




## Life Cycle Analysis

Cradle to Grave Impacts



## What Can the Earth Handle?

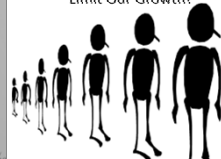
- The estimate of Earth's Maximum supportable population is 13.4 billion.
- Looking at the population statistics, where are we headed?

**Renewable Energy Source Will Limit Our Growth!**

Population (2007)	Annual Growth	Rate (00 - 07)
World	6.7 Billion	1.24%
Least DC	5.4 Billion	1.44%
Most DC	1.2 Billion	0.36%
US	301 Million	1.03%


Average per capita energy consumption is 3 kW/person

- US 12 kW/person
- Industrialized 7.5 kW/person
- Denmark 5.1 kW/person
- Developing 1kW/person




## Being Green is Trendy . . . . . What Does Science Say?

- Industry is looking for ways to green their products and manufacturing processes.
- Individuals and families are looking to green their homes and lifestyles.
- How can you tell if something really is green??
- What is currently happening to achieve this goal?
- Scientists perform a **Life Cycle Assessment (LCA)**



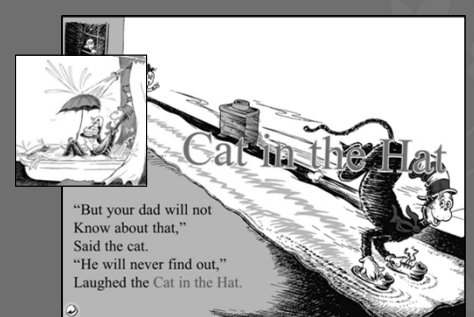
## What is LCA?

Steps and Methodology



**Cradle to Grave  
Cradle to Shelf**

**Comprehensive Evaluation of Impact**



**Cat in the Hat**

“But your dad will not know about that,”  
Said the cat.  
“He will never find out,”  
Laughed the Cat in the Hat.

**LCA helps to avoid shifting environmental problems from one area or medium to another.**

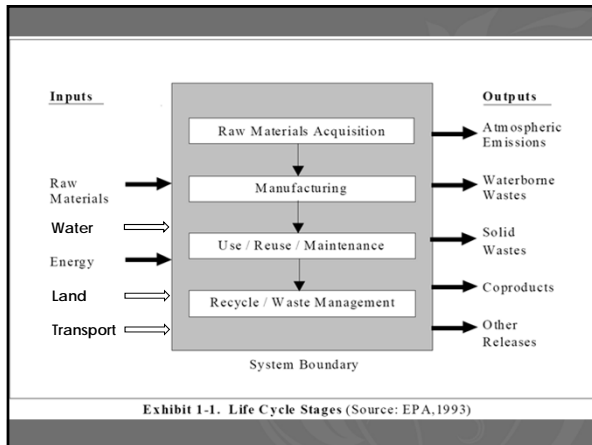
## Who Does LCA?

- Conducted by an industry sector to enable it to identify areas where improvements can be made, in environmental terms.
- LCA may be intended to provide environmental data for the public or for government.
- Companies use LCA for marketing and advertising, to support claims that their products are 'environmentally friendly' or even 'environmentally superior' to those of their rivals.

## A life-cycle approach

- Ensures companies identify the multiple environmental and resource issues across the entire life-cycle of the product
- Knowledge of these issues informs business activities:
  - planning, procurement, design, marketing & sales
- Rather than just looking at the amount of waste that ends up in a landfill or an incinerator, **a life-cycle approach identifies energy use, material inputs and waste generated from the time raw materials are obtained to the final disposal of the product \***

\* Product Life-Cycle Analysis: Environmental activities for the classroom, Waste Management and Research Center, Champaign, IL, 1999



## A life-cycle approach

- With a life-cycle approach, companies employ the tools they need to:
  - Reduce impacts across the life-cycle
  - Capitalize on opportunities for their business**
    - How about Hussey Seating Company?
    - Reduced packaging requirements?
    - Thinner, lighter water bottles?
    - Other examples?
- Tools range from simple mapping of life-cycle stages to comprehensive quantitative assessments

## Life-cycle assessment

- Two attributes make LCA distinct and useful as an analytical tool:
  - Whole system consideration of the total product life-cycle
  - Presentation of tradeoffs among multiple environmental issues
- LCA is quantitative (within limits)**

## LCA Method(s)

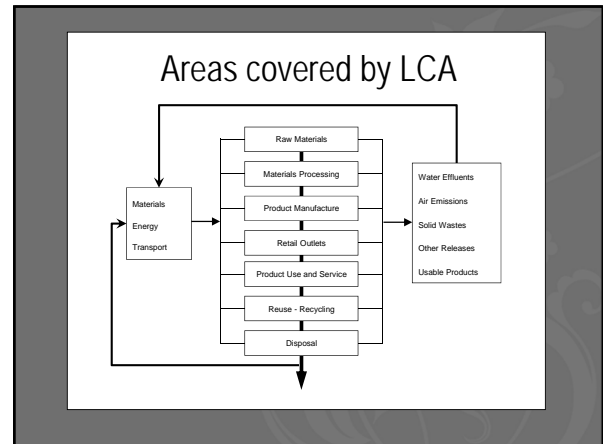
- Initially, numerous variants of LCA "methods" were developed/investigated, but today there is consensus that there is only one basic method with a large number of variants
- Originally called **REPA**s - Resource and Environmental Profile Analysis
- The Society of Environmental Toxicology and Chemistry (SETAC), an international platform for toxicologists, published a Code of Practice, a widely accepted series of guidelines and definitions.
- ISO 14040-14043 is considered to be the LCA standard.**
- EPA/600/R-06/060, May 2006, Life Cycle Assessment: Principals and Practice

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## The Four Steps of an LCA

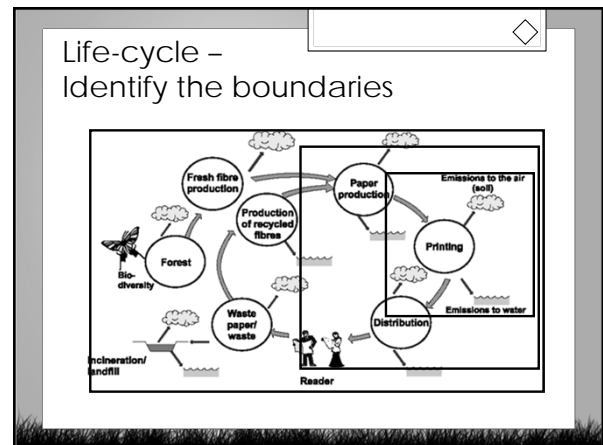
- **Goal and Scope Definition (ISO 14040)**
- **The Life-Cycle Inventory (ISO 14041)**- What are the energy, raw materials, emissions, & wastes? What data are needed?
- **Life-Cycle Impact Analysis (ISO 14042)**- Assess environmental impacts identified in the life-cycle inventory.
- **Life-Cycle Improvement - (ISO 14043)** Identifies opportunities to reduce the environmental impacts by modifying of the life-cycle inventory.

● ISO1400 link provided for reference only.



## How to do LCA

- Determine **scope** and **system boundaries**
  - functional unit
  - life-cycle stages
  - define "unit processes"
- Life Cycle Inventory aka **Data collection**
- Analysis of inputs and outputs
- Assessment of numerous environmental issues
- Interpretation
- Life Cycle Improvement



## Function & Functional Unit

Function	Example
<ul style="list-style-type: none"> <li>● Service provided by a system</li> <li>● What it does!</li> <li>● Functional Unit</li> <li>● Gives the function a number value</li> <li>● Allows comparison between products</li> <li>● Reference point</li> </ul>	<ul style="list-style-type: none"> <li>● Wooden Pencil vs. Mechanical Pencil</li> <li>● Function = "Writing"</li> <li>● Functional Unit = "1 meter of writing"</li> </ul>

## Function and Functional Unit

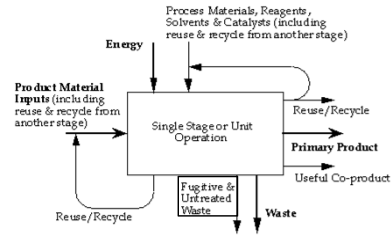
- Where to draw the line?
- HUGE impact on results
- Compare one reusable bag to one single-use plastic bag? How many uses?
- What are some reasonable assumptions?
- Reading assignment used # of bags required to carry 70 items home each week for one year.

### Life-cycle stages

- Products can be evaluated through each stage of their life-cycle:
  - Extraction or acquisition of raw materials
  - Manufacturing and processing
  - Distribution and transportation
  - Use and reuse
  - Recycling
  - Disposal
- For each stage, identify inputs of materials and energy received; outputs of useful product and waste emissions
- Find optimal points for improvement – eco-efficiency

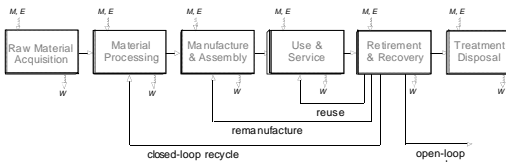
### Single Stage Flow Diagram

- The following diagram contains inputs and outputs to be quantified in a single stage or unit operation



Source: EPA Life-Cycle Design Guidance Manual, EPA Report no. EPA/600/R-92/226, page 104

### Product Life Cycle



M, E = Material and Energy inputs to process and distribution  
 W = Waste (gas, liquid, or solid) output from product, process, or distribution

➔ Material flow of product component

### Data Collection Life Cycle Inventory Analysis

- **Time-sensitive:** past 5 years
- **Geographical:** does it match the location from the goal
- **Technology:** best available technology for process
- **Representativeness:** reflects population of interest
- **Consistency:** matches the procedure
- **Reproducibility:** another person could find it
- **Never Forget . . . . .**
  - **Accuracy:** Quantified values are correct
  - **Precision:** The consistent reproducibility of a measurement
  - **Completeness:** Covers all the areas outlined in the scope

### Items To Consider??

#### Inputs

- What is needed to make the substance
- Energy
- Water
- Materials
- Land
- Labor

#### Outputs

- What comes out of the system!
- Products (electricity, materials, goods, services)
- Waste
- Emissions
- Co-products



### Problems with Inventory Analysis

- The inventory phase usually takes a great deal of **time and effort** and mistakes are easily made.
- There exists published data on impacts of different materials such as plastics, aluminum, steel, paper, etc.
  - However, the data is often **inconsistent** and not directly applicable due to different goals and scope.
  - It is expected that both the quantity and quality of data will improve in the future.
- Mass and energy balances are **not correct** and defy laws of thermodynamics.
- Results are **generalized improperly**.




## Data Analysis Environmental Impact Categories

- Global Warming Potential
- Gases in the atmosphere that absorb and emit radiation
- Trap heat from the sun
- Water vapor, CO<sub>2</sub>, CH<sub>4</sub>, ozone, NO<sub>2</sub>
- Abiotic Depletion
- Consumption of non-living resources
- Human Toxicity Potential
- Value that shows harms to humans from chemicals
- Land Use
- How much land is needed





## Environmental Impact Categories Continued . . .


- Eutrophication
- Increase in chemical nutrients containing nitrogen or phosphorus
- land or water
- overgrowth of plants
- killing organisms at bottom of water
- Water Use
- Mercury
- Acidification
- caused by pollution from fuels & acid rain
- low pH
- Smog (Winter or Summer)
- Energy Use
- Solid Waste
- Oil
- . . . . . AND MANY MORE!!

## Global Impact Categories

-  **Resource depletion**
  - Source: Use of copper, zinc, oil etc.
  - Effect: Reduction of possibilities for future generations
-  **Green house effect**
  - Source: Combustion (transport, energy etc.)
  - Effect: Increase in temperature, desert formation etc.
-  **Depletion of ozone layer**
  - Source: CFC and HCFC from foam and coolants
  - Effect: UV radiation, skin cancer etc.

## Regional Impact Categories

-  **Ozone formation**
  - Source: Transport, energy, industry (Hydrocarbons etc.)
  - Effect: Ozone formation (Damage of lung tissue etc.)
-  **Acidification**
  - Source: Transport, energy, agriculture
  - Effect: Damage to woodlands, lakes and buildings (SO<sub>x</sub>, NO<sub>x</sub>, NH<sub>3</sub>)
-  **Eutrophication**
  - Source: Fertilisers, waste water, transport and energy
  - Effect: Eutrophication (Damage to plants and fish)
-  **Persistent toxicity**
  - Source: Waste water, incineration, industry, ships etc.
  - Effect: Accumulation: Chronic damage to ecosystems and organisms

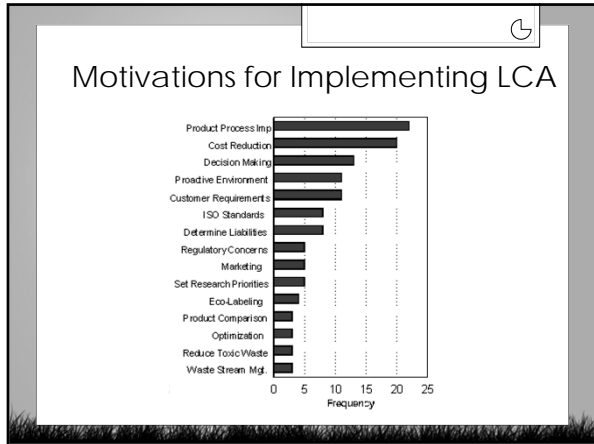


## Why Conduct an LCA?

Benefits and Drawbacks

## LCA and the Regulatory Process

- LCA is voluntary in the U.S. at present
- Its use is limited, but expanding
- LCA is mandatory in some European countries
- Used as the basis of packaging recovery and recycling targets
- Global market means LCA will eventually be required for all products



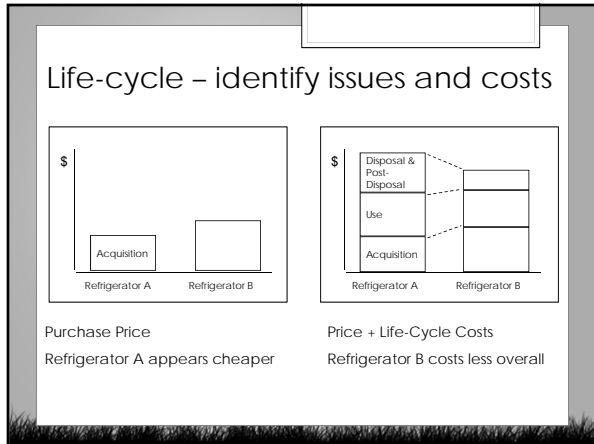
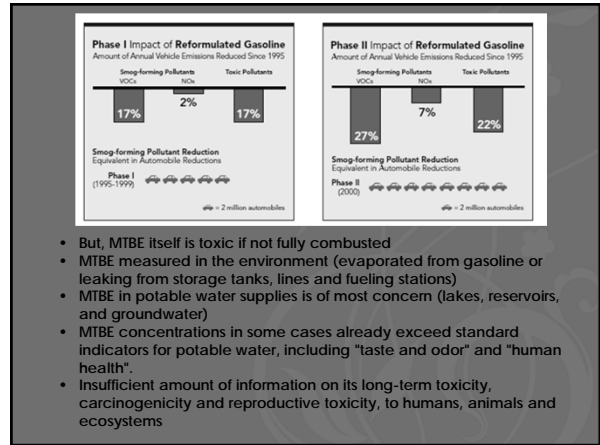
### Life-cycle – helps avoid shifting the issues

- Looking at the entire life-cycle helps ensure reducing waste at one point does not simply create more waste at another point in the life-cycle
- Issues may be shifted** – intentionally or inadvertently – among:
  - Processes or manufacturing sites
  - Geographic locale
  - Different budgets and planning cycles (first cost)
  - Environmental media – air, water, soil (MTBE)
  - Sustainability dimension: economic, social, environmental burdens
- Depends on “boundaries”
- Be conscious of what is shifted and to where!
- For example, MTBE...

### Methyl tertiary butyl ether - MTBE

CONTAINS MTBE  
 THE STATE OF CALIFORNIA HAS DETERMINED THAT THE USE OF THIS CHEMICAL PRESENTS A SIGNIFICANT RISK TO THE ENVIRONMENT

Replaced lead in gasoline. Good!

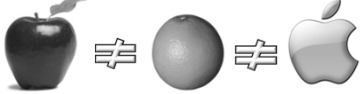


### Benefits Of LCA

- Companies can claim one product is better than another on the basis of LCA
- LCA inventory process helps to narrow in on the area where the biggest reductions in environmental emissions can be made
- Can be used to reduce production costs

### Drawbacks of LCA

- Using LCA to compare products is like comparing apples to oranges.
  - For example, which is worse: a product that pollutes the air by consuming energy from coal-fired power plants or one that disrupts ecosystems by consuming energy from massive hydroelectric dam projects? Both types of pollution should be minimized if possible.



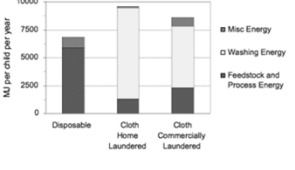
### Drawbacks (cont.)

- Comparison between heavy energy demand and heavy water use: which imposes greater environmental burden?
- How can the use of non-renewable mineral resources like oil or gas (the ingredients of plastics) be compared with the production of softwoods for paper?
- How should the combined impacts of the landfilling of wastes (air and groundwater pollution, transport impacts etc) be compared with those produced by the burning of wastes for energy production (predominantly emissions to air)?

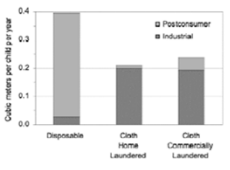
### Drawbacks (cont.)

- LCAs may give different and sometimes contradictory conclusions about similar products.
- Recycling adds more complexity to LCA.

#### The diaper LCA study by Franklin Associates, Ltd., 1992



Diaper Type	Feedstock and Process Energy (MJ)	Washing Energy (MJ)	Misc Energy (MJ)
Disposable	~6000	0	0
Cloth Home Laundered	~1000	~8000	~1000
Cloth Commercially Laundered	~2000	~6000	~2000



Diaper Type	Industrial Waste (m³)	Postconsumer Waste (m³)
Disposable	~0.05	~0.35
Cloth Home Laundered	~0.20	0
Cloth Commercially Laundered	~0.15	0

**Figure 1 - Total energy used by each diaper type in one year.** Feedstock and process energy includes energy used through cotton growing, material processing and diaper manufacture. It also includes energy used and embodied in bleach and detergent.

**Figure 2 - Volume of solid waste per year.** Industrial Waste includes waste used to produce the diaper such as raw material production and process, manufacture trimmings, and ash from electricity generation. Post consumer waste refers to substances thrown out: the diaper itself, child waste, and packaging.


(Source: <http://www.ilea.org/lcas/franklin1992.html>)

### Conclusions – why take a life-cycle approach?


- Systems perspective
- Integrates environment into core business issues
- Efficiency
- Innovation
- Better return on investment – identify point of “biggest bang for the buck” \*
- Engage stakeholders – investors, customers, employees

\* [www.ciwm.ca.gov/EPP/LifeCycle/default.htm](http://www.ciwm.ca.gov/EPP/LifeCycle/default.htm)


### LCA Examples



### Did you know...



- Producing one ton of recycled steel saves the energy equivalent of 3.6 barrels of oil and 1.5 tons of iron ore, compared to the production of new steel?
- Producing paper using a chlorine-free process uses between 20 and 25 percent less water than conventional chlorine-based paper production processes?



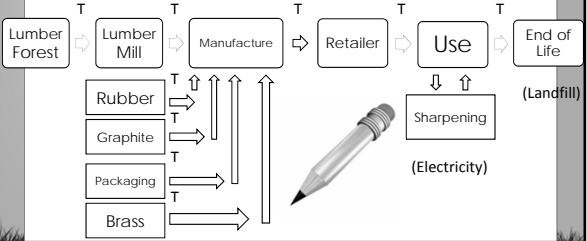
### Goal and Scope

#### Wooden Pencil vs. Mechanical Pencil

**Goal** = Compare 2 writing utensils for classroom use.

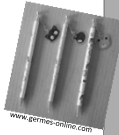
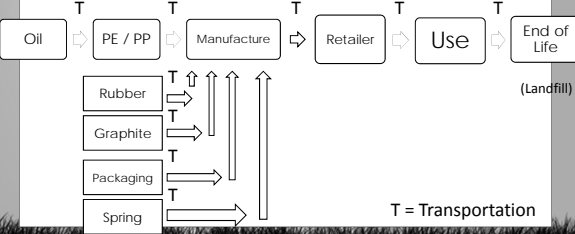
**Scope:** Wooden Pencil (T = Transportation)

#### Process Flow Diagram



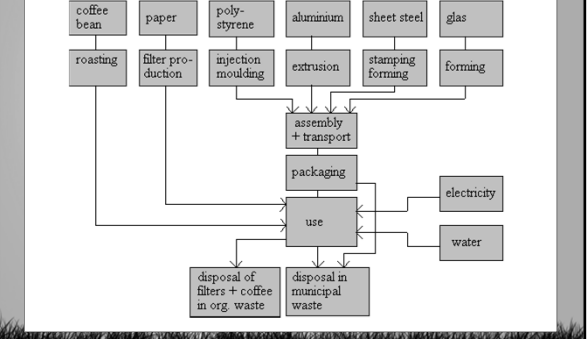
### Scope: Mechanical Pencil

PE = Polyethylene  
PP = Polypropylene  
Both materials are **plastic polymers** (large molecules) used to make many products.

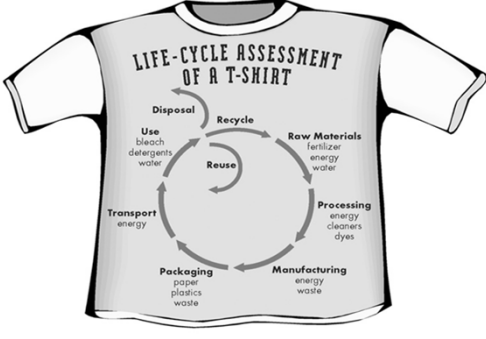



T = Transportation

### Example: Simplified Process Tree for a Coffee Machine's Life-Cycle

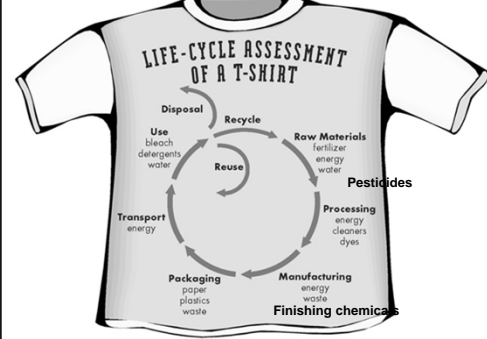


### LIFE-CYCLE ASSESSMENT OF A T-SHIRT



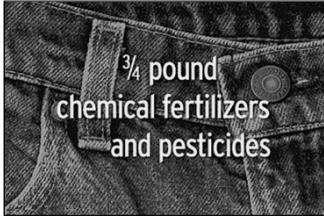
Worldwatch Institute, Worldwatch Paper 166: Purchasing Power: Harnessing Institutional Procurement for People and the Planet, July 2003, www.worldwatch.org

### LIFE-CYCLE ASSESSMENT OF A T-SHIRT



Worldwatch Institute, Worldwatch Paper 166: Purchasing Power: Harnessing Institutional Procurement for People and the Planet, July 2003, www.worldwatch.org

### Identifying issues at each life-cycle stage




**3/4 pound chemical fertilizers and pesticides**

*Estimated amount of synthetic fertilizers and pesticides it takes to produce the cotton for a conventional pair of jeans.*

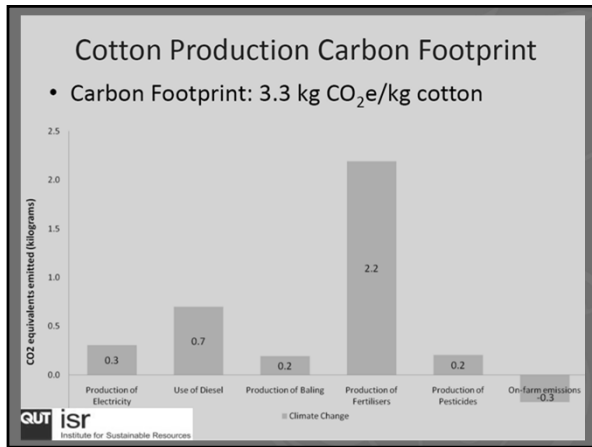
*Source: "The Organic Cotton Site: Ten good reasons"*

### The Study

- Main Focus:
  - GHG emissions
  - Fossil fuel depletion
- Goals:
  - Market communication
  - Identify GHG reduction possibilities in the production and manufacturing chain



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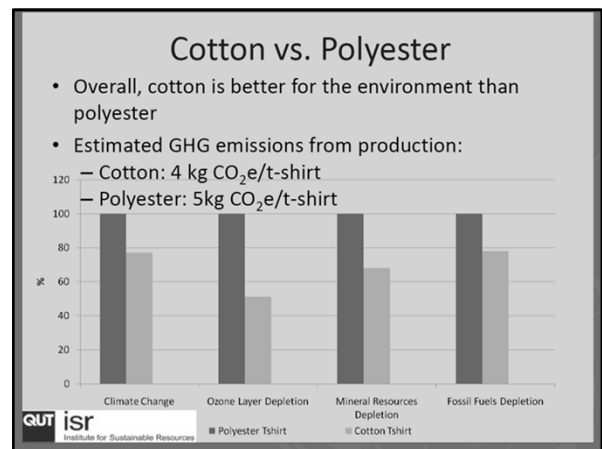
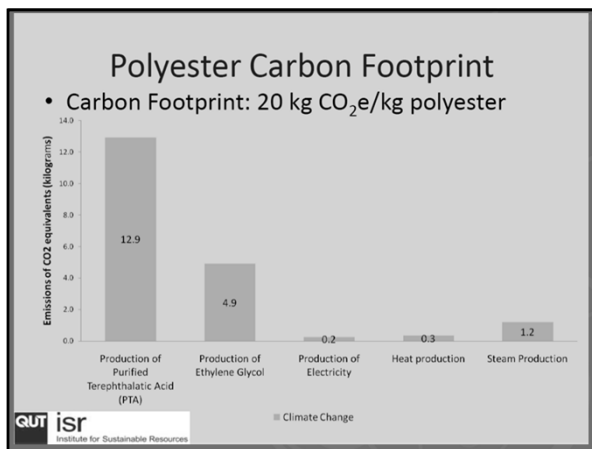


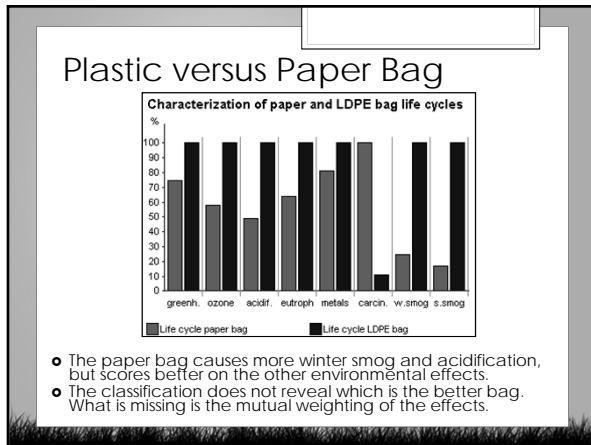
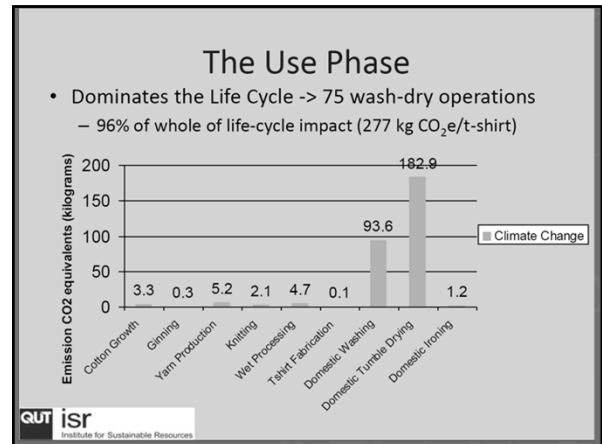
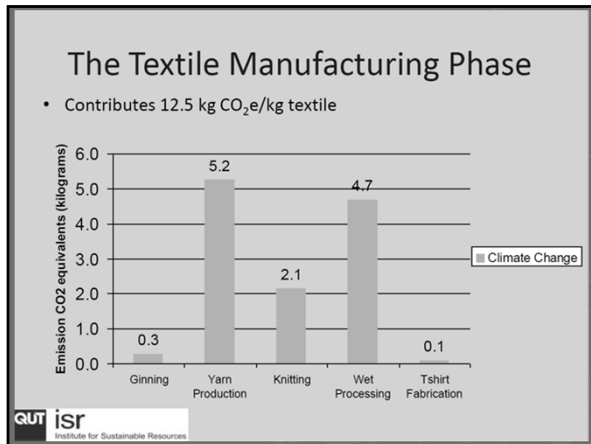
### On-Farm GHG Emissions

- Assume Standard N fertiliser 200 kg N/ha  
+ 0.101 kg CO<sub>2</sub>e/kg cotton
- On-farm use of fuel  
+ 0.15 kg CO<sub>2</sub>e/kg cotton
- Cotton plant absorbs CO<sub>2</sub>  
- 0.567 kg CO<sub>2</sub>e/kg cotton

Net On-farm Emissions are -0.279 kg CO<sub>2</sub>e/kg cotton

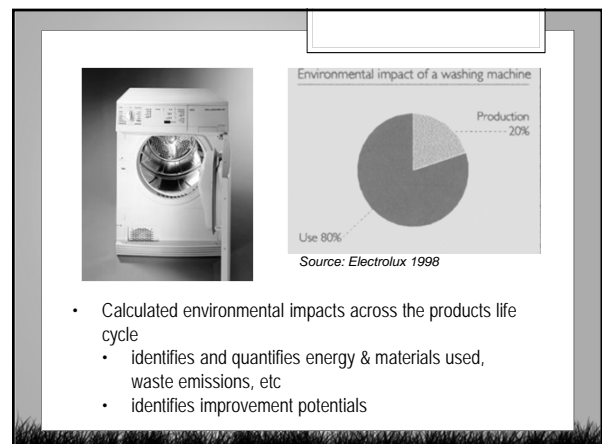
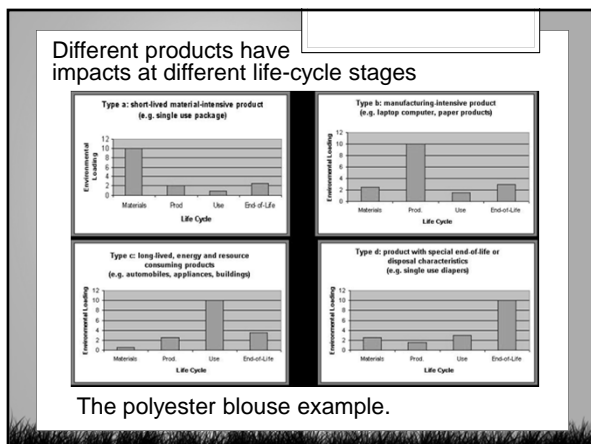
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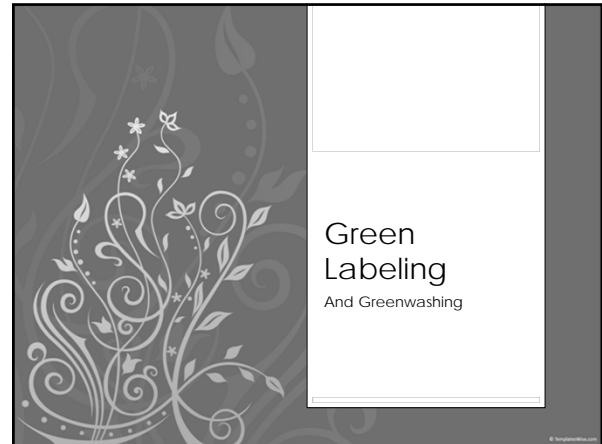
### WHICH CUP SCORES BEST WITH OUR ENVIRONMENT?

ENVIRONMENTAL IMPACT	FOAM PLASTIC	CHINA/GLASS	PAPER
ENERGY CONSERVATION	✓ VERY HIGH: Needs relatively little energy to make	POOR: Needs high energy to run kilns and wash for reuse	POOR: Requires high energy to run mills
WATER CONSERVATION	✓ EXCELLENT: Little required	POOR: Needs large quantities to make and wash	POOR: Requires large quantities to make
WASTE-TO-ENERGY CONVERSION	✓ EXCELLENT	NONE	POOR
RECYCLABILITY	✓ TOTAL	PARTIAL	PARTIAL
LANDFILL CONTAMINANTS	✓ NONE: Inert	✓ NONE: Inert	Can contribute to methane gas and leachates
AIR POLLUTANTS WHEN PROPERLY INCINERATED	✓ NONE	✓ NONE: Doesn't burn	✓ VIRTUALLY NONE
IMPACT ON OZONE LAYER	✓ POSITIVE: Contains no CFCs	✓ POSITIVE: Contains no CFCs	✓ POSITIVE: Contains no CFCs
RELATIVE POCKETBOOK IMPACT (PRICE)	✓ LOW	HIGH	HIGH



### LCA of washing machines

	Production	Distribution	Use	Disposal
Energy	4%		96%	
Air Pollution	2%		98%	
Water Pollution	4%	1%	96%	
Solid Waste	7%	1%	87%	5%
Water Consumption	2%		98%	



- ### Eco-Labeling
- Widely used in Europe to help consumers identify "environmentally friendly"
    - Germany - Blue Angel
    - Netherlands - Dutch Ecolabel
    - EU developing unified European program
    - Also addressed in ISO 14000
  - Recently has been introduced in the U.S.
    - Green Seal in 1989
  - Can be very misleading if not done properly

- ### Eco-Labeling
- 
- 24 products in 1989
  - Today there are thousands
  - Green Seal and ISO set standards based on about 10 to 15% of products meeting the standard.
  - As more products reach the goal, standards are updated to maintain the top 10 to 15% bracket.
  - Moving the goal posts ratchets down green

- ### Greenwashing Examples
- Environmentalists have argued that Bush Administration's Clear Skies Initiative actually weakens air pollution laws.<sup>1191</sup>
  - Many food products have packaging that evokes an environmentally friendly imagery even though there has been no attempt made at lowering the environmental impact of its production.<sup>1201</sup>
  - In 2009, European McDonald's changed the color of their logos from yellow and red to yellow and green; a spokesman for the company explained that the change was "to clarify [their] responsibility for the preservation of natural resources."<sup>12111221</sup>

- ### Greenwashing Examples
- An article in Wired magazine alleges that slogans are used to suggest environmentally benign business activity: the Comcast ecobill has the slogan of "PaperLESSisMORE" but Comcast uses large amounts of paper for direct marketing. The Poland Spring ecoshape bottle is touted as "A little natural does a lot of good", although 80% of beverage containers go to the landfill. The Airbus A380 airliner is described as "A better environment inside and out" even though air travel has a high negative environment cost.<sup>123</sup>
  - According to Fred Pearce's Greenwash column in The Guardian, "clean coal" is the "ultimate climate change oxymoron—pure and utter greenwash" he says.<sup>124</sup>
  - The Advertising Standards Authority in the UK upheld several complaints against major car manufacturers including Suzuki, SEAT, Toyota and Lexus who made erroneous claims about their vehicles.<sup>125126127128</sup>
  - Kimberly Clark's claim of "Pure and Natural" diapers in green packaging. The product uses organic cotton on the outside but keeps the same petrochemical gel on the inside. Pampers also claims that "Dry Max" diapers reduce landfill waste by reducing the amount of paper fluff in the diaper, which really is a way for Pampers to save money.<sup>129130</sup>

## Greenwashing Examples

- **Ubisoft** recently announced that it would no longer include paper manuals with their **Playstation 3** or **Xbox 360** games, claiming that this cost-cutting measure was for the purposes of being environmentally friendly.<sup>121</sup>
- The recent explosion of web-based Green business certifications demonstrate a more sophisticated form of greenwashing. Although asking for online "self-assessment" forms to be filed, online Green certification are "blind audits" that are easily cheated. In many cases, it comes down to paying a fee. The deception is made worse because the sham Green certifications are offered to the public as though they were earned. Credible companies like ISO, LEED, and Green Business League require actual audits to be performed prior to certification.<sup>121</sup>
- A 2010 advertising campaign by Chevron was described by the **Rainforest Action Network**, **Amazon Watch** and **The Yes Men** as greenwash. A spoof campaign was launched to pre-empt Chevron's greenwashing.<sup>122</sup>

Homework for bonus points on next quiz: Visit Green Seal and read one or more of their standards. Be prepared to summarize and/or discuss the one you chose.

<http://www.greenseal.org/GreenBusiness/Standards.aspx>

## Issues with Eco-Labeling

- Misleading or Fraudulent Claims
  - What do these terms really mean?
    - Organic
    - Recycleable
    - Biodegradable
    - Ozone Friendly
    - Flushable
  - Made up terms to trick consumers
- Uninformative Claims
- Green Consumerism – an oxymoron?

## References

- Paul L. Bishop, Pollution Prevention
- Dr. Michael Lepech, Stanford University
- World Business Council for Sustainable Development
- Institute for Sustainable Resources  
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