

Life Cycle Assessment (LCA, also known as life-cycle analysis, ecobalance, and cradle-to-grave analysis) is a measurement technique to assess environmental impacts associated with all the stages of a product's life (i.e., from raw material extraction through materials processing, manufacture, distribution, use, repair and maintenance, and disposal or recycling).

The objective of LCA is to compare the full range of environmental effects by quantifying all inputs and outputs of material flows and assessing how these material flows affect the environment. This information is used to improve processes, support policy and provide a sound basis for informed decisions. Municipalities can use LCA to support decisions that they make when they spend public money to finance infrastructure investments such as biogas and renewable natural gas plants.

LCA has four distinct phases – inventory analysis, impact assessment, interpretation, and a reference test. Life Cycle Inventory (LCI) analysis involves creating an inventory of flows to and from nature for a product system. Inventory flows include inputs of water, energy and raw materials. A flow model of the technical system is created based on input and output data and is illustrated with a flow chart that includes all the activities in the relevant supply chain.

Inventory analysis is followed by impact assessment. This phase of LCA is aimed at evaluating the significance of potential environmental impacts based on the LCI flow results. Life Cycle Impact Assessment (LCIA) consists of selecting the impact categories, classifying categories and using one of the LCIA methodologies that measure the overall impact.

Life cycle interpretation is a systematic technique to identify, quantify, check, and evaluate information from the results of the LCI and/or the LCIA. The results from the inventory analysis and impact assessment are summarized during the interpretation phase. The outcome of the interpretation phase is a set of conclusions and recommendations for the study. A key purpose of performing the life cycle interpretation phase is to determine the level of confidence in the final results and communicate them in a fair, complete, and accurate manner. During the reference test phase, alternative approaches are compared and the approach which causes the least environmental damage is determined.

Life cycle analysis can enable municipalities to develop a systematic evaluation of the environmental consequences, associated with a given project, analyze the environmental trade-offs, quantify the environmental release to water and land and assess the human and ecological effects.

GHGenius is a spreadsheet model that calculates the amount of greenhouse gas generated from the time a fuel is extracted or grown to the time it is converted to energy to produce power. GHGenius is considered to be one of the best LCIA methodologies used to calculate GHG emissions. GHGenius has been developed over the last 17 years by (S&T)<sup>2</sup> Consultants for the federal Department of Natural Resources and other government and industrial clients. The model is continually updated as data becomes available. GHGenius is capable of estimating life cycle emissions of primary greenhouse gases and pollutants from combustion. The specific gases that are measured by the model include:

- Carbon dioxide (CO<sub>2</sub>)
- Methane (CH<sub>4</sub>)
- Nitrous oxide (N<sub>2</sub>O)
- Chlorofluorocarbons (CFC-12)
- Hydro fluorocarbons (HFC-12)
- The CO<sub>2</sub> equivalent of all the contaminants above
- Carbon monoxide (CO)
- Nitrogen oxide (NO<sub>x</sub>)
- Non-methane organic compounds (NMOCs) weighted by their ozone forming potential

Life cycle analysis is only as valid as the data on which it is based. The data on energy use and emission for a natural gas system in the GHGenius model is sourced from federal and provincial government departments and agencies, including: Statistics Canada (energy use), Environment and Climate Change Canada (solution gas CO<sub>2</sub> emissions), the Alberta Energy Regulator (methane emissions for gas recovery and processing) and the Canadian Energy Partnership for Environmental Innovation (methane emissions in gas transmission and distribution).

GHGenius can predict emissions of past, present and future years through to 2050 using historical data or correlations for the changes in energy and process parameters with time that is stored in the model. This model uses a time series of data so that the emissions in future years can be calculated based on historical trends in energy use and emissions. In addition, two distinct pathways have been added to the GHGenius model – one for upgrading landfill gas, and the other for using anaerobic digestion so municipalities can measure the environmental impact of either project.

In a recent report entitled Lifecycle Analysis of Biogas which was prepared for the Canadian Biogas Association by (S&T)<sup>2</sup> Consultants, the lifetime GHG emissions of fossil fuel and renewable natural gas are compared in Ontario and Alberta. The table below shows the results. When renewable natural gas is used instead of fossil natural gas the emission reductions are very significant, although they will depend on where the RNG is produced. The table below shows the GHG emissions reductions that can be achieved under twelve several different scenarios.

	Ontario	Alberta
	g CO <sub>2</sub> eq/KM	
Diesel Fuel	1,406	1,468
5% biodiesel blend (2% in Alberta)	1,352	1,407
Fossil Compresses Natural Gas	1,228	1,207
Compress Landfill Gas RNG	128	407
Source Separated Organics RNG	156	639
Facility Separated Organics RNG	185	872

### GHGenius Assumptions and Data Sources

The GHGenius model is capable of analyzing the emissions from conventional to alternative fuelled internal combustion engines. There are currently approximately 200 vehicle, fuel, feedstock combinations possible with the model.

GHGenius has data for Canada, United States and Mexico for many of the steps in the fuel process. For Canada, reports produced by Statistics Canada, Environment and Climate Change Canada, Natural Resources Canada and the National Energy Board have been used as sources of data. Industry associations such as the Canadian Association of Petroleum Producers and the Canadian Gas Association have also been used as sources of information. The non-energy related process emissions in the model are calculated based mostly on U.S. EPA emission factors. The emissions for conventional vehicles are based on an Environmental Canada model.

The GHGenius model uses the 100-year Global Warming Potential (GWP) for the base case scenarios. Global Warming Potential (GWP) is a relative measure of how much heat a greenhouse gas traps in the atmosphere. It compares the amount of heat trapped by a certain mass of the gas in question to the amount of heat trapped by a similar mass of carbon dioxide. A GWP is calculated over a specific time interval, commonly 20, 100 or 500 years. GWP is expressed as a factor of carbon dioxide (whose GWP is standardized to 1). The concept of a Global Warming Potential (GWP) has been developed to allow the comparison of the ability of each greenhouse gas to trap heat in the atmosphere relative to carbon dioxide (carbon dioxide CO<sub>2</sub>) over a specified time horizon. Often, greenhouse gas emissions are calculated in terms of how much CO<sub>2</sub> would be required to produce a similar warming effect over the chosen time horizon. This is called the carbon dioxide equivalent (CO<sub>2</sub> eq) value and is calculated by multiplying the amount of gas by its associated global warming potential (GWP). The GWPs used in the GHGenius model are summarized in the following table.

### Global Warming Potentials

Contaminant	2007 IPCC GWP	2013 IPCC GWP
CO <sub>2</sub>	1	1
CH <sub>4</sub>	25	34
N <sub>2</sub> O	298	298
CFC-12	10,900	10,200
HFC-134a	1,430	1,550
SF <sub>6</sub>	22,800	23,500
CO	1.57	1.57
NMOC	2.99	2.99

For provinces such as Alberta, all of the pathways have been redone based on the assumption that Alberta has a much higher carbon intensity power system than Ontario. There are also some differences in the fossil fuel reference systems as the Alberta refineries process different crude oils than the Ontario refineries and Alberta natural gas does not have the same transmission energy use and emissions that Ontario does, being closer to the source of the natural gas. All of these factors have an impact on the emission profiles.

The GHGenius model does not provide a direct comparison with CO<sub>2</sub> emission reduction and the equivalent in a cars-off-the-road measure. Other studies have concluded that reducing CO<sub>2</sub> by 1,500 kg is equivalent to taking .2941 cars off the road for a year. Therefore CO<sub>2</sub> would have to be reduced by more than 4,500 kg to be equivalent to taking one car off the road for a year.

### Summary

The GHGenius model is all encompassing as it can measure the past, current and future environmental impacts, take into consideration all types of emissions not just carbon dioxide and it can differentiate between landfill gas projects and anaerobic digestion. Moreover, the input data is based on information from federal departments and provincial agencies.

The federal government and many Ontario companies and organizations base their GHG emission calculations on the GHGenius methodology. Other provinces have taken different approaches to measuring GHG emissions, as described below:

- **British Columbia:** The B.C. government has developed an online measurement tool that adheres to international standards called SMARTTool for all Public Service Organizations (PSOs) to track their energy use, resulting emissions and offset requirements. In contrast to GHGenius, SMARTTool only measures carbon dioxide and, therefore, not the emissions of other gases.
- **Quebec:** Companies and municipalities in Quebec measure their GHG emissions inventory using ISO 14064-1 or the Greenhouse Gas Protocol. ISO 14064-1 is a broad and relatively loose set of guidelines for conducting a greenhouse gas inventory at the organizational or corporate level. These guidelines address different aspects of greenhouse gas, ranging from operational boundaries and the identification of emission sources to quantification, inventory quality management and general reporting principles. It is important to note that ISO-14064 is not an emissions accounting protocol. It does not recommend specific methodologies to assist users in measuring the quantity of greenhouse gas emissions generated from a particular source. Similarly, the GHG Protocol does not refer to specific types of methodologies but rather establishes general guidelines for measuring GHG emissions. Electricity companies such as Hydro Quebec report only CO<sub>2</sub>, SO<sub>2</sub> and NO<sub>x</sub> emissions directly associated with the electricity generation. The GHG emission analysis of electricity companies in Quebec is not based on a life cycle assessment since electricity is generated from renewable resources and, therefore, there are few or no GHG emissions.
- **Alberta:** The Alberta government has published a tool kit for municipalities in which it outlines ways for municipalities to calculate their greenhouse gas emissions. Their calculation methodologies include ISO 14064-1, the International Standard for Determining Greenhouse Gas Emissions for Cities (set of standard data collection tables for reporting GHG emissions), the Community Energy and Emissions Inventory Initiative (developed by the B.C. government), the International Local Government Greenhouse Gas Emissions Analysis Protocol (a joint initiative of the Federation of Canadian Municipalities and International Council for Local Environmental Initiatives (ICLEI)).