Estimates of Hydrogen Production Potential and Costs from California Landfills

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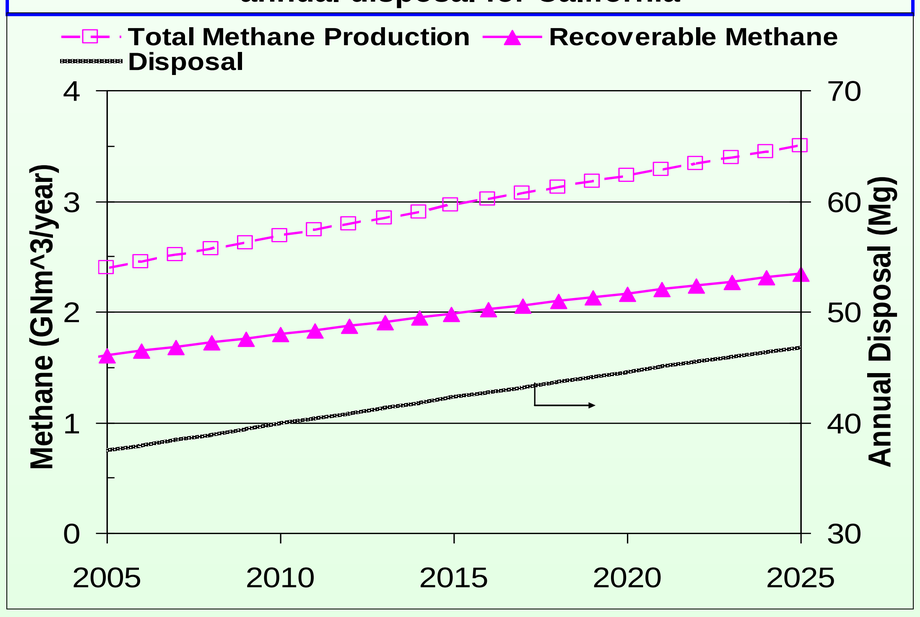
Abstract

Methane production from California landfills is estimated using a first order decay model and actual plus predicted waste disposal amounts from 1970 through 2025. Potential hydrogen production is estimated assuming 67% methane (landfill gas) recovery and upgrading and a 70% energy conversion efficiency of methane to hydrogen (higher heating value basis) using a steam reformer system. Statewide landfill derived methane is predicted to increase from 2.4 to 3.5 billion $Nm^3\ y^{-1}$ between 2005 and 2025. For the same period, potential landfill derived hydrogen production was estimated to range from 300 to 430 $Gg\ y^{-1}$. This hydrogen energy is equivalent to 1.3 Gl of gasoline equivalent (for 2005) or about 2% of California's gasoline usage and could fuel between 1.3 and 1.9 million fuel cell vehicles (FCV). The largest 15 landfills (in terms of current annual disposal) could potentially produce hydrogen equivalent to some 0.4 Gl of gasoline equivalent and could fuel some 500,000 FCV. The cost of landfill derived hydrogen using commercial gas upgrading and small steam methane reformer systems is estimated to be less than US$3.50 kg^{-1} (US$29.10 GJ^{-1}, lower heating value), not including distribution, storage, and dispensing costs.

Landfill gas generation projected for the period 2005 – 2025

(using waste placed beginning in 1970)*

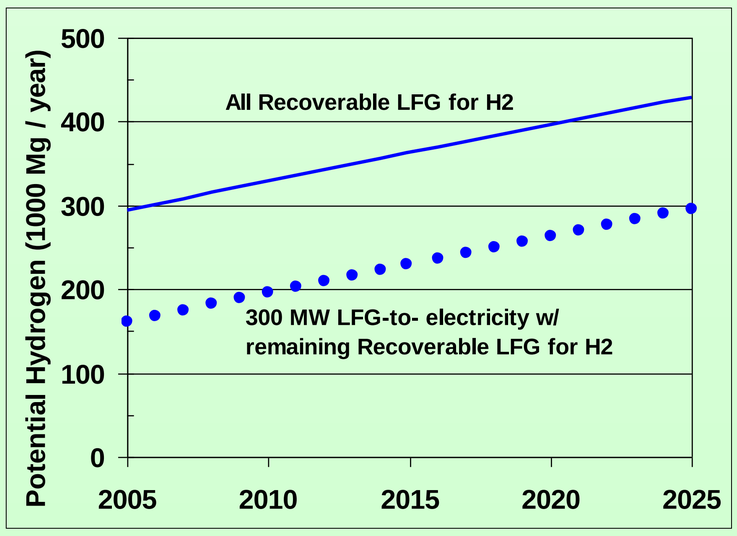
Projected gross and recoverable landfill methane and annual disposal for California



*Landfill gas is produced by anaerobic decay of waste in the landfill. Current and future LFG production depends on current and future waste-in-place (WIP).

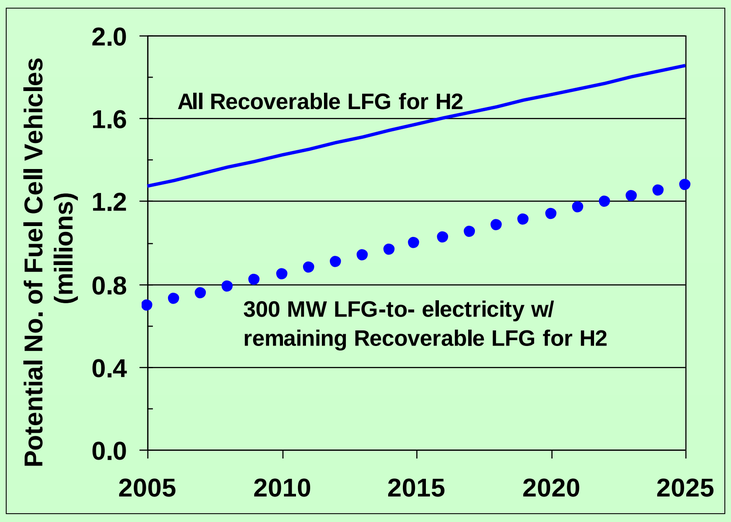
Solid waste landfill disposal from 1970 through 2005 is estimated to be 1000 Tg. Disposal post-1990 contributes most of the landfill gas by 2025. The methane production from California landfills is about 4% of current natural gas consumption (62 $GNm^3\ y^{-1}$)

Potential Hydrogen and Number of Fuel Cell Vehicles Fueled by LFG



Based on estimated recoverable methane, about 300 Gg y^{-1} of renewable hydrogen could be produced from California LFG, increasing to about 430 Gg y^{-1} by 2025.

Assuming LFG-to-electricity production of 300 MW over the analysis period, the remaining recoverable LFG could produce from 160 to 300 Gg y^{-1} of hydrogen



Assuming; a) an average passenger vehicle in California has gasoline fuel economy of 7.8 l per 100km (30 miles per gallon), b) an average vehicle is driven 24,100 km y^{-1} (15,000 miles/yr), and c) a fuel cell vehicle might be twice as efficient as a gasoline vehicle.

- LFG hydrogen from 2005 could have fueled 1.3 million fuel cell vehicles.
- Up to 1.9 million vehicles could be fueled by renewable LFG hydrogen in 2025.

*Landfill Gas Model**

The gas generation rate, g_n ($m^3\ y^{-1}$), as a function of time for waste placed in the landfill in any year *n* is modeled as

$$g_n = W_n\ L\ e^{-kt}$$

Total gas generation, g_t ($m^3\ y^{-1}$), is the sum over all years up to the current year

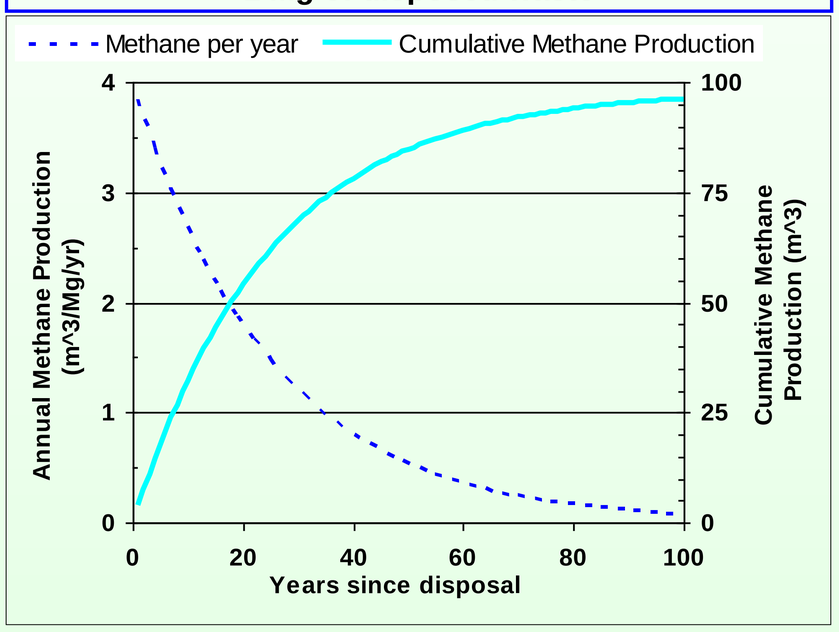
$$g_t = \sum_n g_n = L \sum_n W_n e^{-kt}$$

W_n = quantity of waste placed in year n (wet Mg)
L = 4 $m^3\ Mg^{-1}\ y^{-1}$
k = 0.04 y-1
t = time from base year (y)

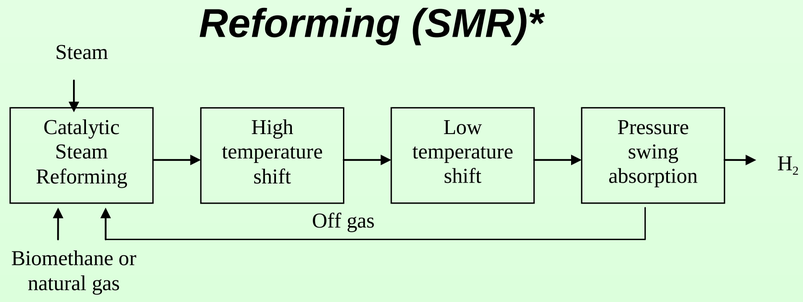
*Based on the USEPA LandGEM model.

The model assumes a first order decay of waste beginning the first year after placement.

Landfill methane model output for 1 Mg of disposed waste



*Hydrogen from Steam Methane Reforming (SMR)**

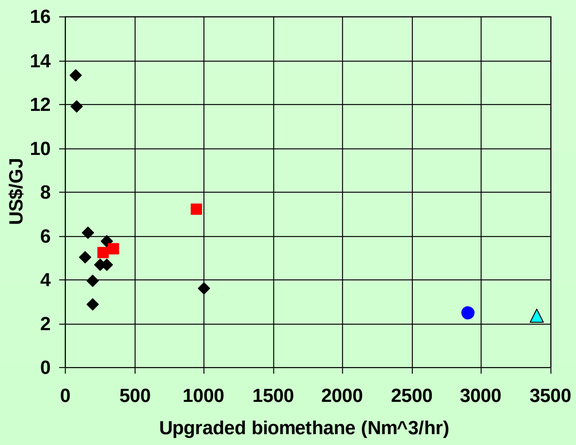


*The net reaction for hydrogen production from methane via SMR is:

$CH_4 + 2H_2O \rightarrow CO_2 + 4H_2$

Hydrogen production estimates assume steam methane reforming (SMR) technology with a 70% net energy efficiency of conversion (HHV basis; feedstock energy to hydrogen energy).

Cost Estimate



Upgrading

The cost to upgrade LFG suitable as vehicle fuel, injection into natural gas pipeline systems, or for SMR, is about US$2.50 GJ^{-1} for large systems and US$6 GJ^{-1} for small systems. This does not include the gas collection costs as gas collection is required at most operating landfills in California for emissions control.

Hydrogen Cost from Upgraded LFG

The hydrogen production cost from natural gas via SMR varies from about US$1.25 kg^{-1} for large systems to about US$ 3.50 kg^{-1} for small systems at a natural gas price of around US$6 GJ^{-1}.

Based on LFG upgrade costs of US$6 GJ^{-1} or lower, hydrogen from LFG is expected to cost less than US$3.50 kg^{-1} (US$29.10 GJ^{-1}, LHV). These costs do not including distribution, storage, and dispensing. Delivered cost is site and mode specific and can add another US$1-2 kg^{-1} (US$8-17 GJ^{-1}).