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Extreme Cost Savings at Extreme Depth: Geothermal Treatment of Biosolids Through Deep Well Injection

Michael Bruno, PhD, PE, GeoEnvironment Technologies
Jeff Couture, GeoEnvironment Technologies
Omar Moghaddam, PE, City of Los Angeles

ABSTRACT

Deep well injection of biosolids has been successfully applied to manage digested sludge, filtration brine, and biosolids for the City of Los Angeles for almost four years. About 250,000 gallons of slurry and about 200 wet tons of biosolids are processed each day at the Terminal Island Treatment Plant. This 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 5000ft 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 is now managing 100% of the residuals output from the City of Los Angeles Terminal Island Plant and about 20% of the residuals output from the City of Los Angeles Hyperion Treatment Plant.

The economic advantages for geothermal treatment in the deep subsurface are significant. A three-well system sufficient to process up to 100 dry tons per day of biosolids can be installed for less than $10 million dollars. This cost compares to several hundred million dollars of capital expense for alternative systems to handle large volumes, such as drying and pelletizing plants, incineration, gasification, and other waste to energy schemes. Operating costs are also lower than such alternatives, and are competitive with long-distance trucking and land application alternatives.

More importantly, however, deep well injection and geothermal treatment provides significant environmental benefits over alternatives. These include greater protection for surface and groundwater, reduced energy use, significant greenhouse gas emission reductions, and elimination of long distance trucking and associated pollution and public nuisance. The technology allows large urban areas to manage their wastes locally, without relying on distant rural counties.

KEYWORDS

Biosolids management, Brine Management, Deep well injection, Waste to energy, Carbon sequestration

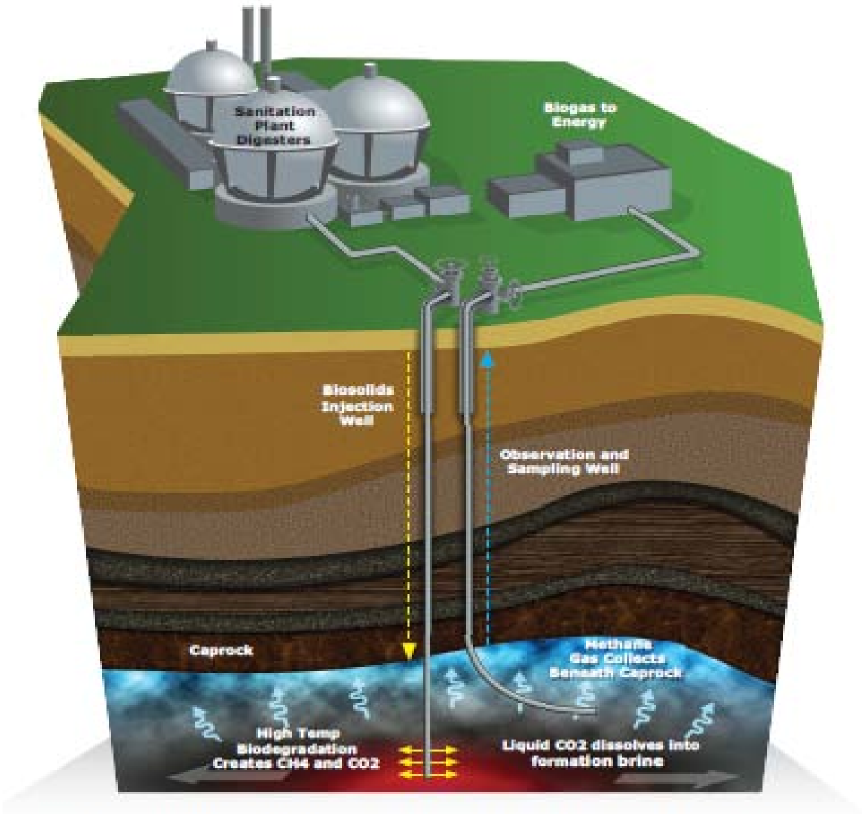
INTRODUCTION AND TECHNOLOGY SUMMARY

GeoEnvironment Technologies has developed, and is currently operating for the City of Los Angeles, 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 a 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). There are, however, unique biodegradation and sequestration aspects involved in subsurface injection of organic wastes, including municipal sanitation and agriculture wastes.

In the deep subsurface (typically 3000 to 7000 feet) the earth's natural heat and pressure converts the organic mass into methane and carbon dioxide. Laboratory experiments at simulated deep subsurface temperatures (about 50°C) and pressure (about 3000psi) 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 is 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) pasteurizing the material and over time (30-60 days) starting conversion to methane and carbon dioxide
3. Design process to capture and sequester generated $C0_2$ in formation water
4. Store or recover high purity methane for beneficial use



*US, Asian, and European Patents held by GeoEnvironment Technologies: www.geoenvironment-technologies.com

Figure 1. Technology Summary for Geothermal Treatment of Wastewater Residuals

ENVIRONMENTAL BENEFITS

There are significant environmental benefits and advantages for geothermal treatment in the deep subsurface, compared to most alternative treatment methods. These include:

1. Greater protection of surface and groundwater;
2. Reduced energy consumption;
3. Reduced trucking and associated emissions;
4. Significantly reduced greenhouse gas emissions;
5. Generation and potential recovery of high purity methane; and,
6. Provides a local solution for urban areas, without relying on distant rural counties.

Placing material 5000 feet in the subsurface is inherently more protective of surface and near surface groundwater than placing material directly on the surface. Regardless of whether the wetcake or sludge material or residual ash is completely safe and benign or contains trace pollutants, placing material directly on the surface allows direct percolation downwards to groundwater, and lateral flow during flooding conditions. In contrast, when such material is placed a thousand feet or more below groundwater and below impermeable shale layers into highly saline sand formations, it is much more difficult to flow upwards. The material is denser than overlying fluids, and is trapped in the pore space by in-situ stresses. Furthermore, the extreme temperature in the subsurface (greater than 50°C) more effectively and rapidly treats and pasteurizes the material, as compared to the lower temperature on the surface.

Slurry injection is ideally suited for concentrated sludge (up to about 10% solids concentration). Such material can be derived from gravity thickeners, from partially de-watered digested sludge, or from a blending of wetcake and sludge or brine. In all of these cases, the energy required to inject the slurry material is ***less than the energy required to de-water*** the equivalent amount of sludge into wetcake (20% to 30% solids). In many situations, there are also additional significant energy savings from avoiding thermophilic digestion, more thorough drying, composting, or pelletization processes.

Deep well injection within or adjacent to sanitation plants avoids offsite trucking and associated emissions and pollution, and the odor, noise, and traffic burden on nearby neighbors. The subsurface biodegradation eliminates CO_2 emissions to the atmosphere. And the biodegradation of the injected biosolids and brine as a slurry produces relatively pure methane that can sometimes be captured to generate green energy. Finally, the discharge of concentrated brine to rivers and ocean outfalls can be potentially eliminated. For these and other reasons, the biosolids injection project operated by GeoEnvironment Technologies for the City of Los Angeles has won several environmental awards, including the 2010 National League of Cities Award for Municipal Excellence (for outstanding programs that improve the quality of life in American Cities) and the 2011 Water Environment Research Foundation Award for Excellence in Innovation (moving research into practice).

COST ADVANTAGES AND COMPARISON

Deep well injection technology provides an environmentally sound alternative for wastewater residual solids (biosolids) and brine management at significantly reduced capital costs compared to other alternatives. A typical three-well facility to manage 100 dry 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 or composting facility for the same volume can exceed 10 times that amount, while more complex incineration, gasification, and waste to energy facilities are significantly more expensive.

We present in Figure 2 approximate capital costs for different types of facilities, using as a baseline (no assumed capital expenditure) a city already producing Class B biosolids for land application. Slurry injection with geothermal treatment, drying and pelletizing, composting, incineration, and gasification can all be considered enhanced treatment processes above Class B standards. There is, of course, a wide range of facility costs in different cities and for different input and output quality, even for the same process. Drying costs in a cold and humid environment are much higher than in a dry and arid environment with plenty of available land area (such as Arizona). Still, the figure below does provide a reasonable order of magnitude comparison. Some specific examples include dryer and pelletizing trains at the City of Houston which cost about $50 million each, and the proposed Thermal Hydrolysis and Anaerobic Digestion Facility planned for the District of Columbia at a capital cost of about $400 million (Cooper et al, 2010).

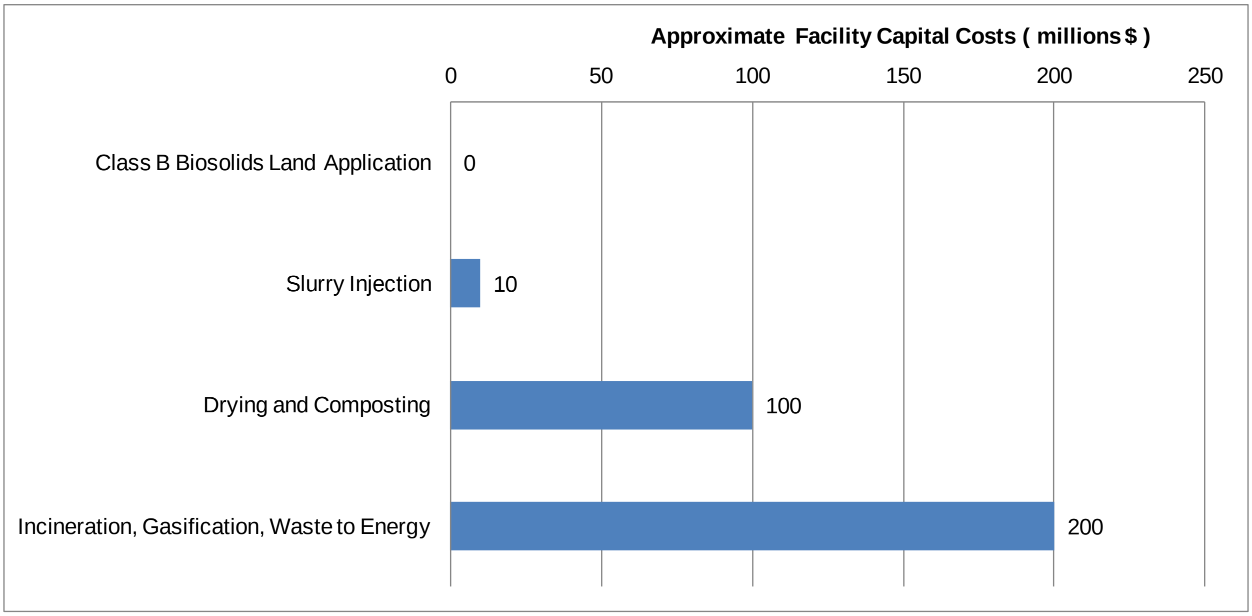


Figure 2. Order of Magnitude Capital Cost Comparison for 100 dry tons per day Facility

Operating and maintenance costs for slurry injection and geothermal treatment facilities are on the same order as long distance trucking and land application (about $150 to $200 per dry ton), and significantly less than many other alternatives (see Figure 3). Again, costs for alternatives are highly variable with respect to region. For example the City of Phoenix, with hot dry air to facilitate drying and an abundance of nearby land for application, has very low land application costs (less than $150/dry ton). The City of New York on the other hand, which sometimes trucks material to distant states, has very high land application costs (greater than $300/dry ton).

Even given the wide variability in alternative process costs, the big picture is that slurry injection capital costs are significantly lower than most alternatives and slurry injection operating and maintenance costs are competitive with low-cost alternatives such as land application. The primary reason for this cost advantage is that deep well injection has a very small physical footprint, requires very little equipment, and is a relatively simple process (although the monitoring and analysis requires sophisticated engineering and technology).

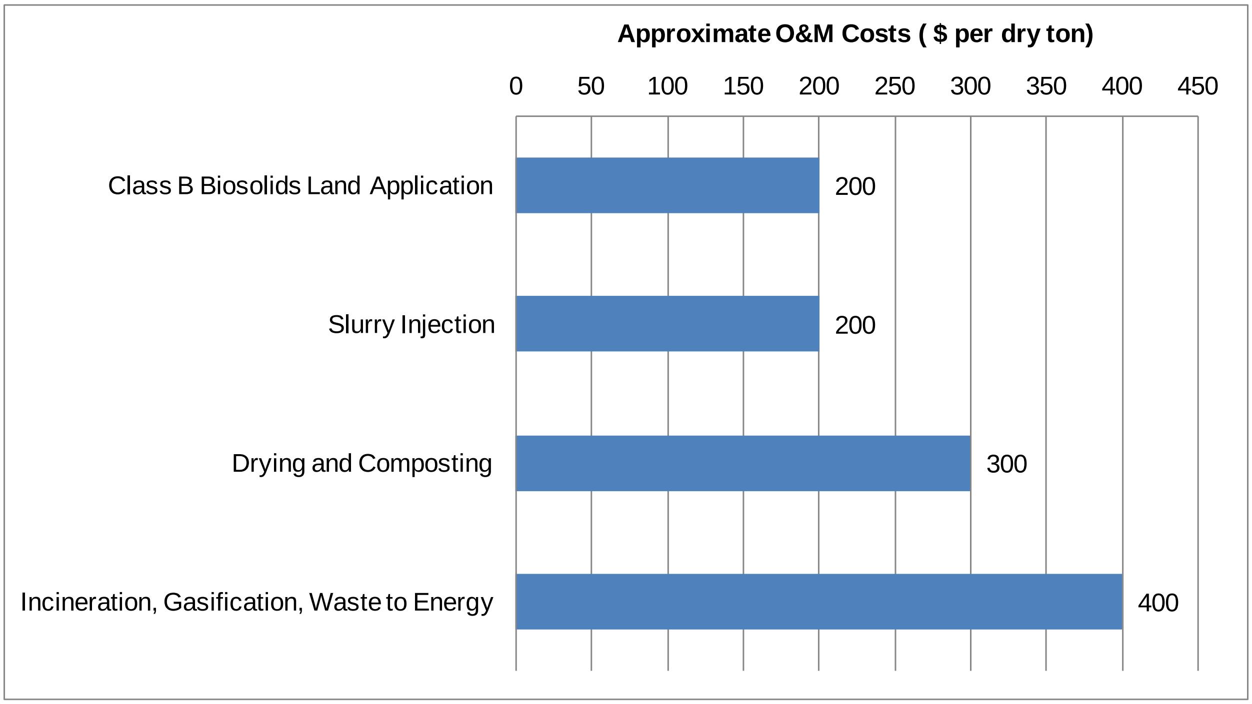


Figure 3. Order of Magnitude Operating and Maintenance Cost Comparison

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 600 feet. The injection interval is about 5200 feet 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 15 miles away.

The project is now managing the entire wastewater residuals stream (digested sludge) output by the Terminal Island Plant, plus about 150 tons per day of trucked wetcake from the Hyperion Treatment Plant. Almost 150 million gallons of total slurry have been injected to date.
We present in Figures 4 and 5 summary plots of the daily total slurry and equivalent wetcake injected at the project during the first 30 months of operations.

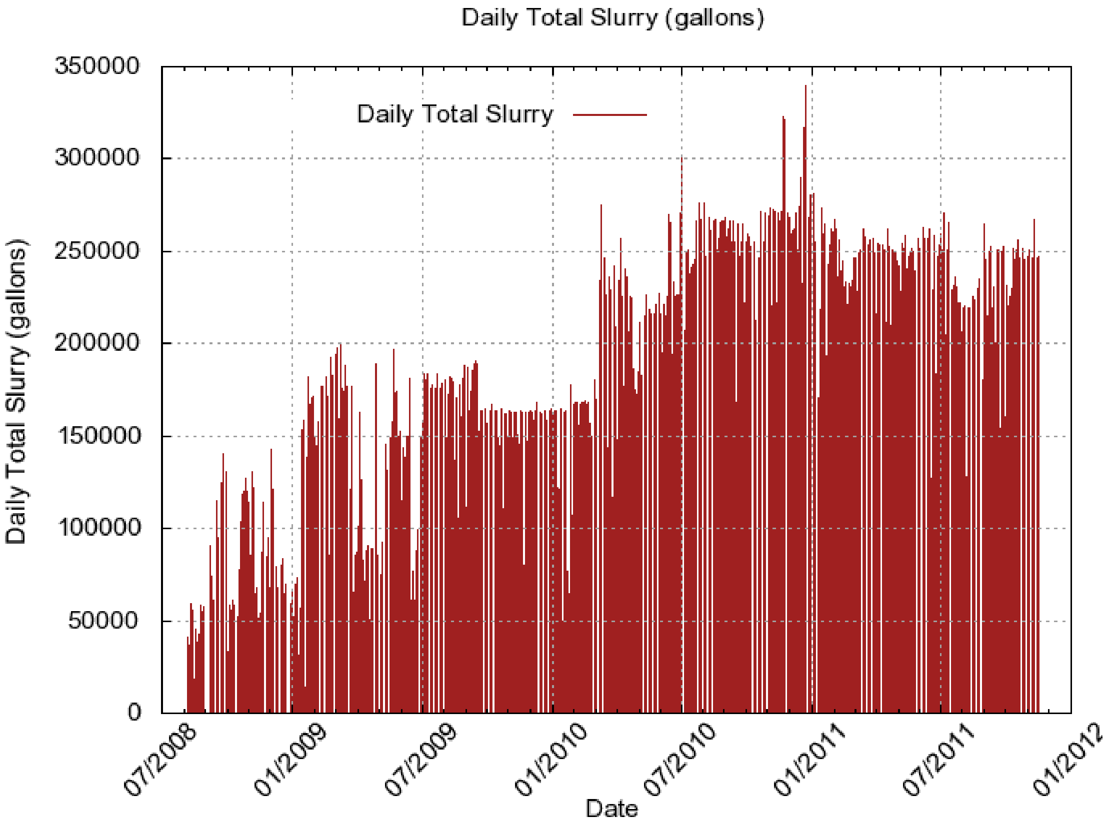


Figure 4. Daily Slurry Injection from July, 2008, through October, 2011

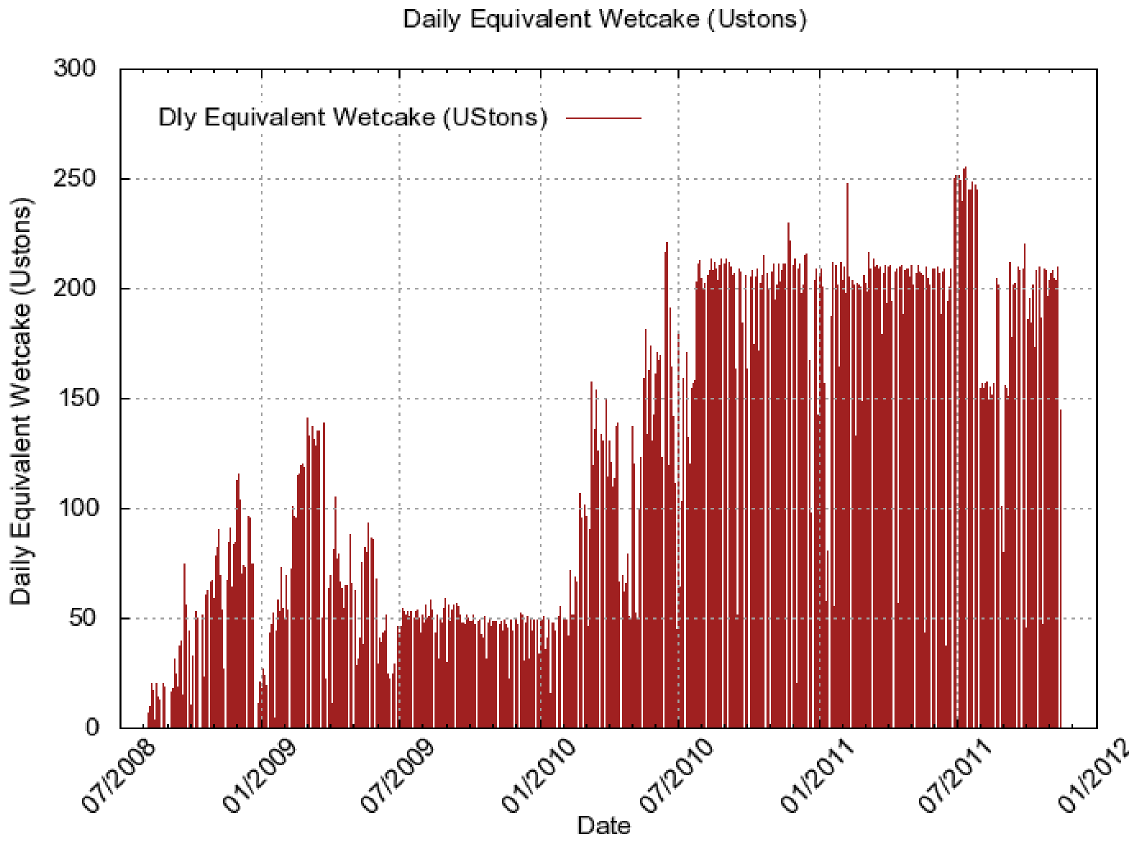


Figure 5. Daily Equivalent Wetcake Injection from July, 2008, through March, 2011

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 5200 feet. This formation 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 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 3.5 inch diameter steel tubing string which is contained within an 8-5/8 inch diameter steel casing that is cemented to surface. The 8-5/8 inch assembly is contained within an additional 13 inch diameter steel casing set at 1500 feet depth that is cemented to the surface, and is further contained within an additional 20 inch diameter steel pipe set at 100 feet and cemented to the surface. In the upper 1500 feet there are therefore 3 layers of steel and 2 layers of cement between the injected slurry and the outside rock formation.

Injection operations at the T.I.R.E. project are extensively and continuously monitored and analyzed with a variety of engineering and geophysical sensors. A fiber optic temperature sensor is placed outside the casing on all three 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 three wells. 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).

GeoEnvironment Technologies applies advanced simulation technology (using the TOUGH2) to estimate fluid and gas migration and saturation (see for example Figure 4). 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.

SUMMARY AND CONCLUSIONS

Geothermal treatment of biosolids through deep well injection provides an innovative solution to an environmental challenge, while simultaneously providing significant economic benefits. The technology 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 capital costs for deep well injection facilities are significantly lower than alternative biosolids management facilities (less than $10million for 100 ton/day capacity) and the operating costs are competitive with low-cost alternatives such as land application (less than $200 per dry ton). The technology has worldwide application, providing large, urban areas a local solution to manage their wastewater residuals in an environmentally sound and economic manner.

REFERENCES

Bruno, M.S. (2010) *Chapter 3: Injection Program Design*, in Solids Injection, Nagel and McLennan, eds., Society of Petroleum Engineers Monograph Volume 24, 2010, pp 23-42.

Bruno, M.S., Young, J.T., Moghaddam, O., Wong, H., Apps, J.A. (2005) *Chapter 46: Thermal Treatment, Carbon Sequestration, and Methane Generation through Deep Well Injection of Biosolids,* Underground Injection Science and Technology, C.F. Tang and J. Apps, ed., Elsevier, Amsterdam, 2005

Bruno, M.S., Reed, A., and Olmstead, S. (2000) *Environmental management, cost management, and asset management for high-volume oil field waste injection projects,* IADC/SPE 59119, Proc. IADC/SPE Drilling Conf., New Orleans, LA, February 23-25.

Cooper, A.B, Benson, L., Bailey, W., Jolly, E., and Krill, W. (2010) Maximizing Benefits from Renewable Energy at Blue Plains AWWTP, Paper presented at the 2010 WEF Residuals and Biosolids Conference, Savannah, Georgia, May 23 – 26, 2010