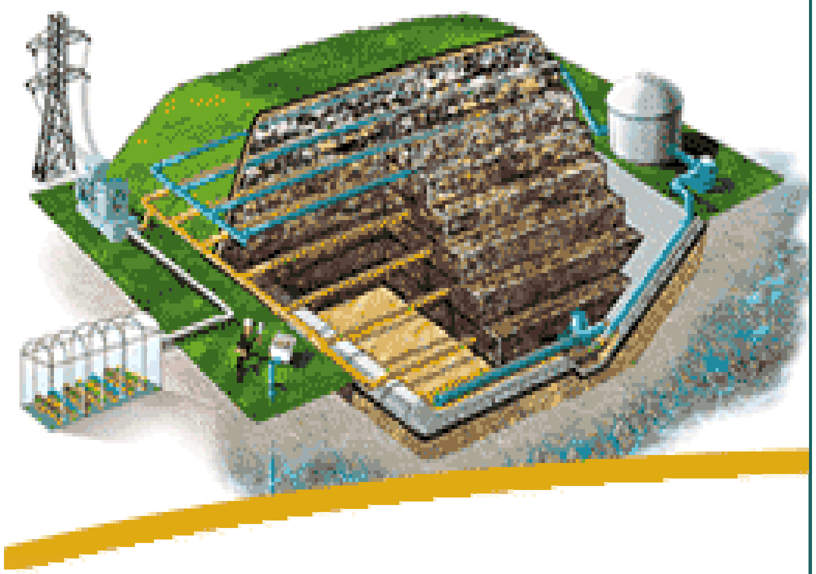
LIFE CYCLE ASSESSMENT OF A BIOREACTOR AND AN ENGINEERED LANDFILL FOR MUNICIPAL SOLID WASTE TREATMENT



Jean-François Ménard, Renée Michaud, Julie-Anne Chayer, Pascal Lesage, Louise Deschênes, Réjean Samson

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Context

- Landfilling is the most common means of disposal for Municipal Solid Waste (MSW) in Canada.
- Today, landfilling is done in engineered landfills equipped with leachate and landfill gas collection and treatment systems.
- However, this technique presents some shortcomings since it:
  - Requires a large area;
  - Generates emissions over several years (possibly more than a century).
- A new landfill technology, the bioreactor, addresses these problems by accelerating the degradation of the organic fraction. This reduces the time necessary to stabilize the landfilled waste and increase the site's capacity.

Presentation outline

1. **Goal & scope**
2. **Life Cycle Inventory (LCI)**
3. **Life Cycle Impact Assessment (LCIA)**
4. **Conclusions**

1- Goal & scope

Goal:

To evaluate, using an LCA, the potential environmental impacts associated with two types of landfills used for MSW:

- The engineered landfill (EL);
- The bioreactor.

1- Goal & scope

Function:

To stabilize an amount of MSW

BUT

Landfill gas can be collected and used to produce energy (electricity or heat) in the case of the bioreactor. This production must be added to the primary function so as to maintain the functional equivalence of the compared systems.

Functional unit:

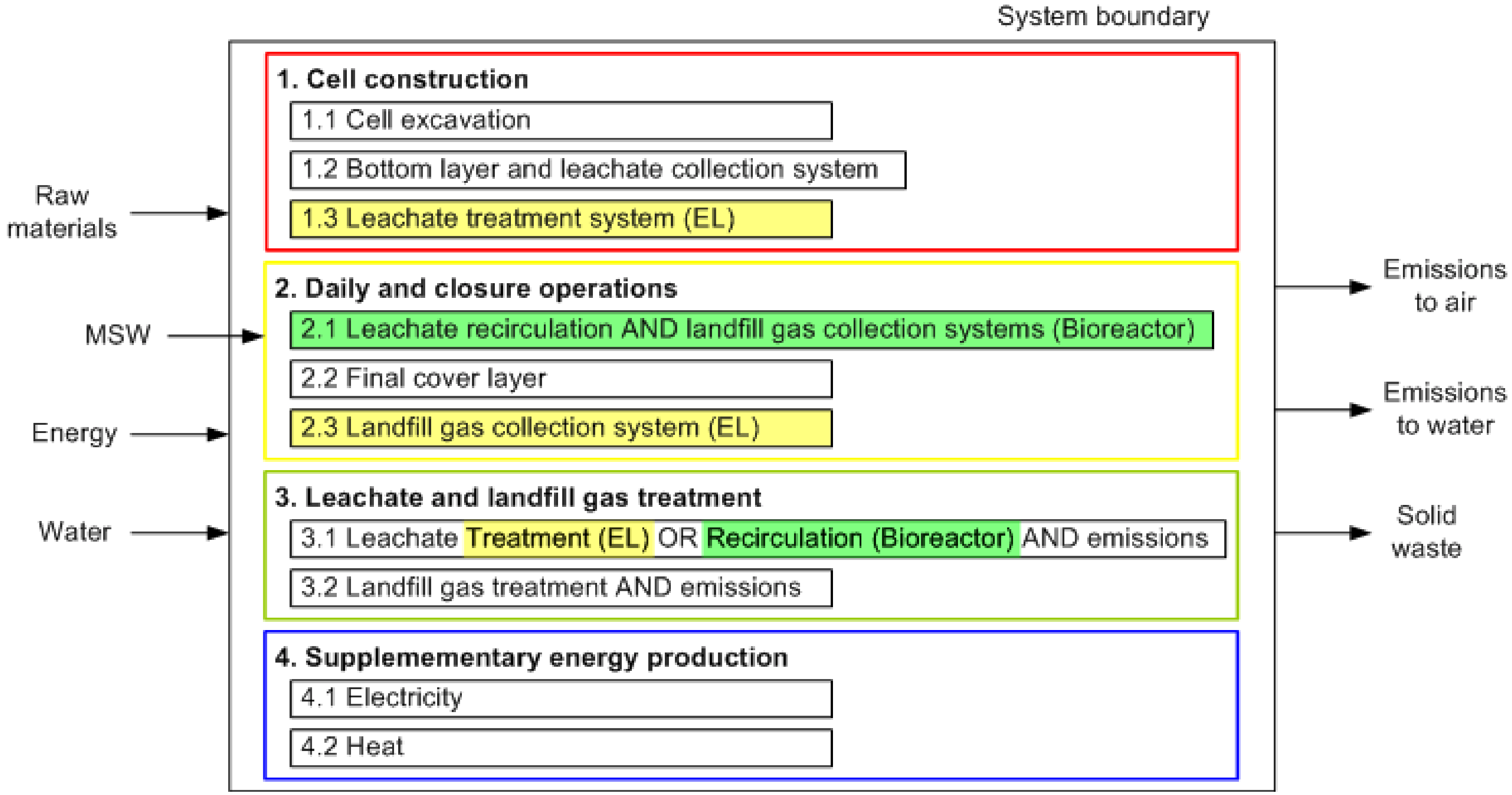
The stabilization of **600 000 tonnes** of MSW and the production of **2.56 x 10^8 MJ** of electricity and **7.81 x 10^8 MJ** of heat.

These amounts correspond to:

- The landfilling of 300 000 tonnes of MSW per year over 2 years;
- The maximum amount of energy that can be recuperated from the landfill gas generated by the bioreactor.

1- Goal & scope

System boundaries and life cycle stages



2- LCI

System description

	EL	Bioreactor
Bottom liner	Geosynthetic clay liner (GCL) Geomembrane Geonet Geotextile	
Leachate collection	Gravel drainage bed HDPE pipes	
Leachate treatment	Aeration pond Release in receiving body of water	Recirculation in horizontal trenches
Landfill gas collection	Vertical wells	Horizontal trenches
Landfill gas treatment	Flare	Internal combustion engine (ICE) Modified boiler
Final cover layer	Sand Geomembrane Organic soil	
Supplementary energy production	Natural gas electrical power station Natural gas industrial boiler	

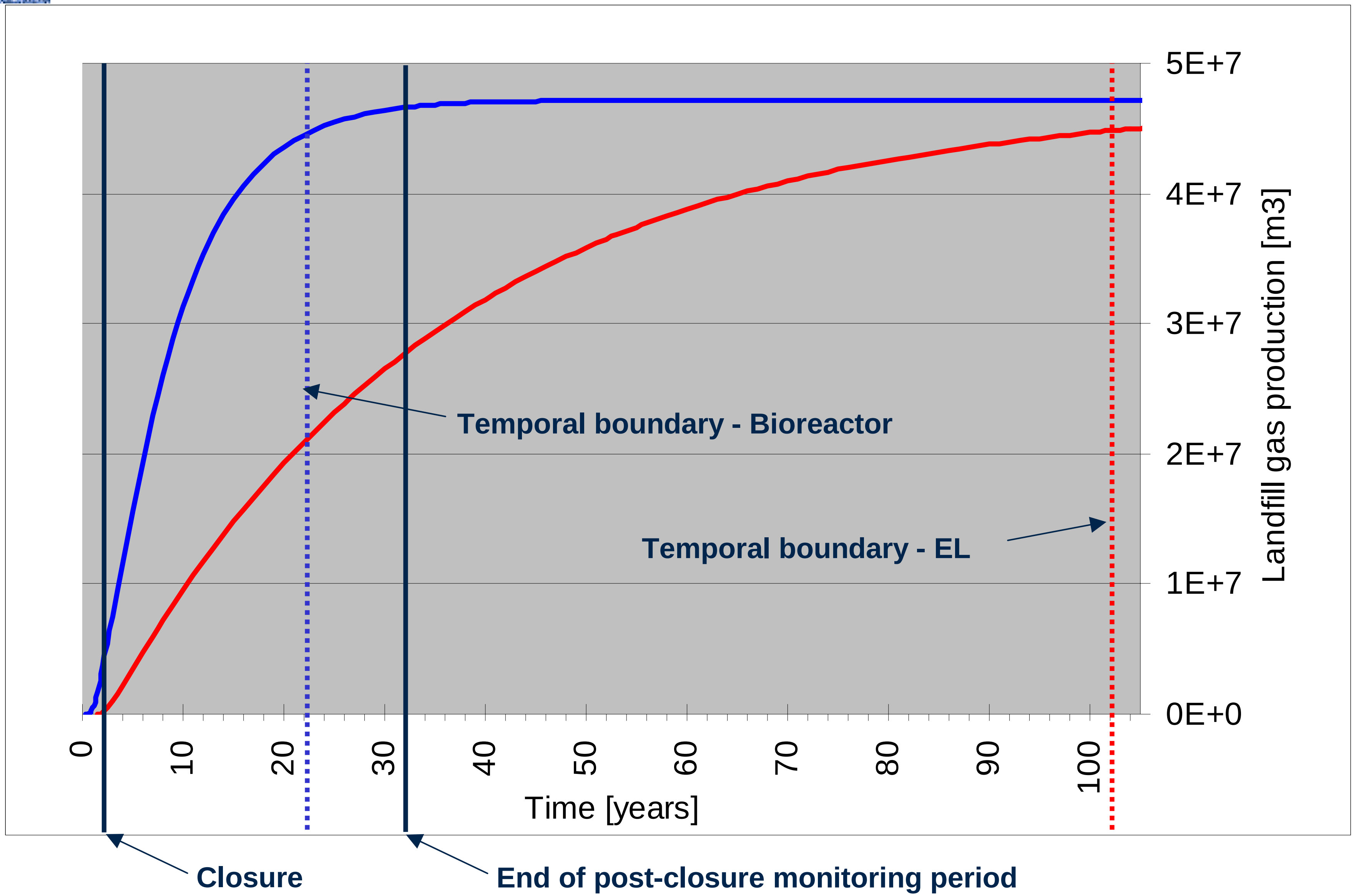
2- LCI

Main assumptions

- Waste density in cell: **800 kg/m³** for the EL;
  1000 kg/m³ for the Bioreactor.
- Post-closure monitoring period = **30 years**.
- Landfill gas production = fraction of Biochemical Methane Potential (BMP) which varies from: **40 to 70%** of the BMP for the EL;
  60 to 90% of the BMP for the Bioreactor.
- CO_2 from the waste = **biogenic** ⇒ not counted as greenhouse gas.
- Residual fraction of BMP converted into an **environmental credit** (CO_2 sequestered in the landfilled waste).
- Bioreactor: waste brought to **field capacity** at closure.
- Temporal boundary corresponds to waste stabilization
  ⇒ time to produce **95% of calculated landfill gas volume**.

2- LCI

Main assumptions – Temporal boundary



2- LCI

Main assumptions

		EL	Bioreactor
Leachate Precipitations (m/m^2/year)		1	
Evapotranspiration losses (%)		60	
Run-off losses (%)	From 0 to 1 year From 1 to 2 years After 2 years	5 10 20	
Final cover efficiency (%)	From 0 to 1 year From 1 to 2 years From 2 to 32 years After 32 years	0 50 99 - 0.01 per year	
Bottom layer efficiency (%)	From 0 to 32 years After 32 years	99,99 - 0.01 per year	
Landfill gas Collection system efficiency (%)	From 0 to 1 year From 1 to 2 years From 2 to 32 years After 32 years	0 50 80 0	0 75 90

2- LCI

Excluded processes

- Pumps for leachate collection;
- Collection and disposal of leachate treatment sludge (EL);
- Compressors for landfill gas collection;
- Dehydrators and pipeline for treatment and transport of landfill gas (Bioreactor).

2- LCI

Data sources

Unit process	Data source
Non-road equipment	NONROAD model (U.S. EPA/Office of Transportation and Air Quality)
Truck transport	Joint EMEP/CORINAIR Atmospheric Emission Inventory Guidebook – 3rd edition (EEA, 2001)
Material production	Commercial generic LCI databases in Simapro 5 software (IDEMAT and Franklin)
Leachate and landfill gas associated emissions	Life Cycle Inventory of a Modern Municipal Solid Waste Landfill (ECOBALANCE, 2002)

- The North-American Franklin database was privileged. The unit processes from the European database were modified so as to better represent the energy production and transport processes.

2- LCI

Inventory results

Inputs		EL	Bioreactor
Mass (kg)	Geosysnthetic clay liner	2.57E+5	2.03E+5
	Geomembrane	2.23E+5	1.82E+5
	Geonet	3.52E+5	3.00E+5
	Geotextile	2.89E+4	2.57E+4
	HDPE pipes	2.65E+5	6.04E+4
	PVC pipes	4.86E+2	
	Vitrified steel tank		3.40E+4
	Aluminum dome		1.91E+3
	Reinforced concrete base		3.00E+5
	Gravel	6.32E+7	6.03E+7
	Bentonite	1.58E+4	
	Sand	6.44E+7	5.38E+7
	Organic soil	1.34E+7	1.12E+7
	Diesel	3.13E+5	2.68E+5
	TOTAL	**1.42E+8**	**1.26E+8**
	Added water		**2.73E+8**
Energy (MJ)	Equipments	2.60E+6	2.15E+6
	Electricity	2.56E+8	1.50E+8
	Heat	7.81E+8	4.55E+8
	TOTAL	**1.04E+9**	**6.07E+8**
	Truck transport (tonne.km)	7.26E+6	6.43E+6

2- LCI

Inventory results – Elementary flows

Inputs/Outputs (kg)	EL	Bioreactor
Raw materials (w/o added water)	2.20E+8	1.75E+8
Emissions to air		
Total emissions	1.59E+8	1.50E+8
Total emissions w/o biogenic CO_2	1.06E+8	6.15E+7
Sequestered CO_2	- 5.96E+7	- 3.31E+7
Emissions to water	2.51E+6	1.41E+6
Solid waste	4.42E+6	2.44E+6

3- LCIA

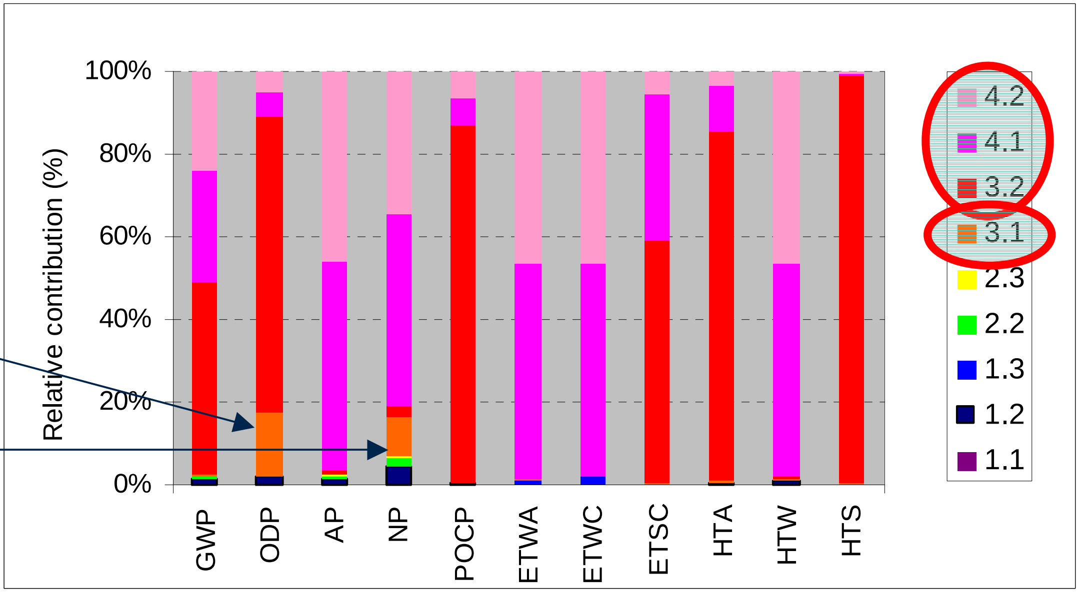
- **EDIP** (Environmental Design of Industrial Products) method developed in 1996 by the Danish EPA;
- Recognized as one of the best LCIA methods and largely used (Sorensen, 2002);
- Follows SETAC and ISO 14042 guidelines.

Environmental impact	Indicator	Scale
Global warming (GWP)	g CO_2 eq.	Global
Stratospheric ozone depletion (ODP)	g CFC_{11} eq.	Global
Acidification (AP)	g SO_2 eq.	Regional
Nutrient enrichment (NP)	g NO_3 eq.	Regional
Photochemical ozone creation (POCP)	g C_2H_4 eq.	Regional
Ecotoxicity Water, acute (ETWA) Water, chronic (ETWC) Soil, chronic (ETSC)	 m^3 water /g m^3 water /g m^3 soil /g	Local
Human toxicity Air (HTA) Water (HTW) Soil (HTS)	 m^3 air /g m^3 water/g m^3 soil /g	Local

3- LCIA

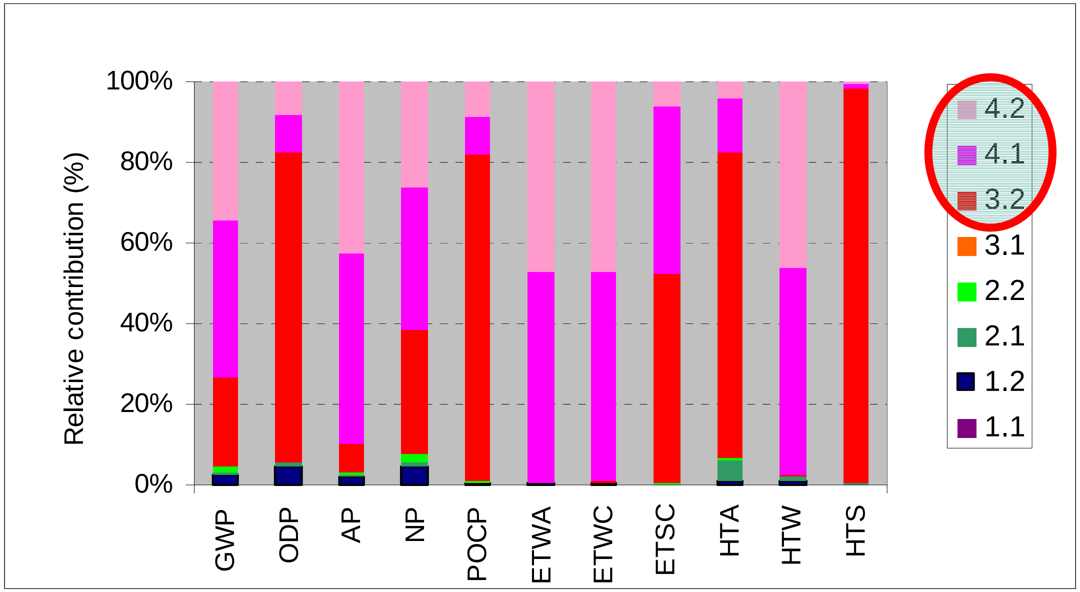
Relative contributions of the life cycle stages

EL



- Volatilization of chlorinated organic compounds (CCl_4) in aeration pond
- Release of treated leachate (NH_3, NO_3) in receiving body of water

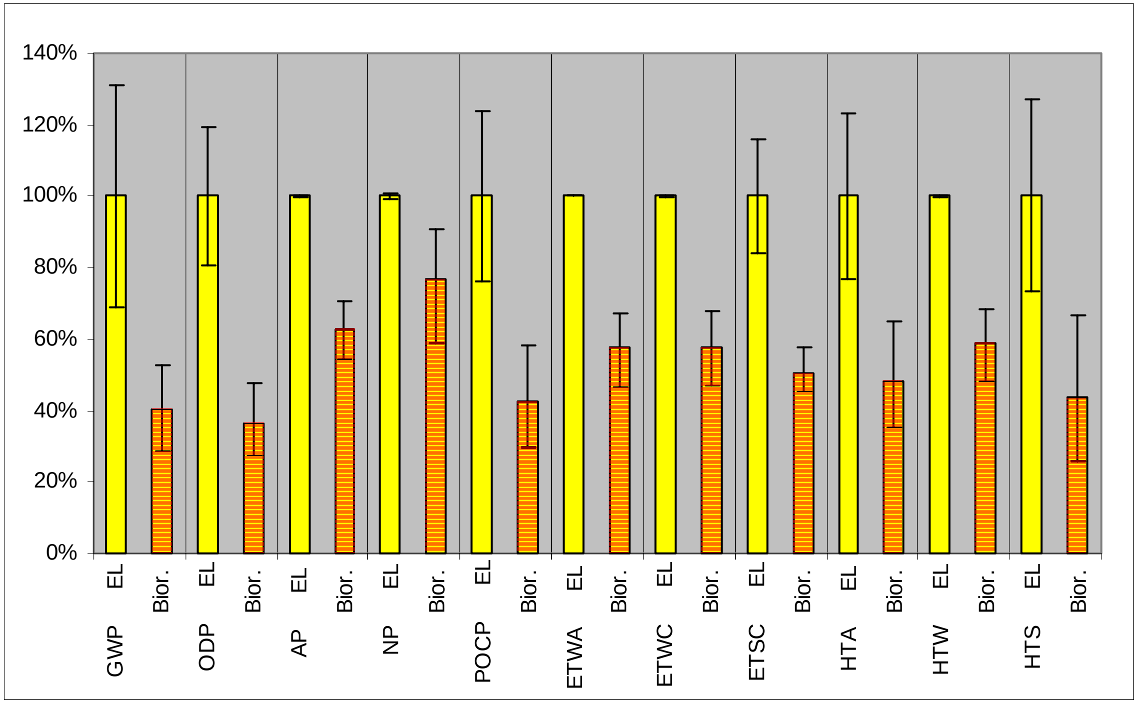
Bioreactor



3- LCIA

Compared emissions with associated impacts

Emissions (kg)	EL	Bior.
Landfill gas		
Treated (Collected)	3.40E+7	8.30E+7
Emitted	2.46E+7	7.64E+6
Total	5.86E+7	9.07E+7
w/o biogenic CO_2		
Treated	2.97E+5	4.53E+5
Emitted	5.98E+6	1.85E+6
Total	6.27E+6	2.31E+6
Energy Production	9.51E+7	5.53E+7
Leachate	2.53E+4	7.65E-2



Landfill gas emissions
- Emitted (Generated): CH_4 CO_2 H_2S BTEX Chlorinated compounds
- Treated: CO_2 CO NO_2 PM SO_2 HCl

Energy Production emissions:
- Air: CO2 CCl4 SOX NOX CO Formaldehyde Cd Pb Hg
- Water: Cd Cyanide

Leachate emissions:
- NH3 NO3

4- Conclusions

- EL uses **26% more raw materials** than the Bioreactor (not considering added water).
- EL generates **82% more solid wastes** than the Bioreactor.
- EL generates, on average, **91% more potential environmental impacts** than the Bioreactor.
- Impacts are associated with **supplementary energy production** (56% for EL and 58% for Bioreactor) and with **landfill gas treatment and emissions** (40% for EL and 39% for Bioreactor).
- **Energetic valorization of landfill gas** (reduces energy added to the system) and **faster stabilization of waste** (reduces emitted landfill gas) are reasons of the Bioreactor's better environmental performance.

HOWEVER

- Sensitivity analysis on **post-closure monitoring period length** shows that it is an important parameter in the study and can greatly affect the study's conclusions.

4- Conclusions

Recommendations

- **Quantify:**
  - Energy needs of excluded equipment since landfill gas and leachate volumes are greater for the Bioreactor.
- **Include in study:**
  - Leachate treatment sludge management (EL);
  - Added water (Bioreactor).
- **Evaluate:**
  - Influence of other parameters (bottom layer, final cover and leachate and landfill gas collection system efficiencies).
- **Expand:**
  - System boundaries to include other MSW management activities (source reduction, recycling, composting and incineration).

Acknowledgements

- **Environment Canada**
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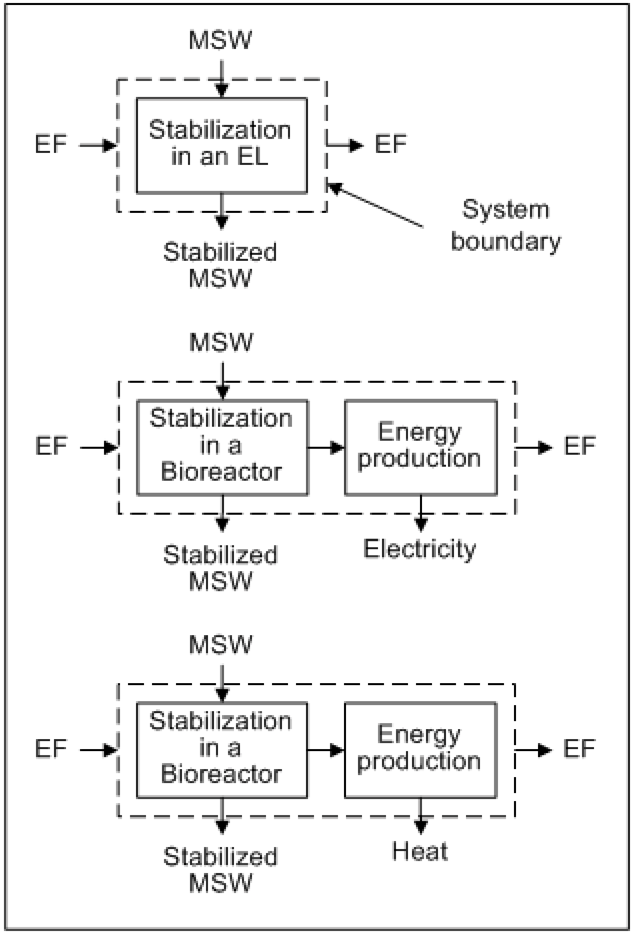
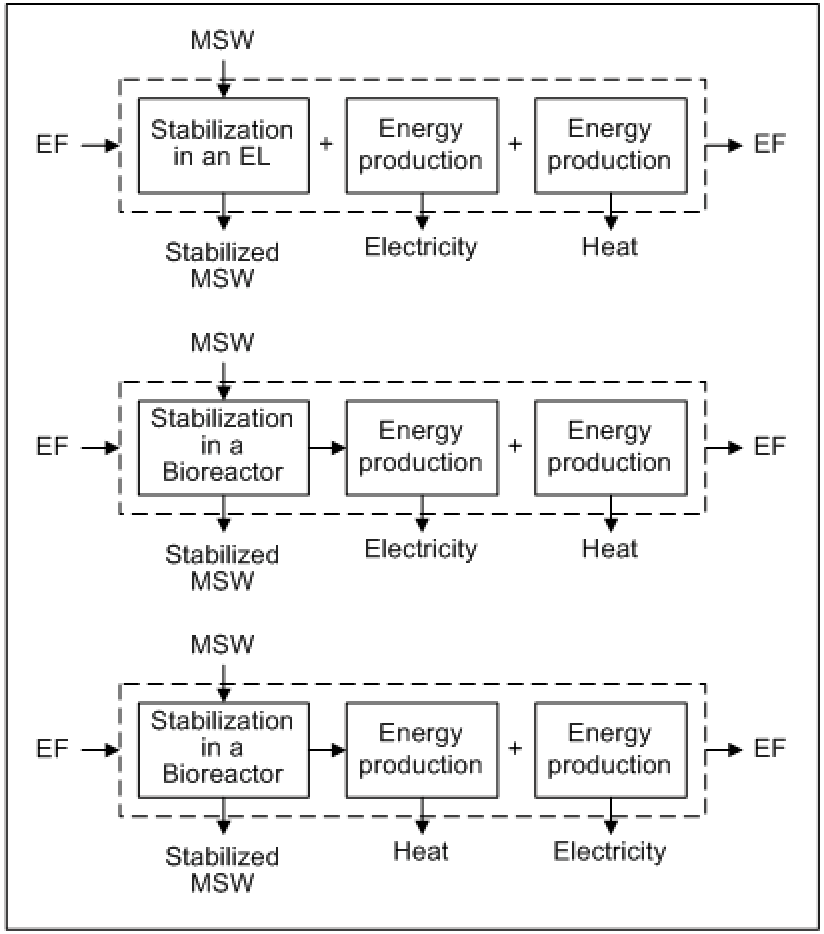
QUESTIONS ?

Functionally equivalent systems



Systems not functionally equivalent



Systems functionally equivalent