GHG EMISSIONS ESTIMATES AND COSTS
FOR DEGRADABLE MATERIALS
ENDING UP IN LANDFILL SITES

Brief Summary Information and Cost Estimation Procedures, June 2022 (Version 2)
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Emissions and costs associated with methane generation from waste foods going to landfill

Each tonne of food going to waste and ending up in landfill = GHG emissions of 1,110 kg CO_2e

The cost of emissions from one tonne of food going to landfill = approximately $56
The cost of emissions from one kg of food going to landfill = approximately $0.056 or 5.6¢

The cost of emissions is relatively small, only about 1.2% of the value of the food, but is noticeable

Resulting preliminary hierarchy for addressing initially unused food stuffs

- Reuse for human consumption, when and where appropriate, based on gleaning
- Reuse for animal consumption, when and where appropriate
- Active composting, but noting that composting action must be actually undertaken, not merely implied or potentially available
- Landfill or disposal, but only as a last resort

Themelis and Ulloa (2007), two researchers from Columbia University in NY, provide a relatively recent, and conservative, approximate estimate of the conversion of degradable (biomass) materials to methane in landfills, this as a result of biological anaerobic methanogenesis processes known to occur:

- Rather than basing on biomass content, per se, they simply assume more conservatively to be based on municipal solid waste (MSW) content, which reflects a mixture of materials.
- They conservatively estimate methane generation to be about 50 Nm^3 methane per ton of MSW landfilled, which translates to 55 Nm^3 methane per tonne of MSW (noting Nm^3 = normal cubic metre, as measured at 0°C, and that 1.0 tonne or 1,000 kg = 1.1 tons approximately).

Dutt (2003) cites a density for methane at 0°C of approximately 0.72 kg per m^3, based on first principles, and also noting the IPCC uses the same approximately density value in its 1996 reference manual.

Methane is a potent greenhouse gas (GHG), with accelerated effects typically quantified using a GWP100 (or global warming potential at 100 years) value. The current value applied to methane by the IPCC is approximately 28× CO_2 reflecting the Fifth Assessment Report (Climate Registry 2022).

Based on this, 1.0 tonne of degradable material (as MSW) generates the equivalent of 55 Nm3 of methane × 0.72 kg methane per Nm3 × 28 magnifier factor for GWP100 = 1,110 kg CO_2e, more than one tonne.

An important, and standardized, means to monetize GHG emissions is using the social-cost of carbon (SCC). The SCC is estimated as reflecting the present-value of future damages resulting from the release today of a unit of GHG (typically per tonne basis). Currently, based on analyses (ECCC 2016), the Government of Canada assumes a social-cost of carbon of approximately $50 per tonne GHG in evaluating costs and benefits. Importantly, the U.S. EPA (2016) has also considered a range of values for SCC, with a similar figure of about $50 per tonne being relatively consistent.

Importantly within Canada, the SCC is very different from carbon pricing, even though the two values currently coincide at $50 per tonne GHG. The latter value involves a price "signal" levy that is applied to commodity fossil fuels in an attempt to reduce consumption, rather than reflecting future damages.

Cost of degradable materials going to landfill and being converted to methane thus can be estimated as:
1,110 kg CO_2e per tonne degradables ÷ 1,000 kg per tonne × $50 per tonne = $55.5 per tonne degradables

This cost translates to about 5.55¢ per kg (or $0.0555 per kg). Rough current five-month average prices listed by Statistics Canada (2022) for eight selected categories of common food stuffs are presented in the following table, along with methane cost as a proportion of value if materials were to simply end up going into landfill. In very approximate terms, the cost as methane translates to about 1% of food value across the selected categories. This is obviously low, but is sufficient to be noticeable, and can mount up if foods are just going to waste.

Table: Methane Cost Compared to Current Food Values Across Eight Categories (February 2022)

Food Product Category	Five-Month Mean Cost per kg	Methane Cost as Percentage
Ground beef	$12.36 per kg	0.45%
Chicken	$8.17 per kg	0.68%
Bread	$4.34 per kg	1.29%
Macaroni	$3.32 per kg	1.67%
Flour	$1.75 per kg	3.17%
Apples	$4.68 per kg	1.19%
Sugar	$6.58 per kg	0.84%
Baby food	$12.94 per kg	0.43%
Mean and standard deviation across selected eight categories		1.2% ± 0.9%

The final mean percentage involves only a selected cross-section of food materials, but does provide a preliminary approximation of what is involved.

A related, but trickier issues relevant to foods going to waste and ending up in landfill, is packaging associated with food products. Some interesting and sometimes unexpected results can occur.

In the past, much packaging for food products involved plastics, including polyethylene, polypropylene and polystyrene. If these materials end up within landfills, they can be treated as effectively **inert**, with breakdown periods, via oxidation, being very long. Such plastics are also not subject to biological degradation via methanogenesis processes, so they do not create any methane in landfills.

Some plastic packaging for specific food products remains quite essential, but the current trend is certainly away from plastics. Some reusable packaging is being employed, albeit subject to concerns, with movement more toward paper and a variety of "compostable" packaging.

One initial and obvious problem is that the mass of plastic for packaging is typically very small, and if paper or compostable materials are employed, the mass of packaging employed will be greater. A recent comparison by author found masses for bags of 47 g for paper versus 6 g for plastic. If these bags can be used equally, roughly 7.8× more mass is involved for paper; or if assume two plastic bags per paper bag required, roughly 3.9× more mass is involved for paper. Similar increased mass for plastic versus compostable containers is assumed.

The greater and emerging problem with paper and compostable packaging is that while the noble intent may be to have materials either recycled or composted, very frequently such does not occur in practice, with packaging ending up simply going to landfill. Just as the case with foods, if degradable packaging ends up in landfill, it too can be broken down via biological methanogenesis processes to methane, which is problematic.

Yu and Chen (2008) undertook a comparative analysis and indicated that conventional food packaging plastic resins involve GHG emissions in the range of 2 to 3 tonne CO_2e per tonne of resin (or 2 to 3 kg CO_2e per kg). Using SCC, this translates to a GHG cost of $100 to $150 per tonne of plastics (or $0.10 to $0.15 per kg). This allows a comparative analysis for degradable packaging materials:

- GHG emissions and costs for paper or compostable packaging will be obviously lower if actually properly recycled or composted, but
- If ending up in landfill, firstly roughly 3.9× to 7.8× greater mass of packaging will be involved with each tonne generating 1.11 tonnes of CO_2e via methane (1.11 kg CO_2e per kg) at a cost of $50 per tonne GHG ($0.05 per kg GHG), translating to $216 to $433 per tonne degradable packaging ($0.216 to $0.433 per kg degradable packaging).

As such, if degradable packaging is recycled or composted the net result is highly positive, but if the material actually ends up simply **going to landfill, the cost for GHG emissions for such recyclable or compostable packaging translates to being much higher, in the range of 2.2× to 2.9× worse than plastics**. This is an unexpected result.

Results are more complicated if so called "bioplastics" are employed, as discussed further by Yu and Chen (2008).

References

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> **Abstract:** Methane gas is a by-product of landfilling municipal solid wastes (MSW). Most of the global MSW is dumped in non-regulated landfills and the generated methane is emitted to the atmosphere. Some of the modern regulated landfills attempt to capture and utilize landfill biogas, a renewable energy source, to generate electricity or heat. As of 2001, there were about one thousand landfills collecting landfill biogas worldwide. The landfills that capture biogas in the US collect about 2.6 million tonnes of methane annually, 70% of which is used to generate heat and/or electricity. The landfill gas situation in the US was used to estimate the potential for additional collection and utilization of landfill gas in the US and worldwide. Theoretical and experimental studies indicate that complete anaerobic biodegradation of MSW generates about 200 Nm3 of methane per dry tonne of contained biomass. However, the reported rate of generation of methane in industrial anaerobic digestion reactors ranges from 40 to 80 Nm3 per tonne of organic wastes. Several US landfills report capturing as much as 100 Nm3 of methane per ton of MSW landfilled in a given year. These findings led to a conservative estimate of methane generation of about 50 Nm3 of methane per ton of MSW landfilled. Therefore, for the estimated global landfilling of 1.5 billion tones annually, the corresponding rate of methane generation at landfills is 75 billion Nm3. Less than 10% of this potential is captured and utilized at this time.

Yu, J. and L.X.L. Chen. 2008. The Greenhouse Gas Emissions and Fossil Energy Requirement of Bioplastics from Cradle to Gate of a Biomass Refinery. Environmental Science & Technology 42(18): 6961–6966. https://pubs.acs.org/doi/abs/10.1021/es7032235

> **Abstract:** Polyhydroxyalkanoates (PHA) are promising eco-friendly bioplastics that can be produced from cellulosic ethanol biorefineries as value-added coproducts. A cradle-to-factory-gate life cycle assessment is performed with two important categories: the greenhouse gas (GHG) emissions and fossil energy requirement per kg of bioplastics produced. The analysis indicates that PHA bioplastics contribute clearly to the goal of mitigating GHG emissions with only 0.49 kg CO_2-ebeing emitted from production of 1 kg of resin. Compared with 2–3 kg CO_2-e of petrochemical counterparts, it is about 80% reduction of the global warming potential. The fossil energy requirement per kg of bioplastics is 44 MJ, lower than those of petrochemical counterparts (78–88 MJ/kg resin). About 62% of fossil energy is used for processing utilities and wastewater treatment, and the rest is required for raw materials in different life cycle stages.

Version 2.0, dated June 15, 2022