	0.00105
25	Sand and clay, unspecified, in ground	Raw	kg	0.00000017	x	x
26	Sand, unspecified, in ground	Raw	kg	0.000000135	x	0.000000135
27	Sodium chloride, in ground	Raw	kg	0.000817	x	0.000749

Incorporating Values

- Self-interest
 - stakeholders
- Knowledge
 - mental models
- Power
 - if fish could vote.....

Valuation: Eco-indicator 95



Weighting of the damage categories by the panel • <http://www.pre.nl/default.htm>

LCA applications and Limitations

- Improvements in products, OK
- Comparisons between products? dicey!
- Beware of “senseless substitutes”

Substitutes and Compliments

- **Substitutes:** replacement or elimination
- **Compliments:** stimulation or generation
- do emails substitute for letters (paper)?
- do telecommunications substitute for travel?
- What were the first words of Alexander Graham Bell over the telephone?
- “Mr Watson, come here; I want you”

Paper or Plastic?

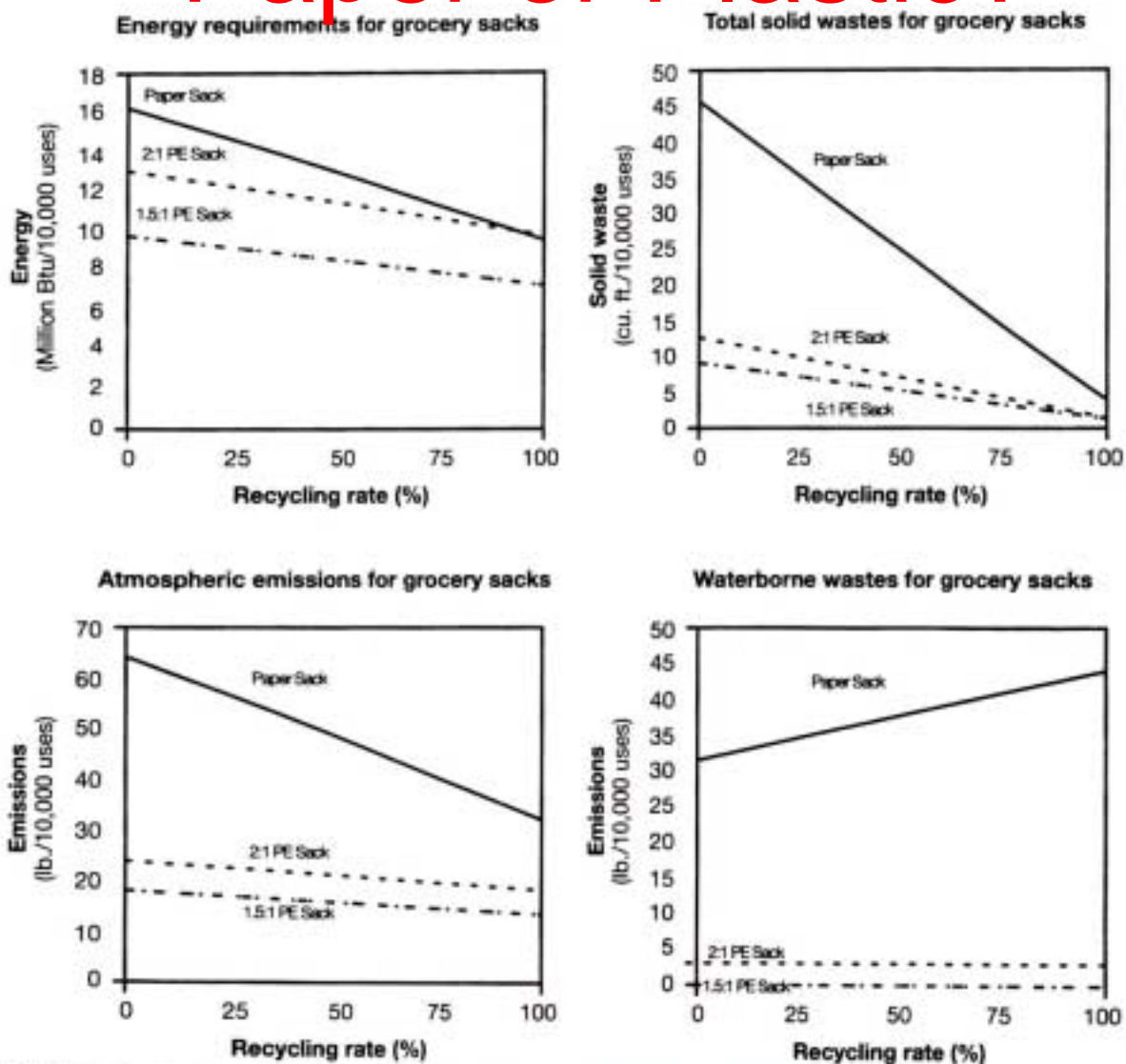


FIGURE 5.5 Environmental stresses attributable to polyethylene and paper grocery sacks. The units in each case are per 10,000 uses, and the analyses are performed for the cases in which 2.0 and 1.5 polyethylene sacks are used in place of each paper sack. (Adapted with permission from The Council for Solid Waste Solutions, Copyright 1993.)

Paper or Silicon?



Toffel, M.W., and A. Horvath.
2004. Environmental implications
of wireless technologies:
News delivery and business meetings.
Environmental Science & Technology
38(June 1):2961-2970.

Reading the New York Times

- weighs about 236 kg/yr
- about 2.6 people read it
- paper production
- printing
- delivery
- half to land fill
- half to recycle
- PDA mfg?
- Uses Williams result 12MB/32MB
- energy usage
- telecommunications infrastructure

Newspaper Vs PDA

- New York Times

- 270 kg CO₂
- 8730 liters H₂O
- 0.9 kg NO_x
- 1.4 kg SO_x

- PDA

- 5 kg CO₂
- 232 liters H₂O
- 4 g NO_x
- 4 g SO_x

Travel Vs Cell phones

- Berkeley – Chicago
- auto, air, train
- average not marginal values
- lodging excluded
- mfg excluded
- mfg included I/O for \$100 phone, 3 year life
- includes infrastructure
- 2 hour call

Travel Vs Cell phones

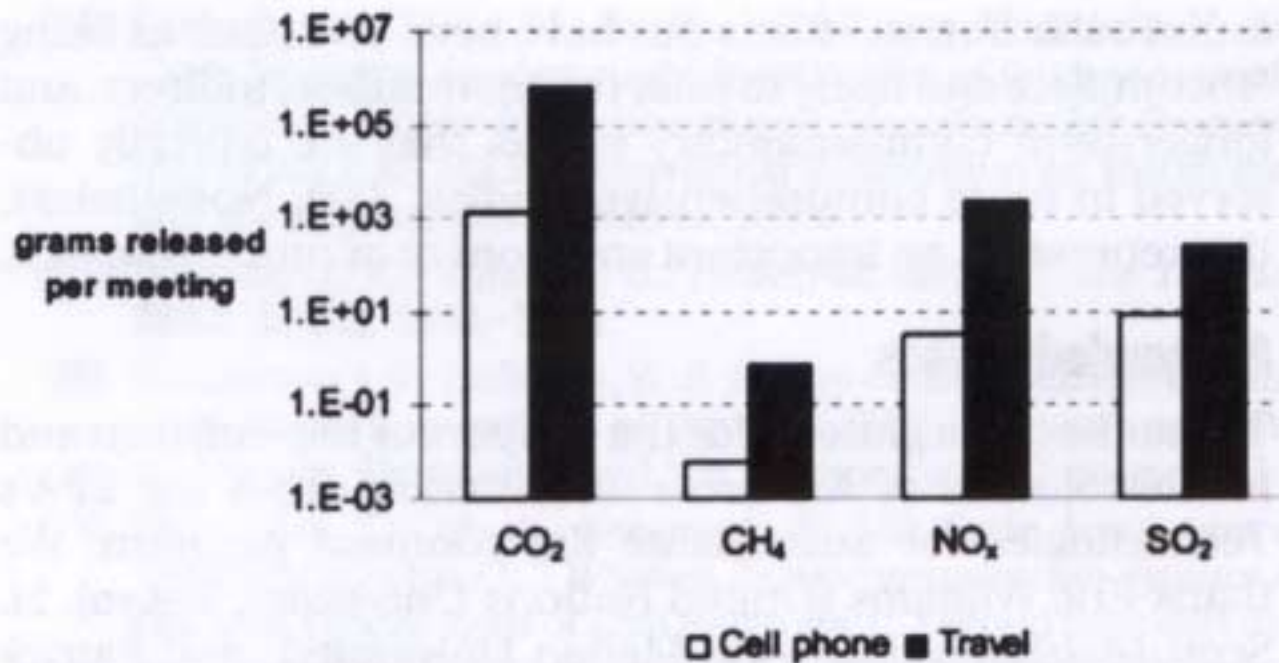
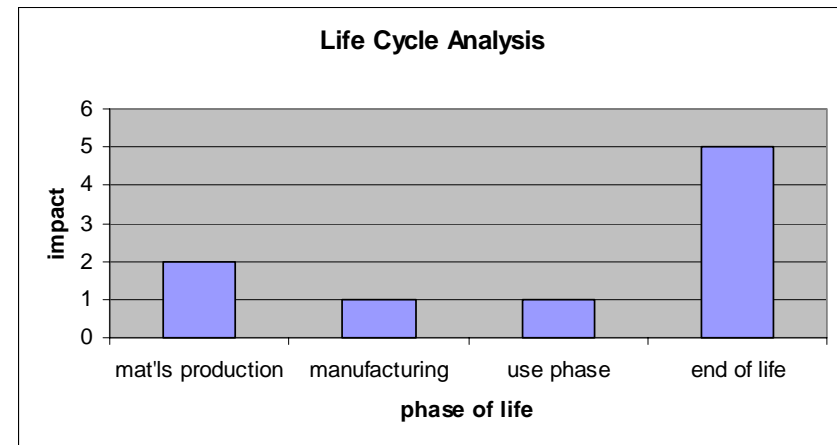
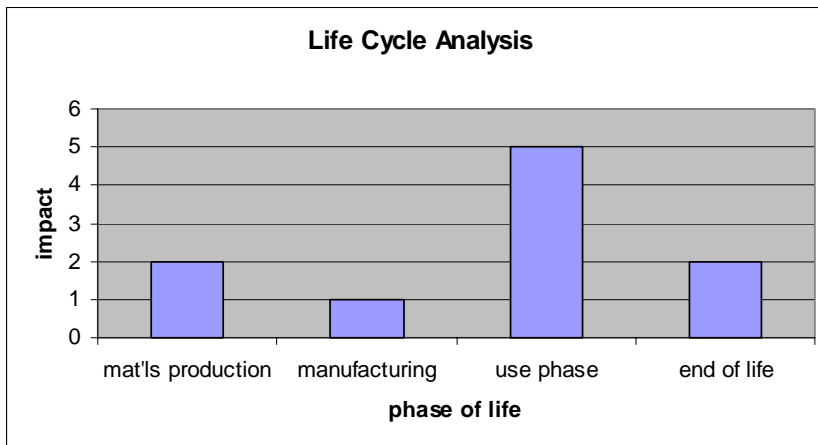
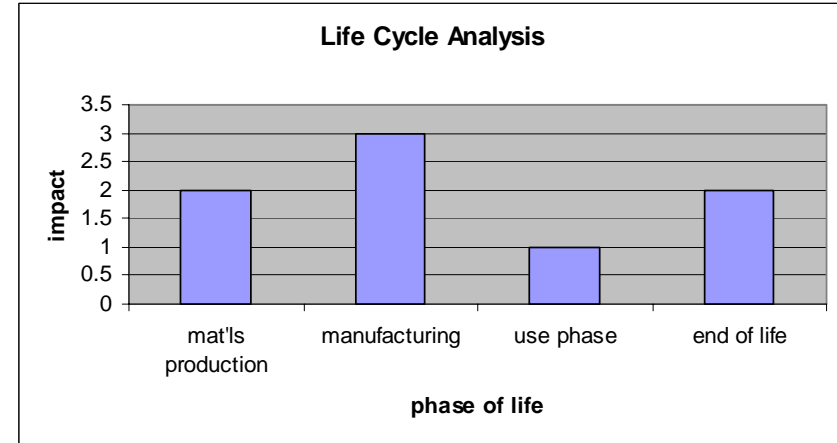
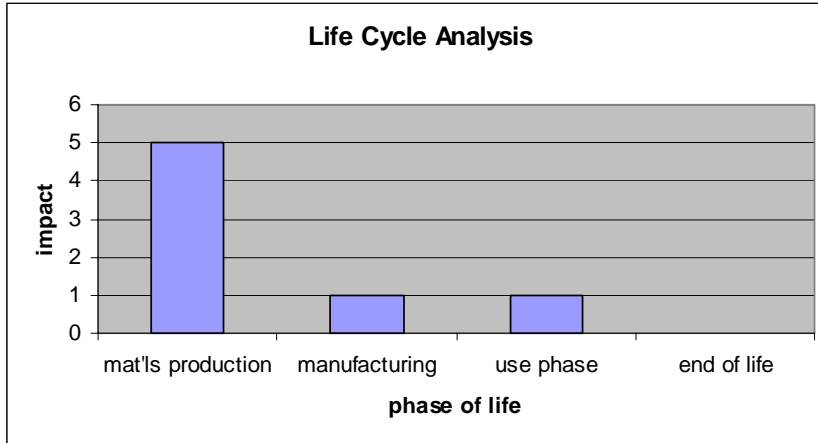


FIGURE 2. Environmental effects of travel versus wireless communication.

Where do major impacts occur?



LCI Summaries

Life Stage	Products with major impact in stage
Extraction and Refining	Paper Products: i.e. paper Vs plastics, paper Vs silicon...
Mfg	Microelectronics, Nano-technology
Use	Use fossil fuels, plug into grid
End of Life	Diapers, short life products

LCA/LCI critique

- Accuracy, looks like an engineering tool but it is not
- System boundaries may not be clear
- Inability to adequately address human behavior
- Gives a passing grade for business as usual
- BUT you have to start somewhere!