D-LAB WASTE:
LIFE CYCLE ASSESSMENT
LIFE CYCLE ASSESSMENT (LCA)

A tool for the systematic evaluation of the environmental aspects of a product or service system through all stages of its life cycle. LCA provides an adequate instrument for environmental decision support.

- UNEP

The term *life cycle* indicates that every stage of the life cycle of the service, from resource extraction to ultimate end-of-life treatment, is taken into account.

For each operation within a stage, the inputs (raw materials, resources and energy) and outputs (emission to air, water and solid waste) are calculated and then aggregated over the life cycle by means of material and energy balances, drawn over the system boundary [4,6].

– Arena, Mastellone, & Perugini (2003)
EXAMPLES

- Biomass (corn, soy) in different manufacturing applications
- Waste management process
- Energy and environmental impact of product alternatives
- Different modes of transportation to inform new infrastructure

- Product, Process or Activity
LIFE CYCLE ANALYSIS APPLIED TO WASTE MANAGEMENT

• Harold Smith presents concept of cumulative energy requirements for production of chemical intermediates and products – 1963

• Oil crisis of 1970s?

• Limits to Growth – MIT researchers for the Club of Rome (international think tank) with computer modeling --- economic collapse and major population decline by 2030.

• Blueprint for Survival
• Coca-Cola comparing different bottle types in the 1969; what had the greatest energy and enviornmental cost. No public.

• Known then as Resource and Environmental Profile Analysis

HISTORY OF LCA (1980S)

• No common methodology for LCA
• LCA used to analyze same products with different results
• Used to ‘greenwash’ or substantiate corporate claims
HISTORY OF LCA (1990S)

- Age of harmonization and embracing LCA
- ISO (international Standards Organizaiton) comes out and promises to standardize LCA in response – development of ISO standards(14,000 family).
- SETAC (Society of Environmental Toxicology and Chemistry) has been involved in harmonizing the efforts of LCA

That said ISO – never sought to standardize LCA methods. “There is no single method for conducting LCA”

HISTORY OF LCA (2000S +)

- Age of Elaboration
- UNEP and SETAC launch the Lifecycle Initiative
- Lifecycle initiative --- to put lifecycle into practice and improve the tools; series of other governmental agencies (in Europe and US) promote LCAs and shared data.

- Opportunity to extend LCA to also include cost (Life Cycle Cost) and even beyond

- Life Cycle Sustainability Analysis to broaden the scope to cover people, planet and prosperity.
- Go beyond a singular product to sector to economy
- Also be the physical relations (like the land/context and resources available), economic and behavioral relations

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LCA APPLIED TO WASTE MANAGEMENT

• First introduced in mid 1990s
• Often system based, focusing on a service
• Scope:
  – “Bin-to-grave” or “curbside to grave”
  – Starting point is waste
• Functional Unit
  – Tons of waste, ash, etc
PHASES OF LCA

GOAL & SCOPE DEFINITION

INVENTORY

IMPACT ASSESSMENT

IMPROVEMENT ASSESSMENT

INTERPRETATION

Source: Garman, J. (2011)
based on ISO 14040

Courtesy of Dovetail Partners, Inc. Used with permission.
GOAL + SCOPE

• Define the objective and system boundaries
• Identify the product, process or activity to be studied:
  – Material (plastic, paper, etc)
  – Waste source (households, industry, etc)
  – Solid waste unit (MSW, ash, compost)
  – Remanufacturing processes, energy recovery or disposal (compost, biogas, etc.)
• Function, functional unit or reference flow
• System boundaries
• Criteria for inputs/outputs
• Data quality requirements
EXAMPLE OF FUNCTIONAL UNITS

• All activities linked with the disposal and recycling of WEEE (waste of electrical and electronic equipment) accumulated over one year (2004) in Switzerland.

• Amount of communal waste generated annually in a selected rural area in Austria

• Treatment and disposal of 1 ton of MSW in Sao Paulo

• Collection and treatment of 566,000 tons of MSW, which correspond to the annual generation in the district of Bologna for 2006

• 1 ton of product gas produced from the assortment of waste materials in Singapore

Fig. 1. The complete life cycle of MSW

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INVENTORY ANALYSIS CALCULATION

Direct Burdens with WM operations
+ Indirect Burdens
  providing materials and energy to WM operations
- Minus: Avoided Burdens
  Economic activities displaced by materials and/or energy

Key Inputs: Electricity, fossil fuels, water, raw materials
Key Outputs: Air emissions, water discharges, solid wastes, resource use
IMPACT ASSESSMENT INDICATORS

Each of these indicators/impacts is connected to something that wants to be changed.

The final goal is figuring out how these indicators impact the actual work/process.

IMPACT ASSESSMENT STEPS

• Classification:
  – What does this emission contribute to?

• Characterization:
  – How much does it contribute?

• Normalization:
  – Is that much?

• Valuation:
  – Is it important?
LCA LIMITATIONS

- Public health, hygiene, procedure safety
- Not all risk factors are incorporated:
  - Pathogenic (virus, bacteria, etc)
  - Eco-toxicological (dose-response relationship)
- Land-use
- Dismenity effects
- Destruction of natural habitat

Source:
LCA LIMITATIONS

• Does not differentiate impacts by time they occur
• Outcome does not reflect:
  – Changing conditions of WM (population, generation, composition)
  – Policy changes
• Not as strong at evaluating site-specific issues (i.e., water consumption)
LCA LIMITATIONS

• Requires relevant data – from literature, databases, or through surveys
• Costly ($50k+ for product analysis)
• Reliability of results
REVIEW OF LCA STUDIES OF SWMS
(LAURENT, ET. AL)


HOW DO WE MEASURE REFUSAL?

• Requires info on waste system and the upstream product system

• Refusing waste may be associated with other behavior changes which need to be measured (rebound effects)
  – Decrease in unsolicited mail = more internet time

• Currently no consensus on how to measure this

**FINDINGS**

In General:

- **Paper:** Recycling > Thermal > Landfill
- **Organics:** Thermal/Compost/Aerobic Digestion > Landfill
- **Plastic:** Recycling > Thermal > Landfill
- **Mixed Waste:** Thermal > Landfill

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Fig. 5. Comparative analysis of key findings for selected waste treatment technologies applied to manage paper, plastic, organic and mixed waste fractions (total of 34 studies). The nodes “R” stand for recycling, “L” for landfiling, “T” for thermal treatment, “C” for composting, “AD” for anaerobic digestion. For each pair comparison, three circled numbers are indicated, representing the number of studies concluding on the better environmental performance (i.e., lower overall environmental impact) of one waste treatment technology over another (numbers closer to each of the two nodes), or reaching either inconclusive results or results with similar environmental burden (numbers in the middle). The size of the circles is proportional to the number of studies.


WHAT’S GENERALIZABLE?

THE WASTE HIERARCHY

Preferred environmental option

- Reduce
- Re-use
- Recycle
- Energy Recovery

Least preferred environmental option

- Disposal

Image by MIT OpenCourseWare.
OPPORTUNITIES IN LCA RESEARCH ON WM

• Sharing findings of existing LCA
• LCA application:
  – In developing countries
  – Beyond household waste (construction and demolition, industry, etc)
  – Extending material scope (plastic, paper, metals, glass)
  – To waste prevention
Stone Age
Copper Age
Bronze Age
Iron Age

PLASTIC AGE

Courtesy of Jennifer Cowley on Flickr. CC BY-NC-SA. Used with permission.
THE PLASTIC AGE

SUSTAINABILITY METRICS: LCA AND GREEN DESIGN IN POLYMERS (TABONE, ET. AL)

12 Polymers
- Petrolum/Fossil Fuels (7)
  - PET
  - HDPE
  - LDPE
  - PP
  - PC
  - PVC
  - GPPS
- Biopolymers (2)
  - PLA made via a general process (PLA-G)
  - PLA made via Nature Works (PLA-NW)
- Polyhydroxyalkanoate (2)
  - PHA from corn grain (PHA-G)
  - PHA from corn stove (PHA-S)
- Hybrid bio/petroleum (1)
  - B-PET

SUSTAINABILITY METRICS: LCA AND GREEN DESIGN IN POLYMERS (TABONE, ET. AL)

- Functional Unit: 1 Liter of pellets
- Scope: Cradle-to-gate (production, not disposal or use)
- Impact categories:
  - Acidification
  - Carcinogenic human health hazards
  - Ecotoxicity
  - Eutrophication
  - Global Warming Potential
  - Noncarcinogenic human health hazards
  - Ozone depletion
  - Respiratory effects
  - Smog
  - Nonrenewable energy use (NREU)

YOUR TURN

• Product, Service or Process
• Define:
  – Boundary, functional unit, process
• For each step indicate:
  – Inputs: energy, raw materials, water
  – Outputs: emissions, waste materials, products
RESOURCES

LCA: http://www.lifecycleinitiative.org/
LC-Impact: http://lc-impact.eu/methodology-home


Barlaz, Morton A. Professor and Head, Department of Civil, Construction and Environmental Engineering at NC State University. “Life Cycle Analysis, Part I” http://people.engr.ncsu.edu/barlaz/teaching.html

Plastics:
National Plastics Resource & Museum (no longer open) http://library.syr.edu/digital/guides/n/npc_mus.htm
Resin Identification Codes: http://speccrew.com/รีซิน/identification-codes-plastic-recycling-codes/
History of plastics: http://www.plasticsindustry.org/AboutPlastics/content.cfm?ItemNumber=670&navItemNumber=1117
Plastic Disclosure Project http://www.plasticdisclosure.org

Biodegradable Plastic: Its Promises: http://dujs.dartmouth.edu/applied_sciences/biodegradable-plastic-its-promises-and-consequences#.ViRsTOmKUz8
