




Life Cycle Assessment and Environmental Accounting

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Environmental Studies 152



Department of Environmental Studies

"What you people call your natural resources, we call our relatives."
- Oren Lyons, Faith keeper of the Onondaga



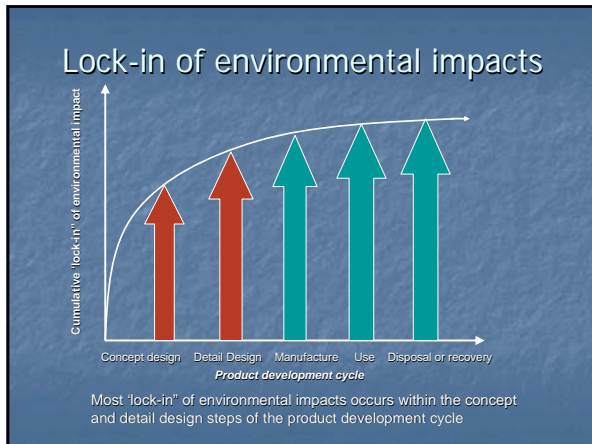
Introduction

Ecodesign requires that environmental impacts be considered during the product planning stage

Designers can have a direct role in determining environmental impacts. **Ecodesign** requires thinking about the entire product life-cycle. This includes understanding overall design process steps and their potential impacts. Any step in the design, manufacture, use and disposal of a product can result in resource depletion, habitat destruction, and the contamination of air, water or soil. These impacts are established early in the product development process.

On the other hand, successful **Ecodesign** can reduce impacts and can also result in significant financial benefits.



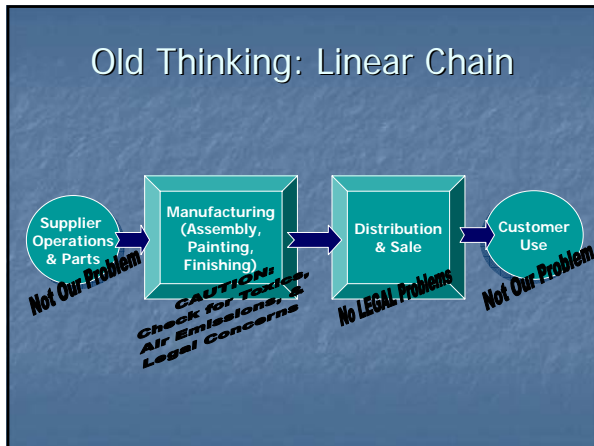


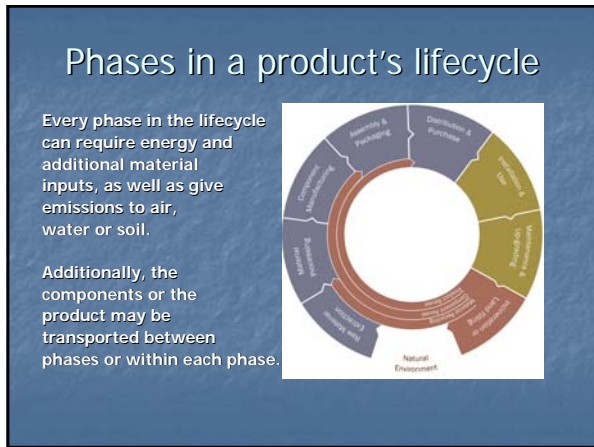
Product Lifecycle

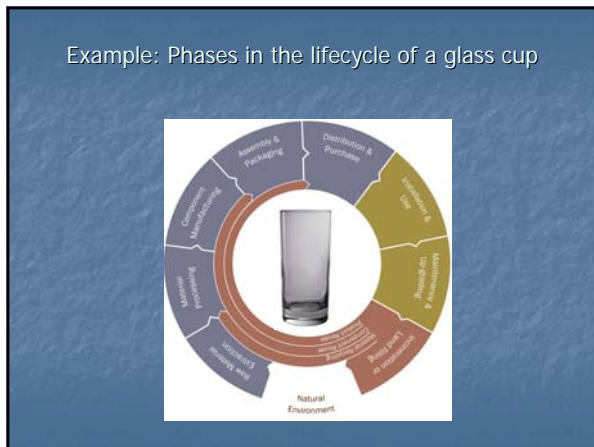
- Designers need to understand the stages of the life of a product when environmental impacts can occur.
- By including all of the stages in the assessment of a product, designers ensure a comprehensive and accurate assessment of the product's potential impacts.

Stages in a product's lifecycle

STAGE	EXAMPLE
Raw material extraction	Wood from forest, oil from well, metal ore from mine, etc.
Material processing	Wood to paper, oil to plastic, ores to metal alloys, etc.
Component manufacturing	Paper printed, plastic molded, alloys into circuitry, etc.
Assembly & packaging	Product is assembled and packaged with documentation.
Distribution & purchase	Product is distributed and purchased.
Installation & use	Energy and additional materials may be used.
Maintenance & upgrading	Product cleaned, parts replaced or upgraded
Transport (among all phases)	Via train, truck, car, automobile, sea vessel or airplane
Reuse, recycling or composting	Product or component reuse or material recycling.
Incineration or landfilling	Product or components are burned or buried in landfill.







Example: Phases in the lifecycle of a glass cup

Material Extraction
Sand and lime are mined from the Earth.

The diagram shows a circular lifecycle for a glass cup. The phases are: Material Extraction, Component Manufacturing, Assembly & Packaging, Distribution & Purchase, Use, Reuse & Refillability, and Recycling & Reuse. A central glass cup is shown. A red circle highlights the 'Material Extraction' phase, which is linked to an inset photograph of a quarry. The text 'Material Extraction' and 'Sand and lime are mined from the Earth.' is placed to the left of the diagram.

Example: Phases in the lifecycle of a glass cup

Materials Processing
Raw materials are cleaned and processed into glass.

The diagram shows a circular lifecycle for a glass cup. The phases are: Material Extraction, Component Manufacturing, Assembly & Packaging, Distribution & Purchase, Use, Reuse & Refillability, and Recycling & Reuse. A central glass cup is shown. A red circle highlights the 'Component Manufacturing' phase, which is linked to an inset photograph of a glass factory. The text 'Materials Processing' and 'Raw materials are cleaned and processed into glass.' is placed to the left of the diagram.

Component Manufacturing
The material is formed into a drinking glass.

Example: Phases in the lifecycle of a glass cup

The diagram shows a circular lifecycle for a glass cup. The phases are: Material Extraction, Component Manufacturing, Assembly & Packaging, Distribution & Purchase, Use, Reuse & Refillability, and Recycling & Reuse. A central glass cup is shown. A red circle highlights the 'Component Manufacturing' phase, which is linked to an inset photograph of a glass being formed. The text 'Component Manufacturing' and 'The material is formed into a drinking glass.' is placed to the left of the diagram.

Assembly and Packaging
The drinking glass is boxed.

Example: Phases in the lifecycle of a glass cup

Example: Phases in the lifecycle of a glass cup

Distribution and Purchase
The glass is distributed and bought.

Example: Phases in the lifecycle of a glass cup

Installation and use
People drink from the glass.

Example:
Phases
in the lifecycle
of a glass cup

Maintenance and upgrade
It is washed and reused many times.

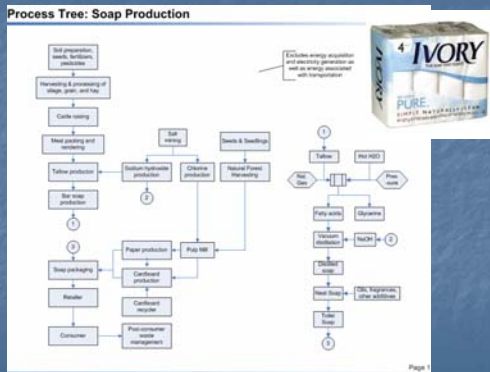
Example:
Phases
in the lifecycle
of a glass cup

Exercise:
What are the phases
in the lifecycle of an
ink cartridge?

Process Tree

- The process tree is a strategic tool that helps designers to explore the extraction and transformation of resources and materials throughout the life of the product. It often triggers common sense thinking about ecological impacts and design priorities.
- Because it diagrams the materials through the manufacturing and use phases of a product, the process tree is also useful for presentation and discussion.

Process Tree: Bar of Soap



Life Cycle Impact Assessment

- Lifecycle impact assessment (LCA) comprehensively quantifies and models the environmental impacts of a product throughout its lifecycle.
- LCA is an internationally recognized method. Its practice is guided by international standards
 - ISO 14040 LCA series

LCA Data Process

1 →	2 →	3 →	4 →	5
Bill-of-materials	Inventory	Characterization	Normalization	Weighting
Materials, processes, energy used, transport, end-of-life	Emissions, resource depletion, and land-use	Environmental impacts: global warming, carcinogens ecotoxicity etc.	Scales impacts according to average impacts of a person in a continental area	Scales impacts according to significance of impacts
<i>Length of list depends on the product</i>	<i>Can be hundreds of chemicals per material</i>	<i>Typically 8-12 categories, via scientific, peer reviewed formulae</i>	<i>North American or European normalization available.</i>	<i>Weighting gives a useful single-figure score.</i>

This table shows the progression of a product's data from the definition of the materials, processes and energy needs, to the emissions data and other environmentally relevant qualities in the inventory, to the estimation and evaluation of the impacts from those emissions. Normalization and weighting are not required by ISO 14040 standards, but they deliver a useful single-figure score.

Simplified Single Figure LCA

All steps combined in one factor

Inventory Characterization Normalization Weighting

Single-figure indicators combine inventory and subsequent steps (as seen in the previous slide) in one multiplication impact factor. Impact factors incorporate **existing inventory data, often from averaged processes**. They report a single figure score per material or process.

Single-figure indicators can be used quickly by designers to model the overall impacts of products.

The LCA Process

1 Define product boundaries

Determine product life, functional unit, system boundaries

2 Make product bill-of-materials

Compile bill-of-materials with energy, transportation and end-of life

3 Calculate estimated impacts

Calculate and compare impacts of the product's components

LCA Factors

- Eco-Indicators provide a simple process for product developers to comprehensively calculate the ecological impacts of products and services.
- The process requires that the total energy and material use of the product be defined over its lifecycle.
- The product elements are each quantified in relevant units and multiplied by their respective eco-indicator factors.
- The resulting numbers are eco-indicators, revealing which elements of the product create the most significant impacts and hold the greatest potential for impact reduction.

1a. Define Product Boundaries

- Product Life
 - The number of years the product will be used
 - The average number of hours/year that the product will be used.
 - Making comparisons...standardize lifetime (e.g., per 1000 hours)

Item	Years	Hrs/Yr	Hrs
Ink-jet printer	6	94	564
Packaging	Quickly consumed		N/A
Automobile	12	600	7,200
Chair	18	600	10,800

Typical life of common products

Wear-out life is used to calculate the life-cycle impacts of products. The technology cycle indicates how soon the technology used in the product is significantly modified. Most products will usually find new homes and be used through the duration of their wear-out life. Determining the life of products not on this list may require speaking with product manufacturers.

Product	Wear-out life, years	Technology cycle, years
audio system	9	4
automobile	20	7
bubblejet printer	8	5
cellular phone	3	1
computer	6	2
computer mouse	6	4
cordless phone	10	5
CRT display	6	3
digital copier	5	2
fax machine	6	2
hand held vacuum	4	6
inkjet printer	4	2
laserjet printer	8	5
LCD display	5	2
miniature robot	5	5
photocopier	5	5
portable CD player	5	10
portable radio	10	2
single use camera	2	4
telephone	5	2
television	11	4
typewriter	15	9
vacuum cleaner	8	7
video projector	5	2
washing machine	10	5

Source: Catherine Rose, A method for formulating Product End-of-Life Strategies, Stanford U., 2001

1b. Define functional unit


- Functional unit
 - The functional unit describes the impacts /primary service of the product. There are no standards for how large or small functional units should be. Often they can be the same as the product lifetime.
 - Functional units enable the comparison of different products that deliver similar services.

Item	Functional Unit
Ink-jet printer	Impacts/1000 prints
Packaging	Impacts/package
Automobile	Impacts/10,000 miles
Chair	Impacts/1000hrs sitting

1c. Define System Boundaries

- System boundaries clearly specify items that are not included in the assessment.
 - Best to include as much of the product system as possible, but often there are items with complex chemical compositions (detergent, toothpaste, and so forth) that we do not have data for, so these are typically left out of this level of assessment.
 - Other items, such as the energy required to wash a drinking glass in a washing machine, can probably be accurately estimated.
- Example: A coffee making machine may or may not include:
 - materials in product and packaging, energy use, coffee filters, water and coffee.
 - It should be possible to include all of this except the water and coffee, given the available impact values.

Example: buttons



Polycarbonate buttons used in a jacket. Jacket has 12 buttons, is worn 150 hrs/yr and has a life of 6 years.

System Boundaries:
 Lifetime: 150 hr/yr x 6 yr = 900 hrs
 Functional unit: impacts/100 hrs worn
 System boundary: excludes jacket, thread, washing

2. Product "Bill of Materials"

- All components in the product
 - noting weight and material per component
- Major processing steps per component
 - such as injection molding
- Additional materials needed in the product's life
 - e.g., fuel, coffee filters, cleaning
- Energy use in primary and secondary modes
 - such as stand-by mode
 - find the amperage & voltage (watts = volts x amps)...convert to kW
- End-of-life scenario
 - recycling, composting, landfill, incineration
- Transportation
 - of components and product among all these phases
 - calculate ton-miles (weight of product (lbs) x miles ÷ 2,000 lbs/ton)
 - Transportation of product and waste

Bill of Materials for Buttons



In the bill-of-materials, we include materials, cardboard packaging, electricity for sewing machine assembly, transport and landfilling.

12 plastic buttons		
Materials	Polycarbonate (PC)	0.050 lb
	Package paper	0.025 lb
Manufacturing process	Injection mold	0.050 lb
	Sewing machine	0.042 kW-hr
Transport	Truck	0.056 ton-mi
Disposal	Landfill	

120 V x 5 Amp
= 1000 W/kW x
5 min/60 min/hr


Weight x distance:
e.g. 0.075 lb x 1500
mi = 2,000 lbs/ton

3. Calculate Impacts

- Compile impact scores
 - Once the bill-of-materials is complete, **materials and processes are multiplied by the impact factors** to give the overall impact score.
 - First, calculate the total impacts over the life of the product. Next, calculate the impacts in the functional unit.


3. Calculate Button Impacts

Input	Amount	x	Factor <i>millipoints/unit</i>	=	Impact <i>millipoints</i>
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



3. Button impacts in the functional unit

We calculate the impacts in the functional unit, which is impacts per 100 hours that the jacket is worn. To do this we multiply by 100 hours and divide by the number of hours the jacket is worn.



We round final impact values to **2 significant figures** because this more realistically represents level of precision of the assessment process.


Examples: 11.99 rounds to 12 and 0.0255 rounds to 0.026

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

$$= \underline{1.33 \text{ millipoints}} \\ \underline{100 \text{ hours worn}}$$

Comparison: Zippered Jacket

- 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



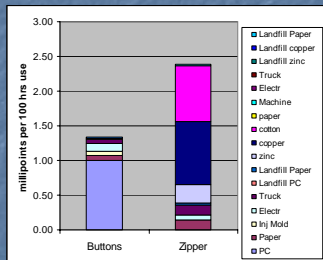
Step 3. Calculate Zipper Impacts

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	0.069 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



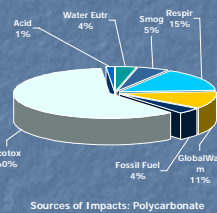
Comparative Analysis

Comparison of the impact of buttons compared to a zipper. Buttons have lower impacts per 100 hours of garment wearing. Polycarbonate is the highest impacting part of the buttons. The cotton tape on the zipper creates larger impacts than the polycarbonate.



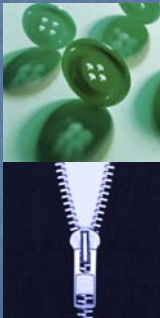
Further analysis

- Can further break down the information to see what contributes to the eco impacts for each component
 - Water eutrophication
 - Photochemical smog
 - Ozone depletion
 - Human toxicity/cancer
 - Human respiratory toxicity
 - Habitat alteration
 - Global warming
 - Fossil fuel depletion
 - Ecotoxicity
 - Acidification



Example Summary

- This example evaluated the environmental performance of a button and zipper;
- It was not a conclusive evaluation of their respective design qualities.
 - Zippers keep out cold better, they are stronger, but they break more often.
 - Buttons pop off but can be readily replaced, while a broken zipper is difficult to replace.
- **Conclusion:**
 A single-figure LCA is a powerful tool for modeling the **environmental performance** of a product or system, but it does not provide all of the necessary design-related information that a designer usually needs to keep in mind.




Comparing Impacts

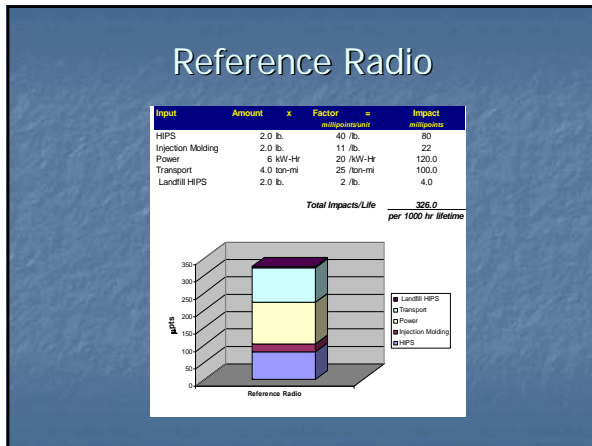
- Reference Product: Radio
 - A hypothetical radio is our reference product. Its housing is made from high impact polystyrene (HIPS), the radio is manufactured in East Asia and transported to North America by airplane (~4000 miles).
 - For the sake of simplicity in demonstrating how to use ecodesign strategies with the impact factors, some components (electronics, cable, switches, paper box) are excluded from this example.
 - Life = 1,000 hours, power = 6 watts

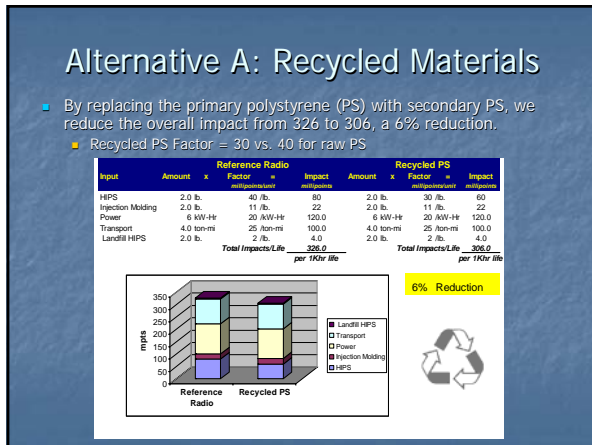


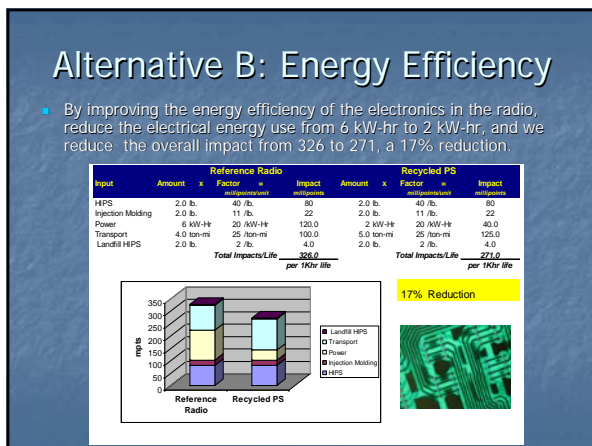
Reference Radio



Input	Amount	x	Factor	=	Impact
			<i>mil/points/unit</i>		<i>mil/points</i>
HIPS	2.0 lb.		40 /lb.		80
Injection Molding	2.0 lb.		11 /lb.		22
Power	6 kW-Hr		20 /kW-Hr		120.0
Transport	4.0 ton-mi		25 /ton-mi		100.0
Landfill:					
HIPS	2.0 lb.		2 /lb.		4.0
Total Impacts/Life					326.0
					<i>per 1000 hr lifetime</i>







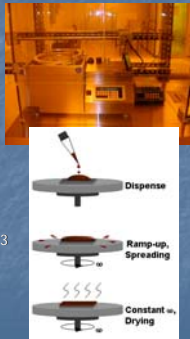
Environmental Accounting

- What are environmental costs?
 - Conventional costs
 - Capital equipment, materials, labor, supplies, utilities, real estate
 - Potentially hidden costs
 - Regulatory: notification, reporting, monitoring, training, insurance, taxes/fees, etc.
 - Upfront costs: site assessments, supplier qualifications, procurement inspection, R&D, etc.
 - Back-end costs: closure, disposal, post-closure care
 - Voluntary: community relations, audits, feasibility studies, etc.
 - Contingent costs
 - Future compliance, penalties, fines, property damage, personal injury damage, legal expenses, natural resource damage, etc.
 - Image costs:
 - Relations with: customers, employees, suppliers, investors, lenders, regulators, etc.
 - Societal costs
 - Environmental degradation; impacts on people, property, and their welfare

Difficulty to quantify



Economic Considerations

- Reduced costs: Conventional Costs
 - Raw materials costs
 - Example: reduction in solvent usage for semiconductor processing
 - Photoresist cost of \$250/gal
 - Coating equipment puts out 7cc per wafer
 - Actual thickness needed is only 0.032cc/wafer
 - 99.5% INEFFICIENT!
 - Simple modifications reduced use to 3 cc/wafer
 - Monthly reduction from 3,431 gal to 1,838 gal
 - 19,116 gal/yr = \$4.8M!



Economic Considerations

- Societal/Global Costs
 - Estimated marginal cost of carbon emissions = £70/t-C ~ \$140/t-C
 - UK FTSE 100 generates 1,126 t of CO2/£1M sales
 - 1 t CO2 = 0.273 t C
 - 307 t C/£1M sales = 153 t C/\$1M sales
 - \$21,500 marginal cost/\$1M sales
 - If accounted for would reduce margins by 2.1%
 - Example: BP
 - 2005 Revenue = \$267B, Net income = \$22B; P/E = 9.63; Market Cap = \$205B
 - Operations → 78Mt CO2 = 21.3 Mt-C x \$140/t-C = \$3B
 - 1% of Revenue; 13.6% of Profit
 - Possible market cap impact = \$3B x 9.63 = \$29B!

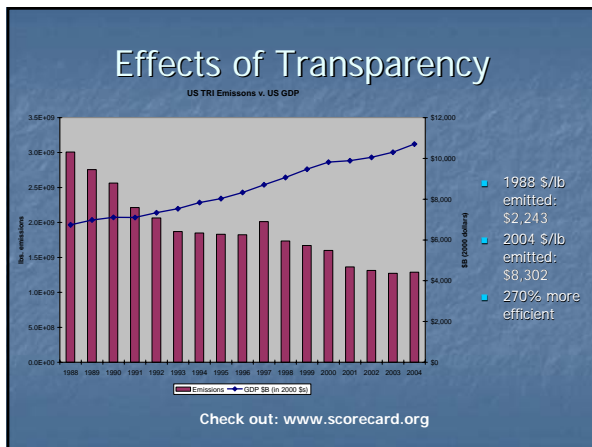



FTSE data from Henderson Global Investors, The Carbon 100, 2005


Sarbanes-Oxley (SOx) 2002



- Sarbanes-Oxley Act of 2002
 - Transparency of information
 - Outcome of Enron, MCI, and other corporate debacles
 - Improved financial liability disclosures
 - §401(a)(j): shall disclose all material off-balance sheet transactions, arrangements, obligations...that may have a material current or future effect on financial condition.
 - "Material" issues in this broad provision, and related §409 include environmental liabilities.
 - Definitely includes environmental clean up liabilities, but what about potential liabilities for climate change?
- Environmental transparency
 - Toxics Release Inventory (TRI), begun in 1988
 - Covers 650 chemicals and chemical categories




Metrics



- "What gets measured, gets done"
 - W. Edwards Demming
 - What gets measured, and rewarded, gets done
- Use of "Scorecards" and "Dashboards"
- Determination of Key Metrics and setting Metric Targets



Metrics


- Energy
 - Energy used
 - Renewable energy used/bought
- Water
 - Water used
 - Water pollution
- Air
 - GHG emissions:
 - Releases to air by type chemical (e.g., NOx)
- Waste
 - Hazardous waste
 - Solid waste
 - Recycled waste
- Compliance
 - NOVs (notices of violations)
 - Fines or penalties paid



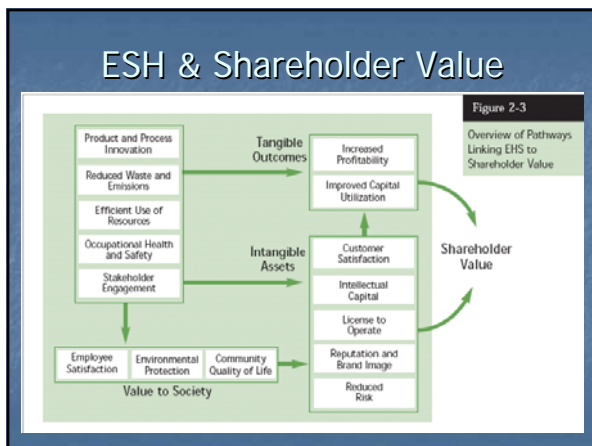
- Track both relative & absolute metrics
 - Per unit of production for normalization and measure of efficiency, but still need to know the TOTAL
- Capture data at multiple levels within the organization
 - Identify divisions, departments or processes that need the most attention
- Collect information for the whole value chain
 - Suppliers
 - Users/Customers

Example:

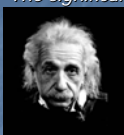





	A	B	C	D	E	F	Trend
5.1.1.1 DART Rate	A	B	C	D	E	F	↑
DOE Average →			0.87				
5.1.1.2 Type A or B accidents	A	B	C	D	E	F	↑
			0				
5.1.2 TRC Rate	A	B	C	D	E	F	↑
DOE Average →			0.95				
5.1.3 Reportable occurrences of releases to the environment	A	B	C	D	E	F	↑
			0				



The significant problems we face cannot be solved at the same level of thinking we were at when we created them.
- Albert Einstein



"Failure is not an option..."
- Gene Kranz, NASA Flight Director
when addressing NASA engineers to come up a solution to filter CO₂ from the air of the crippled Apollo 13 spacecraft to save the crew.

