國立臺北大學自然資源與環境管理研究所
113 學年度第一學期『環境工程科學概論』

課程講義(13)：廢棄物處理與資源回收
Solid Waste Treatment and Resource Recycling

- INTRODUCTION
  - □ Solid Waste (Refuse), Garbage (Food Waste), Rubbish, Discard => MSW
  - □ 一般廢棄物、事業廢棄物（一般事業廢棄物、有害事業廢棄物）
  - □ Waste-to-Energy Combustion/Incineration => Energy from Waste
  - □ Sanitary Landfills =>衛生掩埋；灰渣：底渣＋飛灰
  - □ Treatment of Garbage: Composting, Anaerobic Digestion, Soil Conditioner, etc.
  - □ Recycling Schemes: 3Rs, 4Rs, 5Rs, 6Rs (Reduce, Reuse, Recycling, Recovery, R??)
    「資源循環零廢棄」6R：減量（Reduction）、再使用（Reuse）、物料回收（Recycling）、能源回收（Energy Recovery）、新生土地（Land Reclamation）及改變設計（Redesign）
    ⇒ Sustainable Materials Management, Sound Material-Cycle Society
  - □ 環境部資源循環署全球資訊網

- TREATMENT OF SOLID WASTE
  - □ Collection, Treatment, Disposal, Recycling, and Energy Recovery
  - □ Open Dump, Sanitary Landfill; Incinerators; Recycling and Recovery
  - □ Solid Waste Treatment and Disposal Facility
    ⇒ Externality: NIMBY (Not In My Back Yard)－嫌惡設施 => Positive Externality
  - □ Source Reduction（源頭減量）=> Waste Minimization; Cleaner Production
  - □ Collection and Transfer Operation =>「四合一」回收系統、垃圾費隨袋徵收
  - □ 垃圾焚化廠興建經營方式：公有公營、公有民營、民有民營 BOO/BOT

- SUSTAINABLE PRODUCTION AND CONSUMPTION
  - □ Sustainable Production: Waste Minimization, Eco-Design, Cleaner Production
  - □ Eco-Labelling => Environmental Statement
    ⇒Environmentally friendly products labelling network | Global Ecolabelling Network
    ⇒ISO 14020:2022 Environmental statements and programmes for products (*)
    ⇒self-declared environmental claims (14021); environmental labels aka ecolabels (14024) environmental product declarations (EPDs) (14025); footprint communications (14026).
    ⇒Carbon Footprint=>自願性：產品碳足跡資訊網 強制性：氣候變遷因應法第 37 條
  - □ Life Cycle Assessment
    ⇒ISO 14040 &14044 (ISO/TC 207/SC5) => Life Cycle and Functional Unit
    ⇒Cradle-to-Grave; Cradle-to-Gate; Cradle-to-Cradle => CBAM; Wheel-to-Grid
    ⇒LCA Cases: Diapers and Hot-Drink Cups
  - □ Circular Economy => the "Butterfly Diagram"
    ⇒Technological Cycle; Biological Cycle
    ⇒Cradle to Cradle Products Innovation Institute
    ⇒Sustainability => Circularity + NZE (Agenda 2050?)

Arthur D. Little emerged with the following results:

Life-Cycle Analysis of Disposable and Reusable Diapers
(based on weekly diaper needs)

Category	Disposable	Reusable
Raw Materials Consumption (lbs)	25.30	3.60✓
Energy Consumption (Btu)	23,290.00✓	78,890.00
Water Consumption (gal)	23.60✓	144.00
Atmospheric Emissions (lbs)	0.09✓	0.86
Waste Water Effluents (lbs)	0.01✓	0.12
Process Solid Waste (lbs)	2.02✓	3.13
Post-Consumer Waste	22.18	0.24✓
Total Costs ($/week)	10.31	7.47-16.92

Questions:

1. Put yourself in the position of the leader of the Arthur D. Little project team that must recommend one type of diaper over the other. Are all of your assumptions correct? Which diaper would you recommend, based on the data?

2. In addition to the environmental information, the study also included an analysis of both the health and the economic implications of each diaper type.

- *Health:* Disposables were found to cause, on average, less incidence of diaper rash (caused by contact between skin and urine) than reusables.

- *Economic:* To calculate the cost to the consumer of using each type of diaper, the research team had to make some assumptions about the cost of washing reusable diapers. It found that when home labor was valued at the minimum wage or higher, disposable diapers were cheaper to use than reusables.

Are the assumptions regarding diaper economics correct? Do the health and economic data change or influence your decision? Should they?

3. Put yourself in the position of the vice president of the diaper division at P&G. P&G was recently rated the most "environmentally conscious" company in an *Advertising Age* survey and yet, the state of Vermont has proposed a ban on disposable diapers. What, if any, action should you take?

References:

Arthur D. Little, Inc., *Disposable versus Reusable Diapers: Health, Environmental, and Economic Comparisons*, report to Procter and Gamble, March 16, 1990.

Society of Environmental Toxicology and Chemistry and SETAC Foundation for Environmental Education, *A Technical Framework for Life-Cycle Assessment,* Workshop Report, January 1991, p. xvii.

David Stipp, "Life-Cycle Analysis Measures Greenness, But Results May Not Be Black and White," *Wall Street Journal*, February 28, 1991.

An Example Lifecycle Assessment: Polystyrene Cups

As an example of the value (and difficulty) of performing a complete lifecycle assessment, consider a comparison of the environmental impacts of single-use, 8-ounce, hot-drink containers made from polystyrene foam with similar cups made from uncoated paper (Hocking, 1991). As shown in Table 6, the raw materials inputs for the two types of cups are very different. A paper cup requires about 21 g of wood and bark plus 1.2 g of chemicals to produce an 8.2-g cup, while a 1.9-g polystyrene

TABLE 6

Life-Cycle Assessment for Single-Use, Hot-Drink Cups (per 1,000 Cups)

	8.3 g Paper Cup	1.9 g Polyfoam Cup
Raw Materials		
Wood and bark (kg)	21	0
Petroleum feedstock (kg oil)	0	2.4
Other chemicals (kg)	1.2	0.08
Purchased Energy		
Process heat (kg oil)	1.8	1.9
Electricity (kg oil)[a]	2	0.15 ✓
Water Effluent		
Volume (m^3)	1	0.05 ✓
Suspended solids (g)	80	1 ✓
BOD (g)	90	0.4 ✓
Organochlorines (g)	20	0 ✓
Inorganic salts (g)	500	30 ✓
Fiber (g)	10	0 ✓
Air Emissions		
Chlorine (g)	2	0 ✓
Chlorine dioxide (g)	2	0 ✓
Reduced sulfides (g)	10	0 ✓
Particulates (g)	20	0.8 ✓
Carbon monoxide (g)	30	0.2 ✓
Nitrogen oxides (g)	50	0.8 ✓
Sulfur dioxide (g)	100	7 ✓
Pentane (g)	0 ✓	80
Ethylbenzene, styrene (g)	0 ✓	5
Recycle/Reuse Potential		
Reuse	Possible	Easy ✓
Recycle	Acceptable	Good ✓
Ultimate Disposal		
Proper incineration	Clean	Clean
Heat recovery (MJ)	170	80 ✓
Mass to landfill (kg)	8.3	1.9 ✓
Volume in landfill (m^3)	0.0175	0.0178
Biodegradability (landfill)	Yes ✓	No

[a]Calculated using 33-percent efficient power plant burning residual fuel oil.
Source: Based on data in Hocking, 1991.