Anaerobic Digestion and CO_2 Sequestration of Municipal Sanitation Waste in the Deep Subsurface

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Abstract
The Terminal Island Renewable Energy (T.I.R.E.) Project is the nation's first full scale application of deep well injection technology to convert wastewater residuals (biosolids and brine) into a renewable energy source (high purity methane) while simultaneously sequestering greenhouse gases. A slurry mixture composed of digested sludge, trucked wetcake, and reverse osmosis treatment brine is injected into deep subsurface sand formations more than 1500 m beneath the City of Los Angeles Terminal Island Wastewater Treatment Plant. At that depth the earth's natural high temperature biodegrades the organic mass into methane and carbon dioxide. The carbon dioxide dissolves as a liquid (due to the high pressure) into the native formation brine and is permanently sequestered. Relatively high purity methane collects for potential use as a renewable fuel. The process provides enhanced high temperature treatment at relatively low cost, and reduces pollution and greenhouse gas emissions associated with offsite truck transport. During the first three years of the project, more than 500,000 cu-m of slurry have been injected. The process is now managing 100% of the residuals output from the Terminal Island Plant and about 25% of the residuals output from the Hyperion Treatment Plant.
Keywords
Biosolids; deep well injection; CO_2 sequestration; waste to energy

INTRODUCTION AND TECHNOLOGY SUMMARY

The City of Los Angeles and its partners, GeoEnvironment Technologies, and the U. S. Environmental Protection Agency (US-EPA), are demonstrating an innovative technology to manage wastewater residuals (biosolids and brine). Slurry mixtures comprised of varying ratios of digested residuals, biosolids wetcake, and concentrated brine from advanced water treatment, are injected into sand formation in the deep subsurface (see Figure 1). Such deep well injection technology has been applied to manage petroleum waste slurry and solids in the oil and gas industry for many years (see for example Bruno, 2010; Bruno et al, 2000). But there are unique biodegradation and sequestration aspects during subsurface injection of organic.

In the deep subsurface (typically 1000 to 2000 m) the earth's natural heat and pressure converts the organic mass into methane and carbon dioxide. Laboratory experiments at simulated deep subsurface temperatures (about 50C) and pressure (about 15.17 MPa) indicate it takes about 90 days (Bruno et al, 2005) to biodegrade about 90% of the organic mass. Due to the high pressure in the deep subsurface, the CO_2 generated exists as a liquid and dissolves into the native formation brine. The CH_4 generated remains as a gas, and collects in relatively pure form beneath the caprock for storage or eventual recovery and use.

Geothermal Treatment Technology Summary

1. Inject biosolids into deep (hot) geologic formation

2. Allow material to undergo natural process of high-temperature anaerobic biodegradation, instantly (within 24 hrs) sterilizing the material and over time (30-60 days) starting conversion to methane and carbon dioxide

3. Design process to capture and sequester generated CO2 in formation water

4. Store or recover high purity methane for beneficial use

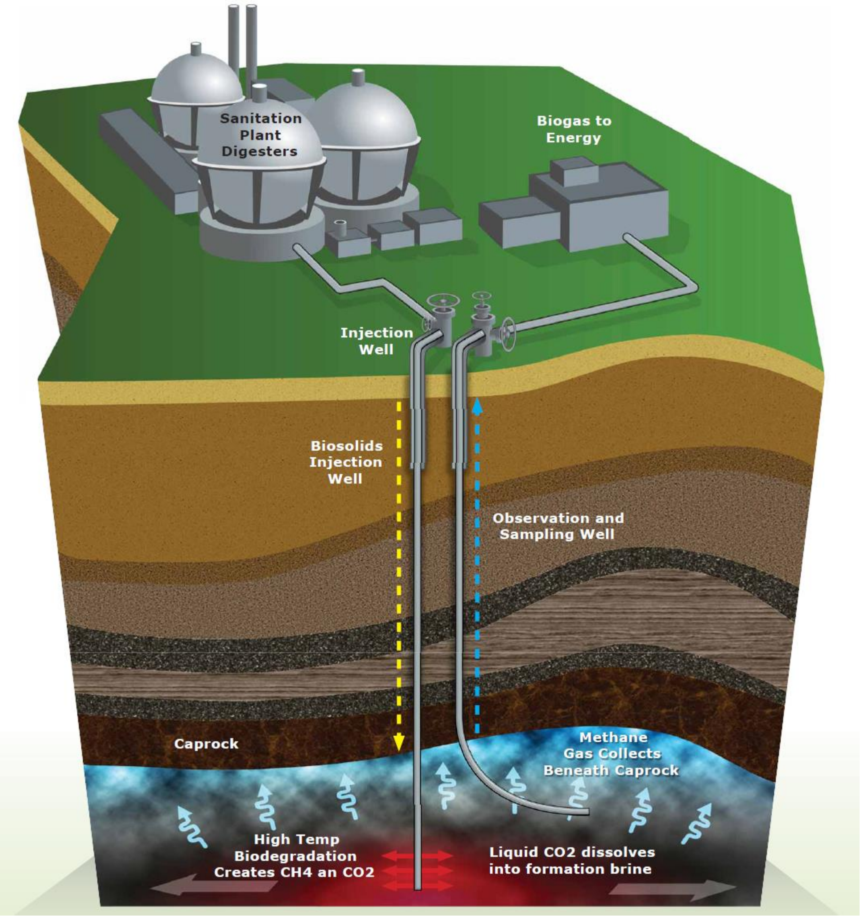

Figure 1. Technology Summary for Geothermal Treatment of Wastewater Residuals

CITY OF LOS ANGELES DEMONSTRATION PROJECT

The Terminal Island Renewable Energy Project was approved by the US EPA as a Class V Demonstration Injection Project, and initiated operations in July, 2008. Three wells were drilled for the project, including one vertical injection well and two deviated monitoring wells with subsurface lateral spacing of about 200 m. The injection interval is about 1500 m deep. During the early stages of the project only wastewater effluent and concentrated brine from reverse osmosis filtration facilities were injected. After a few months digested sludge was introduced, followed a few months later by wetcake transported from the Hyperion Treatment Plant, about 20km away.

The project is now managing the entire wastewater residuals stream (digested sludge) output by the Terminal Island Plant, plus about 140 tons per day of trucked wetcake from the Hyperion Treatment Plant. We present in Figures 2 and 3 summary plot of the daily total slurry and equivalent wetcake injected at the project during the first 30 months of operations. More than 380,000 cu-m of total slurry have been successfully injected to date.

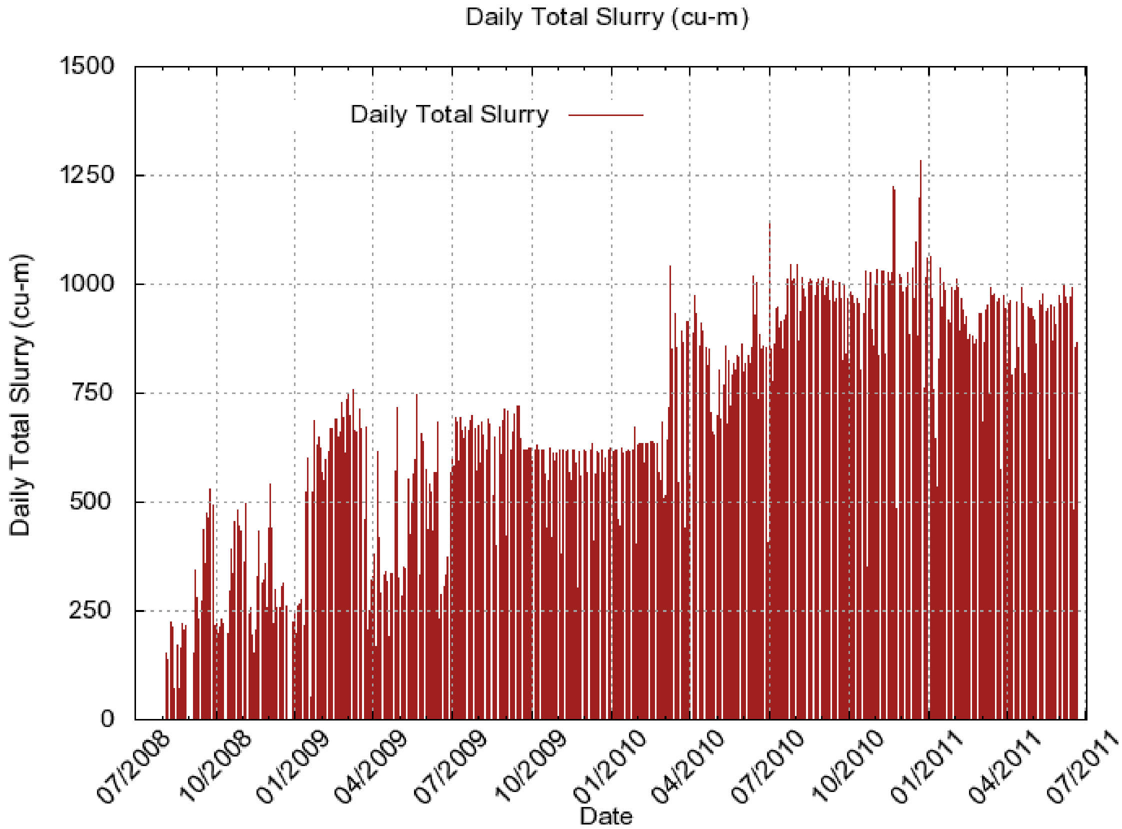

Figure 2. Daily Total Slurry Injection from July, 2008, through March, 2011

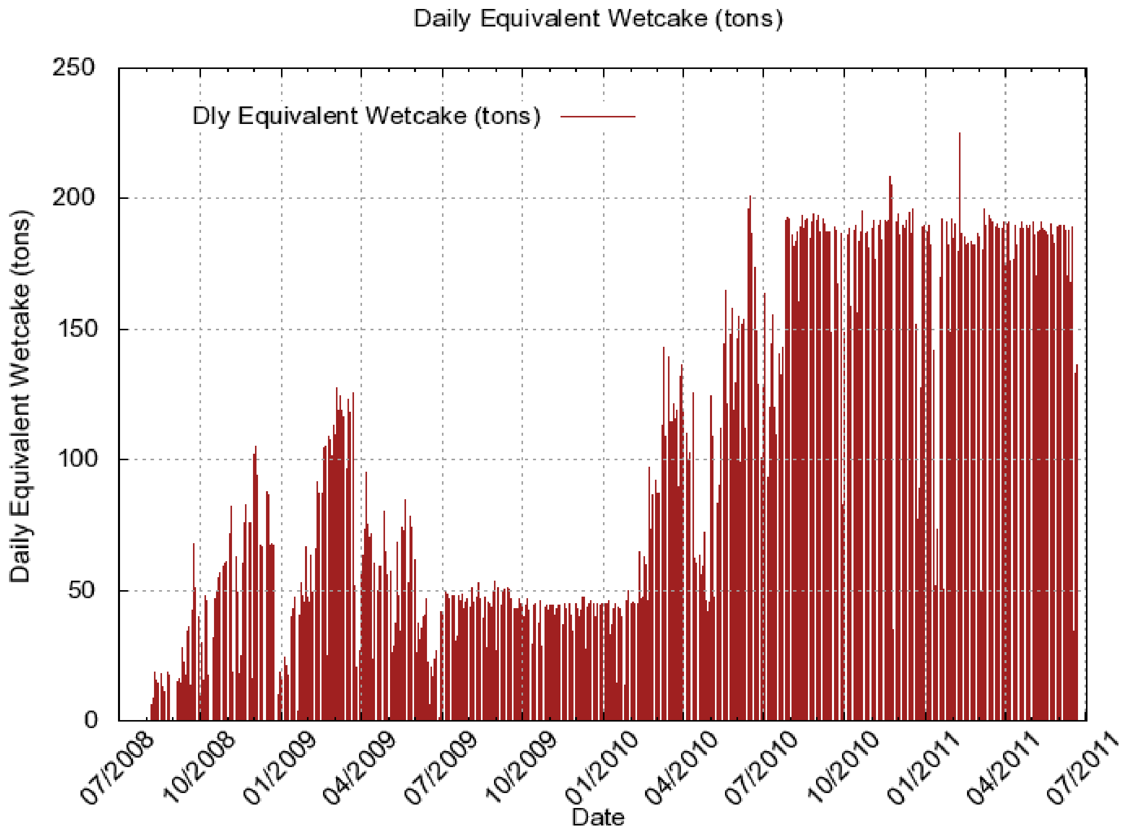

Figure 3. Daily Equivalent Wetcake Injection from July, 2008, through March, 2011

INJECTION AND CONTAINMENT MONITORING AND ANALYSIS
Containment in the target subsurface formation is achieved in three ways:

1. By selecting the appropriate geology;
2. Through appropriate well design; and,
3. Through appropriate monitoring and analysis.

The target injection well interval at the T.I.R.E project is a high porosity sand located at a depth of about 1500 m, as shown in Figure 4. This is overlain by several alternating impermeable shale and permeable sand formations. The shales provide a series of seals. The sands provide a series of sinks (and potential future injection intervals. This alternating sequence of seals and sinks prevents vertical migration of injected material. It is also important to note that the injected residuals are heavier than water, so there is little driving energy to facilitate upwards migration.

The wells designed and constructed for the T.I.R.E. project contain multiple layers of casing, cement, and tubing. Slurry is injected down a 8.9 cm diameter steel tubing string which is contained within an 21.9cm diameter steel casing that is cemented to surface. The 21.9cm assembly is contained within an additional 33cm diameter steel casing set at 457m depth that is also cemented to surface. And that is further contained within an additional 50.8cm diameter steel pipe set at 30.5cm and cemented to surface. In the upper 457m there are therefore 3 layers of steel and 2 layers of cement between the injected slurry and the outside rock formation.

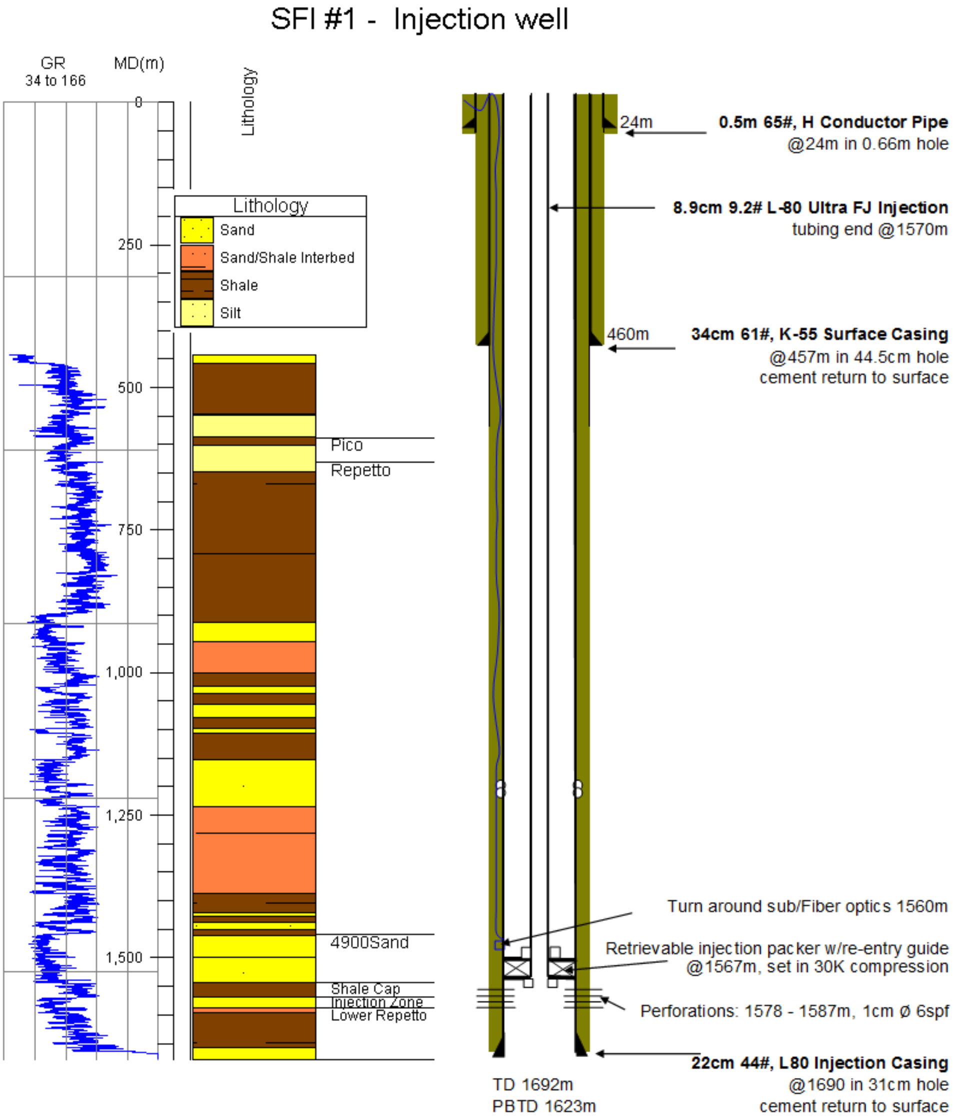

Figure 4. Lithology and injection well schematic

Injection operations at the T.I.R.E. project are continuously monitored and analyzed with a variety of engineering and geophysical sensors. A fiber optic temperature sensor is placed outside the casing on two wells at the project. Because injected slurry is a different temperature than native formation fluids (contained in the rock pore space), it is easy to track fluid migration by looking at the temperature signal from these wells. The temperature in the earth increases linearly with depth. Injected fluids will distort this linear increase and create a zone of relatively constant temperature which can be measured and tracked over time (see Figure 5).

Pressure sensors are also installed on all three wells. Analysis of the daily injection pressures and fall-off pressures during shut-in, and analysis of periodic step rate tests, provide information on fluid migration and on changing formation properties (see for example Chapter 10 and 11 of reference Bruno, 2010).

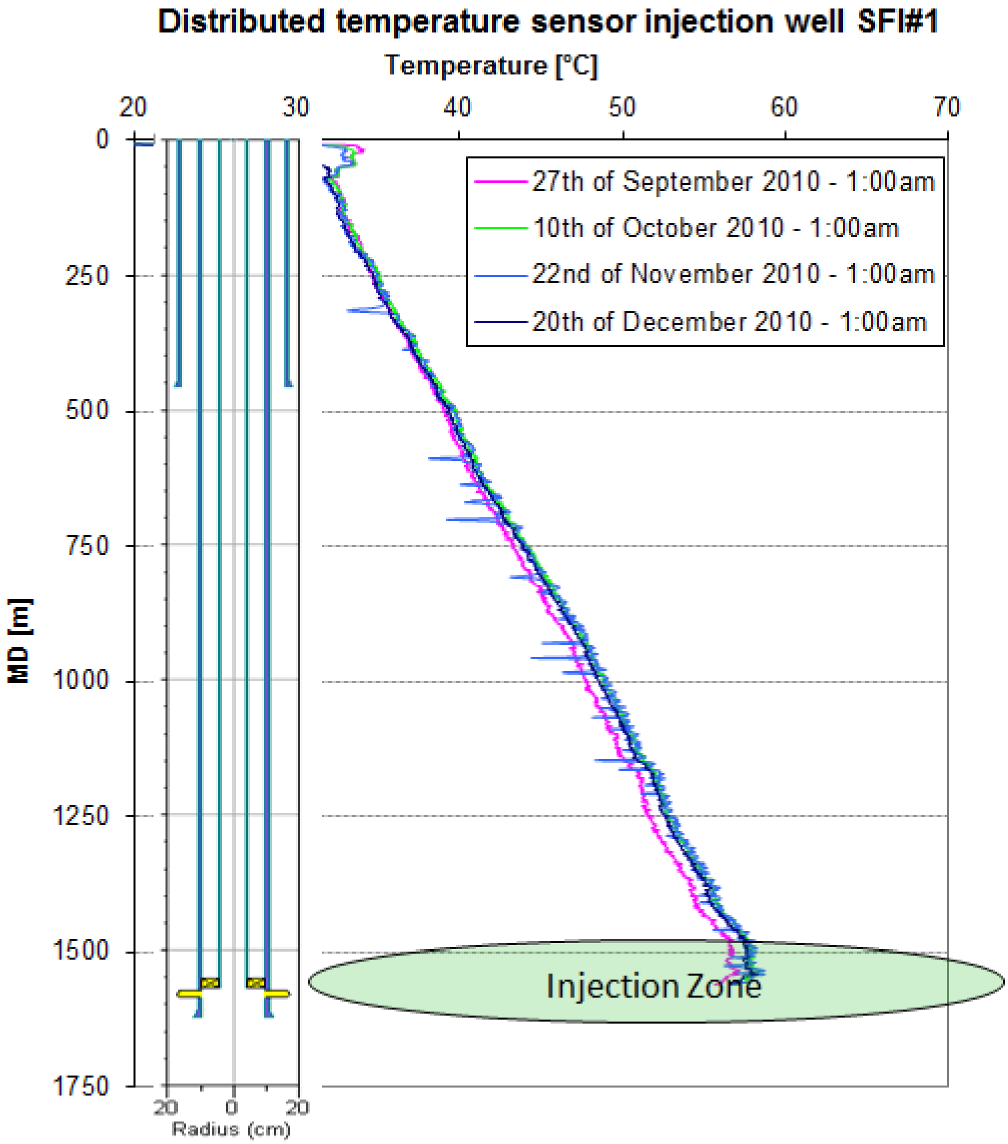

Figure 5. Distributed temperature sensor showing cooling of formation due to injected fluid

GeoEnvironment Technologies applies advanced simulation technology (using the TOUGH2) to estimate fluid and gas migration and saturation (see for example Figure 6). TOUGH2 was developed by Lawrence Berkeley National Laboratory to simulate multi-phase, multi-component fluid and heat flow in porous and fractured media. The simulation results are compared to fluid and gas sampling from both the injection well and the offset monitoring wells, and updated as appropriate.

The results of the monitoring and analysis are reported continuously on a public website, and in written reports submitted weekly and quarterly by GeoEnvironment Technologies to the City of Los Angeles and to the US EPA.

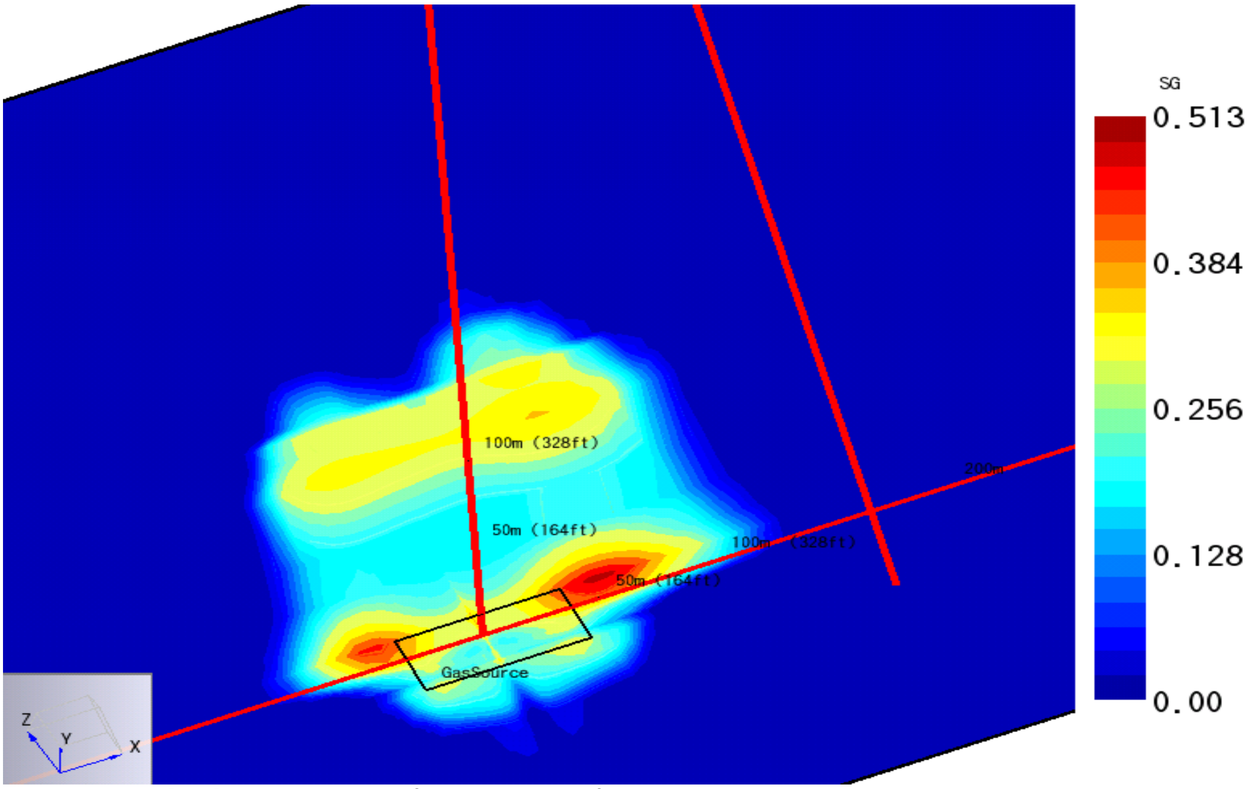

Figure 6. Simulated Gas Saturation After Two Years of Injection Operations

ECONOMIC AND ENVIRONMENTAL BENEFITS

Deep well injection technology provides a cost-effective and environmentally sound and alternative for wastewater residual solids (biosolids) and brine management. A typical two or three well facility to manage 200 to 300 tons per day of biosolids can be constructed at a capital expense of less than 10 million dollars. In comparison, the capital costs to construct a drying facility or gasification facility or incineration facility to manage the same volume can easily exceed five to ten times that amount. Annual operating costs for deep well injection facilities are significantly lower than such facilities, and about on the same order as long-distance truck transport and land application.

More importantly, there are significant environmental benefits that come from the local subsurface anaerobic treatment and sterilization of biosolids in a confined environment. Placing material 1500 m in the subsurface is inherently more protective surface and near surface groundwater than placing material on the surface. Deep well injection at the sanitation plant avoids offsite trucking and associated emissions and pollution. The subsurface biodegradation eliminates CO2 emissions to the atmosphere. And the biodegradation of the injected biosolids and brine as a slurry ultimately produces methane that can be captured to generate green energy. Finally the discharge of concentrated brine to the Los Angeles harbor can be potentially eliminated.

SUMMARY AND CONCLUSIONS

The T.I.R.E. project provides an innovative solution to an environmental challenge, while simultaneously providing economic and environmental benefits. The project improves air quality, protects water quality, and reduces greenhouse gas emissions. The full-scale demonstration project at the City of Los Angeles is the first application in the world of deep well injection technology to manage large volume municipal wastewater residuals, and has been extremely successful. The process is now managing 100% of the residuals output from the Terminal Island Plant and about 20% of the residuals output from the Hyperion Treatment Plant. The technology has application worldwide, providing large urban areas a local solution to manage their wastewater residuals in an environmentally sound and economic manner.

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