Case for Caution Revisited: Health and Environmental Impacts of Application of Sewage Sludges to Agricultural Land

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Over the past 15 years since the 40CFRPart503 rules were promulgated, there have been many new scientific findings regarding the environmental and health implications of the application of sewage biosolids to agricultural soils. Many of these findings show increased risks, risks that were not assessed as part of the risk assessment that USEPA used as the basis for the standards promulgated in 1993. These new findings support the rational basis for U.S. EPA to revise the federal regulations and for states and municipalities to regulate the application of sewage biosolids in order to protect their citizens and the land-base.

Agricultural soils are a unique and valuable resource. Protecting agricultural soils requires anticipating and avoiding potential harms since once contaminated with persistent pollutants, the damage will remain for the foreseeable future. Once contaminated, stopping the application of pollutants such as metals and many organic chemicals that are in sewage biosolids will not correct the problem. The contamination will remain for decades or centuries. It is thus critical to prevent this essentially permanent degradation.

Current Rules are Based on Outdated and Inadequate Science

As pointed out the by the National Research Council, the risk assessment on which current rules are based was conducted nearly 20 years ago and is outdated. A tremendous amount of new knowledge about the presence and behavior of chemicals and pathogens has been developed in the last decades.

NRC Targets Pathogens in Sludge for Research. Rebecca Renner, 2002.Environmental Science and Technology: Science News - July 24. <http://pubs.acs.org/doi/pdf/10.1021/es022404s>

The U.S. EPA rules for using treated sewage sludge as fertilizer are based on outdated science, according to a report released in July from the National Academies, National Research Council (NRC). The report, which was produced after two years of study, recommends new research to update the rules. In particular, EPA needs to investigate the growing number of complaints about illnesses and even deaths from exposure to Class B sludge.

Under a 1993 Clean Water Act rule, treated sewage sludge, or biosolids, can be applied to land with certain limitations. Pathogen-containing Class B sludge, which makes up the bulk of sludge applied to land, may be used as fertilizer in situations in which public exposure is limited. Class A sludge can be applied on public sites. Of the 5.6 million tons of sewage sludge generated in the United States each year, 60% ends up being applied as fertilizer.

The agency needs to investigate the potential health effects from sludge exposure and find out more about the pathogens in sludge, according to committee chair Thomas Burke, a public health professor at Johns Hopkins University in Baltimore, Md. There is a serious lack of health-related information about populations exposed to treated sludge, adds Burke.

The NRC report also recommends a new national sludge survey to measure sludge contaminants, which would update the previous 1988 survey. This earlier study was unreliable and needs to include newly recognized chemicals of potential concern, including polybrominated biphenyl ether flame retardants, pharmaceuticals, and personal care products such as shampoos and soaps, says the NRC committee. EPA also needs to redo its assessment of the human health risks posed by metals in sludge. The revised risk assessments should reflect the potential for variations in climate, water flow, and sludge characteristics. The report also notes that more rigorous enforcement of the current standards is needed."

Targeted National Sewage Sludge Survey Report Released in 2009. USEPA, <http://earth1.epa.gov/waterscience/biosolids/tnsss-overview.html>

The last EPA survey of sewage sludges nationally occurred in 1988. The EPA 503 rule was based in large part on the levels of contaminants detected in that survey. Many contaminants have emerged since then as being potentially harmful in the environment. This new survey by

EPA provides much-needed information on chemicals likely to be found in sewage sludges across the country.

In 2006 and 2007, the USEPA collected samples of sewage sludge from 74 randomly-chosen wastewater treatment facilities in 35 states. The sampled facilities are considered to be representative of the nation's 3,337 largest treatment facilities. The samples were tested for 145 chemicals, including metals, PAHs, nitrogen, phosphorus, flame retardants (PDBEs), pharmaceuticals, hormones, and steroids.

It is notable that, while the median concentrations of toxic metals, trace elements, and organic chemicals were generally many times lower than the highest concentrations observed, quite high concentrations of one or more chemicals were measured in a substantial fraction of the 74 treatment plants. This survey, while quite informative, is not able to assess variability of sludge composition over time, as the sewage sludge was sampled at a single time point. The survey showed some very high concentrations of specific chemicals at one or more treatment plants, with peak concentration for the following elements being:

Barium	3,460 mg/kg		Mercury	8.26 mg/kg
Fluoride	234 mg/kg		Nickel	526 mg/kg
Molybdenum	132 mg/kg		Copper	2,580 mg/kg
Silver	856 mg/kg		Tin	522 mg/kg
Cobalt	290 mg/kg		Vanadium	617 mg/kg
Iron	299,000 mg/kg		Zinc	8,550 mg/kg
Lead	450 mg/kg			

This list is only a sampling of the inorganic contaminants reported in the survey.

In many cases, the highest contaminant concentrations were found in the smallest wastewater treatment plants included in the survey (1-10 MGD plant). The very high Fe sludge (reported in the list above) also had very high phosphorus, attributable to a tertiary treatment process using iron salts to remove P from wastewater. As tertiary treatment to lower P in treated water is likely to increase in the future, we can perhaps expect to see more sewage sludges with very high Fe content. Although ferric iron is not a toxic metal when mixed into soil, it has been known to be toxic to cattle where sludge was applied directly to pasture.

The high levels of several unregulated or inadequately regulated and potentially toxic metals (e.g., silver, molybdenum, tin) are a concern for land application. It should also be of great concern for land application that the measured concentrations of persistent organic pollutants (POPs), including the brominated fire retardants (PBDEs), and the antimicrobial chemicals (triclosan and triclocarban) are so high in some sludges. These POPs are likely to build up in soils with repeated application, and have the potential to bioconcentrate in foraging animals and therefore in meat and milk. One of the eleven PBDE congeners measured (BDE 209) reached a concentration of 17,000 µg/kg in one sludge, and the highly bioaccumulative BDEs 47 and 99 reached levels as high as 5,000 µg/kg. Triclocarban and triclosan had peak concentrations of 441,000 and 133,000 µg/kg in separate sludges. The impact of these persistent chemicals on soil organisms, the safety of food crops, and the environment is not known at this time because of very limited research on their behavior and toxicity in soil.

The prevalence of a wide array of pharmaceuticals, steroids and hormones, as summarized in the EPA report, is a clear indication that the sewage treatment process does not degrade these organic chemicals effectively, and sewage sludge therefore becomes the repository for a large fraction of the chemicals used commercially and domestically.

New information on the impacts of the regulated contaminants

Endocrine Disruption

New information indicates that some of the handful of metals that are regulated under Part 503 pose risks that were not evaluated in the risk assessment upon which the Part 503 USEPA rules are based. The whole subject of endocrine disruption due to exposure to chemicals in the environment (i.e. our knowledge regarding the disruption to human and animal hormones and reproductive systems posed by a number of chemicals) has developed since those rules were promulgated.

Examples of several of the regulated metals for which new risks have been identified are lead and cadmium. Recent work shows that lead has a number of effects on sperm and may play a role in the rising infertility that is being observed. Cadmium has been shown to mimic estrogen and may be related to increased breast cancer. These metals are contained in all sewage biosolids. The contaminant limits in Part 503 do not include any recognition of these endocrine-disrupting impacts.

Increased seminal plasma lead levels adversely affect the fertility potential of sperm in IVF. Susan Benoff, Grace M. Centola, Colleen Millan, Barbara Napolitano, Joel L. Marmar and Ian R. Hurley, 2003. Human Reproduction, V. 18, No. 2, 374-383

BACKGROUND: Lead remains in high levels in the environment and is known to reduce fertility in animal models, but a direct link between lead exposures and human infertility has not yet been established. METHODS: In a prospective, double-blind study of the metal ion levels and sperm function, semen was obtained from partners of 140 consecutive women undergoing their first IVF cycle. Lead in seminal plasma was determined by atomic absorption spectroscopy. Motile sperm populations were assessed for surface receptors for mannose binding, and the ability to undergo premature ('spontaneous'), and free mannose-induced acrosome reactions. Fertile donor (n = 9) sperm were exposed to exogenous lead during capacitating incubations and then assessed for mannose receptor expression and acrosome loss. RESULTS: Lead levels were negatively correlated with IVF rates. Lead levels were negatively correlated to two of the three sperm function biomarkers (mannose receptors, mannose-induced acrosome reactions). Lead levels positively correlated with the spontaneous acrosome reaction. These findings were mimicked by in-vitro exposure of fertile donor sperm to lead. CONCLUSIONS: Multiple sperm parameters are affected as lead levels rise. Increased lead levels may contribute to the production of unexplained male infertility.

Cadmium mimics the in vivo effects of estrogen in the uterus and mammary gland. Michael D Johnson, Nicholas Kenney, Adriana Stoica, Leena Hilakivi-Clarke, Baljit Singh, Gloria Chepko,

Robert Clarke, Peter F Sholler, Apolonio A Lirio, Colby Foss, Ronald Reiter, Bruce Trock, Soonmyoung Paik, and Mary Beth Martin, 2003. Nature Medicine, 9:1081-1084. Letter Published online: 13 July 2003.

Abstract: “It has been suggested that environmental contaminants that mimic the effects of estrogen contribute to disruption of the reproductive systems of animals in the wild, and to the high incidence of hormone-related cancers and diseases in Western populations. Previous studies have shown that functionally, cadmium acts like steroidal estrogens in breast cancer cells as a result of its ability to form a high-affinity complex with the hormone binding domain of the estrogen receptor1, 2. The results of the present study show that cadmium also has potent estrogen-like activity *in vivo*. Exposure to cadmium increased uterine wet weight, promoted growth and development of the mammary glands and induced hormone-regulated genes in ovariectomized animals. In the uterus, the increase in wet weight was accompanied by proliferation of the endometrium and induction of progesterone receptor (PgR) and complement component C3. In the mammary gland, cadmium promoted an increase in the formation of side branches and alveolar buds and the induction of casein, whey acidic protein, PgR and C3. *In utero* exposure to the metal also mimicked the effects of estrogens. Female offspring experienced an earlier onset of puberty and an increase in the epithelial area and the number of terminal end buds in the mammary gland.”

Cadmium mimics effects of estrogen. NewScientist.com News Service, 13:44, July 14, 2003.

Cadmium is astonishingly good at mimicking the effects of the female sex hormone estrogen, new research on rats has revealed. The discovery raises concerns that the metal, and others like it, could increase the risk of illnesses like breast cancer in people.

Cadmium is widely used in batteries, and is present in cigarette smoke and sewage sludge spread on agricultural land. It is best known for obvious toxic effects on the liver and kidneys.

But new research by Mary Beth Martin's team at Georgetown University in Washington DC shows that, at much lower doses, cadmium can cause very similar effects as estrogen.

Martin gave cadmium to female rats whose ovaries had been removed, so they could not make estrogen themselves. The animals received doses comparable to the level set by the World Health Organization as a tolerable weekly intake for people. The results were unexpectedly striking, with the effects of the cadmium appearing almost identical to those of estrogen.

Denser tissue

Rats given cadmium rapidly developed heavier wombs, denser mammary glands and thicker womb linings - just as they did when given estrogen itself. They also began to make milk, and two genes usually activated by estrogen were switched on.

And when Martin's team gave cadmium to pregnant rats, their female offspring went through puberty sooner and developed denser mammary gland tissue, again matching the effects of estrogen.

Impacts on livestock

Livestock that graze on sludge-amended pastures ingest biosolids that adhere to the forage plants and also ingest soil directly. Particularly in arid conditions, soil can be up to 18% dry weight of a grazing animal's diet. Even where lesser amounts are ingested, recent research has shown impacts to grazing animals from biosolids additions to soils. These impacts include an accumulation of toxic metals in edible body organs, with implications for the human food chain. Additionally, endocrine disruption (reduced testis size) has been documented, with implications for livestock reproduction. There is now evidence that elements in sludge, particularly molybdenum and sulfur, are readily taken up by forages and can lead to Cu deficiency in livestock.

Accumulation of potentially toxic elements by sheep given diets containing soil and sewage sludge. 1. Effect of type of soil and level of sewage sludge in the diet. Hill, J. B. Stark, J. Wilkinson, M. Curran, I. Lean, J. Hall, C. Livesey, 1998. Animal Science, 67:73-86.

Live weight gain was depressed by the addition of sludge to the diet. Levels of cadmium and lead in liver and kidneys increased, with the lead levels approaching the UK statutory limit for human food.

The long-term effect of sludge application on Cu, Zn, and Mo behavior in soils and accumulation in soybean seeds. B.J. Kim, M.B. McBride, B.K. Richards, T.S. Steenhuis, 2007. Plant and Soil, 299:227-236.

Molybdenum and copper uptake by forage grasses and legumes grown on a metal-contaminated sludge site. M.B. McBride, 2005. Communications in Soil Science and Plant Analysis, 36: 2489-2501.

Molybdenum extractability in soils and uptake by alfalfa 20 years after sewage sludge application. M.B. McBride and B. Hale, 2004. Soil Science, 169:505-514.

Molybdenum, sulfur, and other trace elements in farm soils and-forages after sewage sludge application. M.B. McBride, 2004. Communications in Soil Science and Plant Analysis, 35:517-535.

The EPA 503 rule regulated the loading of only 8 heavy metals on agricultural soils. Molybdenum loading on soils is not limited by the 503 rule even though this trace metal presents a well-documented danger for ruminant animals due to its ready uptake into forage legumes, grasses, soybeans and other crops. The 4 research papers cited above demonstrates that molybdenum in land-applied sewage represents a sustained and long-term risk to livestock health from increased molybdenum in forages and soybeans.

Effects of pasture applied biosolids on performance and mineral status of grazing beef heifers. M.E. Tiffany, L.R. McDowell, G.A. O'Connor, F.G. Martin, N.S. Wilkinson, E.C. Cardoso, S.S. Percival and P.A. Rabiansky, 2000. J. Animal Science, 78:1331-1337.

Effects of residual and reapplied biosolids on performance and mineral status of grazing beef steers. M.E. Tiffany, L.R. McDowell, G.A. O'Connor, F.G. Martin, N.S. Wilkinson, S.S. Percival and P.A. Rabiansky, 2002. J. Animal Science, 80:260-269.

Molybdenum and sulfur in forage crops are known to reduce the availability of copper to ruminant animals, and can lead to severe copper deficiency in livestock.

Studies in Florida have revealed that, while molybdenum applied with sewage sludges on bahiagrass was not taken up by the grass to a significant degree, grazing beef cattle nevertheless developed signs of copper deficiency as confirmed by reductions in liver copper stores. This negative effect of sewage sludge on copper availability to the cattle was attributed to high sulfur concentrations in the sludge-amended pastures. The low uptake of molybdenum by grass in that study can be attributed to the low pH of the pasture soils.

Exposure to pastures fertilised with sewage sludge disrupts bone tissue homeostasis in sheep. P. Monica Lind, M. Gustafsson, S.A.B. Hermsen, S. Larsson, C.E. Kyle, J. Orberg and S.M. Rhind, 2009. Science of the Total Environment, 407:2200-2208.

A recent study has shown that male sheep exposed to low levels of pollutants by grazing on pastures fertilized with sewage sludge developed bone tissue abnormalities.

Cellular and hormonal disruption of fetal testis development in sheep reared on pasture treated with sewage sludge. Catriona Paul, Stewart M. Rhind, Carol E. Kyle, Hayley Scott, Chris McKinnell, and Richard M. Sharpe, 2005. Environmental Health Perspectives, 113(11):1580-1587

Fetuses of pregnant sheep reared on sludge-treated pasture had reduced body weight. Male fetus testis were significantly reduced. "These findings indicate that exposure of the developing male sheep fetus to real-world mixtures of environmental chemicals can result in major attenuation of testicular development and hormonal function, which may have consequences in adulthood." This has the potential for impact on fertility.

Movement to groundwater through facilitated transport

New understanding about the movement of contaminants (both chemicals and pathogenic organisms) through soils into groundwater has been developed in recent years. This includes information showing that contaminants may "piggy-back" on other chemicals that move in water (this is termed "facilitated transport"). Thus a chemical which by itself is relatively immobile in soils (such as many metals), can move rapidly through soils when other chemicals are present (such as organic matter in biosolids). In addition, another mechanism that provides for rapid movement of chemicals through soils is that water and the contaminants carried in it can move through soils along preferential flow paths (such as worm holes, root channels or wetting fingers).

Recent short feature articles on these topics prepared by Cornell include *Colloidal transport: the facilitated movement of contaminants into groundwater* (B.K. Richards, J.F. McCarthy, T.S. Steenhuis, A.G. Hay, Y. Zevi, A. Dathe. 2007. Journal of Soil & Water Conservation 62(3)55A-

56A) and *The unintentional secret*. (B.K. Richards, N. Peranginangin, T.S. Steenhuis and L.D. Geohring. 2003. Journal of Soil & Water Conservation, September-October 2003 59(5):104A-105A). By these mechanisms, contaminants can move through the soil and into groundwater much more quickly than predicted in the very limited risk assessment of groundwater transport potential performed to support the Part 503 rules. The rate of contaminant movement predicted by that risk assessment relied on data from a *single* paper based on *test tube* mobility tests from a *single soil type*. No actual field data were used. Furthermore, the transport models employed by that assessment assumed uniform homogenous soils. The risk assessment thus did not account for these common rapid flow phenomena.

Biosolid colloid-mediated transport of copper, zinc, and lead in waste-amended soils. A.D. Karathanasis, D.M.C. Johnson, and C.J. Matocha, 2005. Journal of Environmental Quality, 34(4):1153-1164

A significant increase in the leaching of metals (up to 10,000 times) was measured in a laboratory experiment as a result of the binding of metals to the organic colloids in sewage sludge. "The findings demonstrate the important role of biosolids colloids as contaminant carriers and the significant risk they pose."

Effect of Mineral Colloids in Virus Transport through Saturated Sand Columns. Yan Jin, Ellen Pratt, and Marylynn V. Yates, 2000. Journal of Environmental Quality, 29(2):532-539

The movement of viruses through soils was facilitated by adsorption on to colloidal particles.

Facilitated Transport of Napropamide by Dissolved Organic Matter in Sewage Sludge-Amended Soil. L. Nelson, W. Farmer, C.J. Williams, and M. Ben-Hur, 1998. Journal of Environmental Quality, 27:1194-1200.

Abstract: The application of sewage sludge to agricultural soils is practiced to minimize landfill disposal. Organic matter amendments to soil are generally thought to improve soil quality, but pesticide application to these soils may lead to groundwater contamination problems. The complexation of pesticides with a water-soluble carrier such as dissolved organic matter (DOM) may facilitate chemical movement through soil. Sewage sludge amendments may lead to greater downward movement of organic chemicals if associated with DOM. Napropamide [2-α-napthoxy)-*N*,*N*-diethylpropionamide] was applied to a silt loam soil with (SS) and without (NoSS) sewage sludge application. Laboratory batch equilibrium and soil column studies were performed to determine the potential for herbicide complexation with DOM. Over 98% of the herbicide in soil columns followed typical adsorption and transport behavior as the center of mass of the lower organic matter soil (NoSS) moved twice the depth as that of SS. However, napropamide was detected in the initial leachate eluted from repacked soil columns with steps taken to prevent preferential flow. Napropamide concentrations in the initial leachate of SS were twice that from NoSS with <1.5% of the total applied chemical mass eluting from the bottom of each column. A strong positive relationship was found between napropamide concentration and DOM content in soil leachates. Equilibrium dialysis methods were used to determine that napropamide moving

through the soil columns was complexed with DOM. The results show that DOM can facilitate herbicide movement through soil and that sewage sludge-derived DOM may lead to enhanced chemical transport in sludge-amended soils.

Enhanced Transport of Pesticides in a Field Trial with Treated Sewage Sludge. E. Grager, I. Dror, F. Bercovich, and M. Rosner, 2001. Chemosphere, 44: 805-811

Pesticide leaching in arid field soils was increased by the application of sewage sludge.

Aerosols and human health effects

Health effects from exposure to sewage sludge during land spreading have been reported frequently, but these reports have been considered anecdotal and not confirmatory evidence that illness can result from aerosols released during application. Few studies have actually addressed symptoms related to land application. A study of people living near application sites compared with a control population showed statistically elevated health-related symptoms in the exposed population. Another study of 48 people located near 10 land application sites indicated that chemical irritants and pathogens in sludge may interact to cause symptoms.

Several recent publications have tracked aerosol emissions from fields during sewage sludge (biosolids) application and tillage. DNA-based microbial tracking has proven that wind is a critical factor in the formation and off-site migration of aerosols. Biosolids aerosols of inhalable size (< 10 µm), containing bacteria such as coliforms and Health survey of residents living near farm fields permitted to receive biosolids.

Health Survey of Residents Living near Farm Fields Permitted to Receive Biosolids. Sadik Khuder, Sheryl A. Milz, Michael Bisesi, Robert Vincent, Wendy McNulty, and Kevin Czajkowski, 2007. Archives of Environmental and Occupational Health, 62(1):5-11.

Abstract: The authors studied the health status of residents living in Wood County, OH, near farm fields that were permitted to receive biosolids. They mailed a health survey to 607 households and received completed surveys from 437 people exposed to biosolids (living on or within 1 mile of the fields where application was permitted) and from 176 people not exposed to biosolids (living more than 1 mile from the fields where application was permitted). The authors allowed for up to 6 surveys per household. Results revealed that some reported health-related symptoms were statistically significantly elevated among the exposed residents, including excessive secretion of tears, abdominal bloating, jaundice, skin ulcer, dehydration, weight loss, and general weakness. The frequency of reported occurrence of bronchitis, upper respiratory infection, and giardiasis were also statistically significantly elevated. The findings suggest an increased risk for certain respiratory, gastrointestinal, and other diseases among residents living near farm fields on which the use of biosolids was permitted. However, further studies are needed to address the limitations cited in this study.

Interactions of pathogens and irritant chemicals in land-applied sewage sludges (biosolids). David L Lewis, David K Gattie, Marc E Novak, Susan Sanchez, and Charles Pumphrey , 2002.

BMC Public Health, 2:11

Background: Fertilisation of land with processed sewage sludges, which often contain low levels of pathogens, endotoxins, and trace amounts of industrial and household chemicals, has become common practice in Western Europe, the US, and Canada. Local governments, however, are increasingly restricting or banning the practice in response to residents reporting adverse health effects. These self-reported illnesses have not been studied and methods for assessing exposures of residential communities to contaminants from processed sewage sludges need to be developed.

Methods: To describe and document adverse effects reported by residents, 48 individuals at ten sites in the US and Canada were questioned about their environmental exposures and symptoms. Information was obtained on five additional cases where an outbreak of staphylococcal infections occurred near a land application site in Robesonia, PA. Medical records were reviewed in cases involving hospitalisation or other medical treatment. Since most complaints were associated with airborne contaminants, an air dispersion model was used as a means for potentially ruling out exposure to sludge as the cause of adverse effects.

Results: Affected residents lived within approximately 1 km of land application sites and generally complained of irritation (e.g., skin rashes and burning of the eyes, throat, and lungs) after exposure to winds blowing from treated fields. A prevalence of *Staphylococcus aureus* infections of the skin and respiratory tract was found. Approximately 1 in 4 of 54 individuals were infected, including 2 mortalities (septicaemia, pneumonia). This result was consistent with the prevalence of *S. aureus* infections accompanying diaper rashes in which the organism, which is commonly found in the lower human colon, tends to invade irritated or inflamed tissue.

Conclusions: When assessing public health risks from applying sewage sludges in residential areas, potential interactions of chemical contaminants with low levels of pathogens should be considered. An increased risk of infection may occur when allergic and non-allergic reactions to endotoxins and other chemical components irritate skin and mucus membranes and thereby compromise normal barriers to infection.

Particulate matter composition and emission rates from the disk incorporation of class B biosolids into soil. Tania Paez-Rubio, Xin Huab, James Anderson, Jordan Peccia, 2006. Atmospheric Environment, 40:7034-7045

Abstract: Biosolids contain metal, synthetic organic compound, endotoxin, and pathogen concentrations that are greater than concentrations in the agricultural soils to which they are applied. Once applied, biosolids are incorporated into soils by disking and the aerosols produced during this process may pose an airborne toxicological and infectious health hazard to biosolids workers and nearby residents. Field studies at a Central Arizona biosolids land application site were conducted to characterize the physical, chemical, and biological content of the aerosols produced during biosolids disking and the content of bulk biosolids and soils from which the aerosols emanate. Arrayed samplers were used to estimate the vertical source aerosol concentration profile to enable plume height and associated source emission rate calculations. Source aerosol

concentrations and calculated emission rates reveal that disking is a substantial source of biosolids-derived aerosols. The biosolids emission rate during disking ranged from 9.91 to 27.25 mg s^{-1} and was greater than previously measured emission rates produced during the spreading of dewatered biosolids or the spraying of liquid biosolids. Adding biosolids to dry soils increased the moisture content and reduced the total PM10 emissions produced during disking by at least three times. The combination of bulk biosolids and aerosol measurements along with PM10 concentrations provides a framework for estimating aerosol concentrations and emission rates by reconstruction. This framework serves to eliminate the difficulty and inherent limitations associated with monitoring low aerosol concentrations of toxic compounds and pathogens, and can promote an increased understanding of the associated biosolids aerosol health risks to workers and nearby residents.

Source Tracking Aerosols Released from Land-Applied Class B Biosolids during High-Wind Events. Carolina Baertsch, Tania Paez-Rubio, Emily Viau, and Jordan Peccia, 2007. Applied and Environmental Microbiology, 73:4522-4531

Abstract: DNA-based microbial source tracking (MST) methods were developed and used to specifically and sensitively track the unintended aerosolization of land-applied, anaerobically digested sewage sludge (biosolids) during high-wind events. Culture and phylogenetic analyses of bulk biosolids provided a basis for the development of three different MST methods. They included (i) culture- and 16S rRNA gene-based identification of Clostridium bifermentans, (ii) direct PCR amplification and sequencing of the 16S rRNA gene for an uncultured bacterium of the class Chloroflexi that is commonly present in anaerobically digested biosolids, and (iii) direct PCR amplification of a 16S rRNA gene of the phylum Euryarchaeota coupled with terminal restriction fragment length polymorphism to distinguish terminal fragments that are unique to biosolid-specific microorganisms. Each method was first validated with a broad group of bulk biosolids and soil samples to confirm the target's exclusive presence in biosolids and absence in soils. Positive responses were observed in 100% of bulk biosolid samples and in less than 11% of the bulk soils tested. Next, a sampling campaign was conducted in which all three methods were applied to aerosol samples taken upwind and downwind of fields that had recently been land applied with biosolids. When average wind speeds were greater than 5 m/s, source tracking results confirmed the presence of biosolids in 56% of the downwind samples versus 3% of the upwind samples. During these high-wind events, the biosolid concentration in downwind aerosols was between 0.1 and 2 µg/m 3. The application of DNA-based source tracking to aerosol samples has confirmed that wind is a possible mechanism for the aerosolization and off-site transport of land-applied biosolids.

Off-Site Exposure to Respirable Aerosols Produced during the Disk-Incorporation of Class B Biosolids. Swee Yang Low, Tania Paez-Rubio, Carolina Baertsch, Matthew Kucharski, and Jordan Peccia, 2007. Journal of Environmental Engineering, 133:987-994

Abstract: Field experiments were conducted at a Class B biosolids land application site in central Arizona to measure, model, and source-track the off-site transport of aerosols emitted when biosolids were disk-incorporated into soils. Real-time PM10 monitoring provided time-resolved

aerosol information sufficient for verifying both off-site concentration and off-site exposure time model results. Under the conditions considered and at a distance of 165 m from the aerosol source, biosolids disk-incorporation resulted in an intermittent exposure to biosolids-derived aerosol concentration between 15 and 40 µg/m3 and an inhalable biosolids dose between 2 and 8 µg. Transport modeling predicted that these doses will decrease with increasing wind speed. In addition, three DNA sequence-based biosolids source tracking methods were applied to aerosol samples and confirmed the presence of biosolids in aerosols at 5, 65, and 165 m from the aerosol source. Field measurements and modeling indicate that the nature of biosolids-derived aerosol exposure is a series of intermittent high concentration puffs, rather than a continuous low concentration.

Emission Rates and Characterization of Aerosols Produced During the Spreading of Dewatered Class B Biosolids. Tania Paez-Rubio, Abel Ramarui, Jeffrey Sommer, Hua Xin, Hua, James Anderson, and Jordan Peccia, 2008. Environmental Science and Technology, 41(10):3537-3544.

Abstract: This study measured aerosol emission rates produced during the spreading of dewatered class B biosolids onto agricultural land. Rates were determined in multiple independent experimental runs by characterizing both the source aerosol plume geometry and aerosol concentrations of PM10, total bacteria, heterotrophic plate count bacteria (HPC), two types of biosolids indicator bacteria, endotoxin, and airborne biosolids regulated metals. These components were also measured in the bulk biosolids to allow for correlating bulk biosolids concentrations with aerosol emission rates and to produce reconstructed aerosol concentrations. The average emission rates and associated standard deviation for biosolids PM10, total bacteria, HPC, total coliforms, sulfite-reducing Clostridia, endotoxin, and total biosolids regulated metals were 10.1 ± 8.0 (mg/s), $1.98 \pm 1.41 \times 10^9$ (no./s), $9.0 \pm 11.2 \times 10^7$ (CFU/s), $4.9 \pm 2.2 \times 10^3$ (CFU/ s), $6.8 \pm 3.8 \times 10^3$ (CFU/s), $2.1 \pm 1.8 \times 10^4$ (EU/s), and 36.9 ± 31.8 (µg/s) respectively. Based on the land application rates of spreaders used in this study, an estimated 7.6 ± 6.3 mg of biosolids were aerosolized for every 1 kg (dry weight) applied to land. Scanning electron microscopy particle size distribution analysis of the aerosols revealed that greater than 99% of the emitted particles were less than 10 µm and particle size distributions had geometric mean diameters and standard deviations near 1.1 ± 0.97 µm. The demonstrated correlations of bulk biosolids concentrations with aerosol emission rates, and the reconstruction of aerosol concentration based on PM10 and bulk biosolids concentration provide a more fundamental, bulk biosolids based approach for extending biosolids aerosol exposure assessment to different land application scenarios and a broader range of toxins and pathogens.

Non-regulated contaminants and POPs

Only 9 contaminants are regulated under the Part 503 rules. There are many unregulated contaminants present in sewage biosolids. Some were considered when the rules were being developed and EPA decided not to regulate them. Chemicals considered for regulation, but not included in the 503 rules, include both chemicals for which there were insufficient data to evaluate the risks as well as chemicals for which EPA determined the risk was not substantial. There are,

however, many other chemicals now in widespread usage that were not even considered when the 503 rules were promulgated. Among those are the brominated flame retardants, antibacterials, wastewater treatment flocculant polymers, organotins, surfactants, fragrance chemicals and pharmaceuticals.

Over 500 different synthetic organic chemicals have been reported in sewage sludges. Concentrations of many exceed Soil Screening levels set by EPA. None are regulated in sewage biosolids in the US. EPA eliminated organic chemicals from regulatory consideration based on insensitive analyses that had high detection limits for most organic chemicals, too high to measure levels that would be of environmental significance.

All sewage biosolids contain an array of synthetic organic chemicals. An array of pharmaceuticals was found in all of the biosolids tested, regardless of the type of treatment. All biosolids are "highly enriched" in organic wastewater contaminants. Some are present in high concentrations in sewage biosolids (up to 1% by dry weight). Some have demonstrated toxicity. Pharmaceuticals are designed to be biologically active at very low concentrations and thus even at trace levels they may impact plants and animals. There is new information showing that antibiotics and other pharmaceuticals have an impact on plants grown in soils containing these chemicals.

The fate of chemicals entering a wastewater treatment plant depends on the chemical and the treatment processes. They may pass through the treatment plant virtually undegraded and travel with the water effluent, they may be sorbed onto the sludge solids, they may volatilize or they may be transformed or degraded in the treatment process. Most organic chemicals tend to sorb onto and thus concentrate in sewage biosolids rather than volatilizing or traveling through the wastewater treatment plant for discharge with the water effluent.

While many organic chemicals are not degraded or transformed by treatment processes (including composting), some compounds are transformed through chemical and biological process, creating daughter products that may be more or less toxic than the original compound. For example, surfactants are a group of chemicals present in large quantities in biosolids. The degradation products of alkyl phenol ethoxylate (APE) surfactants are significantly more toxic than the original compounds and anaerobic digestion processing at wastewater treatment plants promote this transformation, resulting in high concentrations of the recalcitrant and toxic daughter product. This has led to the restriction in use of APEs in Europe. Even compounds that may degrade to less toxic products may be present in such high concentrations in sludges that despite degradation that may take place when the sludge is applied to land, the concentration of the original compound remains at levels of concern. The surfactant LAS is such a compound.

Determination of Anionic and Nonionic Surfactants, Their Degradation Products, and Endocrine-Disrupting Compounds in Sewage Sludge by Liquid Chromatography/Mass Spectrometry. M. Petrovic and D. Barcelo, 2000. Analytical Chemistry, 72: 4560-4567

Surfactants are present in sludges in high concentrations. Degradation may result in more toxic compounds. Aerobic conditions are necessary for more complete degradation of some surfactants to more benign products.

Organic Chemicals in Sewage Sludges. Ellen Z. Harrison, Summer Rayne Oakes, Matthew Hysell, and Anthony Hay, 2006. Science of the Total Environment 367(2-3):481-497.

Abstract: Sewage sludges are residues resulting from the treatment of wastewater released from various sources including homes, industries, medical facilities, street runoff and businesses. Sewage sludges contain nutrients and organic matter that can provide soil benefits and are widely used as soil amendments. They also, however, contain contaminants including metals, pathogens, and organic pollutants. Although current regulations require pathogen reduction and periodic monitoring for some metals prior to land application, there is no requirement to test sewage sludges for the presence of organic chemicals in the U. S. To help fill the gaps in knowledge regarding the presence and concentration of organic chemicals in sewage sludges, the peer-reviewed literature and official governmental reports were examined. Data were found for 516 organic compounds which were grouped into 15 classes. Concentrations were compared to EPA risk-based soil screening limits (SSLs) where available. For 6 of the 15 classes of chemicals identified, there were no SSLs. For the 79 reported chemicals which had SSLs, the maximum reported concentration of 86% exceeded at least one SSL. Eighty-three percent of the 516 chemicals were not on the EPA established list of priority pollutants and 80% were not on the EPA's list of target compounds. Thus analyses targeting these lists will detect only a small fraction of the organic chemicals in sludges. Analysis of the reported data shows that more data has been collected for certain chemical classes such as pesticides, PAHs and PCBs than for others that may pose greater risk such as itrosamines. The concentration in soil resulting from land application of sludge will be a function of initial concentration in the sludge and soil, the rate of application, management practices and losses. Even for chemicals that degrade readily, if present in high concentrations and applied repeatedly, the soil concentrations may be significantly elevated. The results of this work reinforce the need for a survey of organic chemical contaminants in sewage sludges and for further assessment of the risks they pose.

Survey of Organic Wastewater Contaminants in Biosolids Destined for Land Application. C.A. Kinney, E.T. Furlong, S.D. Zaugg, M.R. Burkhardt, S.L. Werner, J.D. Cahill, and G.R. Jorgensen, 2006. Environmental Science and Toxicology, 40(23):7207-7215.

Abstract: In this study, the presence, composition, and concentrations of organic wastewater contaminants (OWCs) were determined in solid materials produced during wastewater treatment. This study was undertaken to evaluate the potential of these solids, collectively referred to as biosolids, as a source of OWCs to soil and water in contact with soil. Nine different biosolid products, produced by municipal wastewater treatment plants in seven different states, were analyzed for 87 different OWCs. Fifty-five of the OWCs were detected in at least one biosolid product. The 87 different OWCs represent a diverse cross section of emerging organic contaminants that enter wastewater treatment plants and may be discharged without being

completely metabolized or degraded. A minimum of 30 and a maximum of 45 OWCs were detected in any one biosolid. The biosolids used in this study are produced by several production methods, and the plants they originate from have differing population demographics, yet the percent composition of total OWC content, and of the most common OWCs, typically did not vary greatly between the biosolids tested. The summed OWC content ranged from 64 to 1811 mg/kg dry weight. Six biosolids were collected twice, 3-18 months apart, and the total OWC content of each biosolid varied by less than a factor of 2. These results indicate that the biosolids investigated in this study have OWC compositions and concentrations that are more similar than different and that biosolids are highly enriched in OWCs (as mass-normalized concentrations) when compared to effluents or effluent-impacted water. These results demonstrate the need to better describe the composition and fate of OWCs in biosolids since about 50% of biosolids are land applied and thus become a potentially ubiquitous nonpoint source of OWCs into the environment.

Organic Contaminants in Canadian Municipal Sewage Sludge. Part II. Persistent Chlorinated Compounds and Polycyclic Aromatic Hydrocarbons. J. Kohli, H.B. Lee and T.E. Peart, 2006. Water Quality Research Journal of Canada, 41: 47-55

PAHs, PCBs, and other persistent organic pollutants are found in essentially all sludges, but at widely varying concentrations depending on the source of sludge.

Persistence of organic contaminants in sewage sludge-amended soil: A field experiment. S.C. Wilson, R. E. Alcock, A.P. Sewart, K.C. Jones, 1997. J. Environ. Qual., 26: 1467-1477.

POPs introduced into soils by sewage sludge incorporation, specifically dioxins and PCBs, persisted in the soil with concentrations unchanged up to 260 days.

Partitioning, persistence, and accumulation in digested sludge of the topical antiseptic triclocarban during wastewater treatment. J. Heidler, A. Sapkota, R.U. Halden, 2006. Environmental Science & Technology, 40, 3634-3639.

Antibacterial chemicals, including triclosan and triclocarban, are common additives in many antimicrobial household products, including soaps and other personal care products. Research now confirms that most of the triclocarban in wastewater sludge is not decomposed during anaerobic digestion in the wastewater treatment plant, with the result that it concentrates to a high degree in sewage sludge.

Bioaccumulation of pharmaceuticals and other anthropogenic waste indicators in earthworms from agricultural soil amended with biosolid or swine manure. C.A. Kinney, E.D. Furlong, D.W. Kolpin, M.R. Burkhardt, S.D. Zaugg, S.L. Werner, J.P. Bossio and M.J. Benotti, 2008. Environmental Science & Technology, 42:1863-1870.

Triclosan has been shown to bioaccumulate in earthworms sampled from an agricultural field amended with sewage sludge.

Fate of higher brominated PBDEs in lactating cows. A. Kierkegaard, L. Asplund , C.A. deWit , M.S. McLachlan , G.O. Thomas, A.J. Sweetman, K.C. Jones, 2007. Environ. Sci. Technol., 41:417-423

Brominated fire retardant chemicals in contaminated feed accumulated in the fat of cows, indicating that meat consumption may be an important human exposure route to higher brominated BDEs. This

observation has important implications for pasture and forage land contamination by these chemicals in sewage sludge.

EPA finds record PFOS, PFOA levels in Alabama grazing fields. R. Renner, 2009. Environmental Science & Technology, 43(5):1245-1246.

Scientists with the EPA, USDA and FDA are investigating whether the high levels of perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA) measured in agricultural soils in Alabama could have entered the food chain through beef cattle grazing on the land. Sewage sludge had been applied to these pasture lands used for grazing over a 12 year period, and is the likely source of these stable perfluorinated chemicals which are possibly carcinogenic.

Removal of Organotins During Sewage Treatment: A Case Study. N. Voulvoulis, M.D. Scrimshaw, and J.N. Lester, 2004. Environmental Technology, 25(6):733-740.

Organotins are highly toxic compounds found in sludges. They do not degrade in the wastewater treatment process.

The potential impact of veterinary and human therapeutic agents in manure and biosolids on plants grown on arable land: a review. Patrick K. Jjemba, 2002. Agriculture, Ecosystems and Environment, 93(1-3):267-278

Substantial quantities of pharmaceuticals are applied to land in sludges and manures. Detrimental impacts of pharmaceuticals on crops is observed with some species of plants.

Bacterial regrowth/viable non-culturable (VNC)

Recent research has demonstrated that sewage biosolids believed to meet Class A or Class B standards were subject to regrowth and reactivation of bacteria. Thus materials have been land applied that contained bacterial levels far above those of Class A or Class B as defined by USEPA under Part 503. Coliform concentrations were found to increase by 100-1000-fold in biosolids and in soil/biosolid mixtures after centrifugation of anaerobically digested biosolids. Coliform concentrations up to 100,000 times those measured by conventional culture methods may be found in thermophilically digested sludges after centrifugation. This results from the presence of viable but non-culturable bacteria.

Increases in Fecal Coliform Bacteria Resulting From Centrifugal Dewatering of Digested Biosolids. Yinan Qi, Steven. K. Dentel, and Diane S. Herson, 2007. Water Research, 41(3):571-580.

Abstract: In many countries, the classification of biosolids for disposal purposes can be based, in part, on fecal coliform levels, with alternative criteria also available based on the stabilization process used, such as anaerobic digestion. The assumption that these alternative criteria provide equivalent protection may be flawed. This paper demonstrates that fecal coliform levels determined after digestion do not always indicate the bacterial levels after the same biosolids have been dewatered by centrifugation. In samples from mesophilic digestion, half had significant

increases in coliform numbers ($P<0.05$) with up to one order of magnitude increase during centrifugation, suggesting coliform regrowth. Thermophilically digested samples had significant increases of several orders of magnitude during dewatering, more likely from reactivation of viable but non-culturable coliforms than from regrowth. In other cases, centrifugation induced coliform regrowth or reactivation upon incubation and storage of dewatered samples, but not digested samples. These 2–3 order of magnitude increases occurred with both 25 and 37 °C incubations. Coliform increases continued for up to 5 days, then gradually declined. However, by day 20 coliform numbers were still 2 orders of magnitude greater than when originally sampled. The magnitude of the increases could be due either to regrowth or reactivation, but the nature of the longer-term increases—also seen in biosolids/soil mixtures—suggests regrowth. Differences in numbers between digested and dewatered samples could not be duplicated with high shear processing in lab-scale devices, with nitrogen purging to remove volatile or gaseous constituents, or with redilution using centrate. They could not be attributed to enumeration methods, to interference of Bacillus spp. on apparent coliform counts, or to temperature changes. The increases have practical implications in the use of fecal coliform or alternative criteria to define pathogen content in biosolids.

Reactivation and Growth of Non-Culturable Indicator Bacteria in Anaerobically Digested Biosolids After Centrifuge Dewatering. Matthew J. Higgins, Yen-Chih Chen, Sudhir N. Murthy, Donald Hendrickson, Joseph Farrel, Perry Schafer, 2007. Water Research, 41(3):665-673

Abstract: Recent literature has reported that high concentrations of indicator bacteria such as fecal coliforms (FCs) were measured in anaerobically digested sludges immediately after dewatering even though low concentrations were measured prior to dewatering. This research hypothesized that the indicator bacteria can enter a non-culturable state during digestion, and are reactivated during centrifuge dewatering. Reactivation is defined as restoration of culturability. To examine this hypothesis, a quantitative polymerase chain reaction (qPCR) method was developed to enumerate Escherichia coli, a member of the FC group, during different phases of digestion and dewatering. For thermophilic digestion, the density of E. coli measured by qPCR could be five orders of magnitude greater than the density measured by standard culturing methods (SCMs), which is indicative of non-culturable bacteria. For mesophilic digestion, qPCR enumerated up to about one order of magnitude more E. coli than the SCMs. After centrifuge dewatering, the non-culturable organisms could be reactivated such that they are enumerated by SCMs, and the conditions in the cake allowed rapid growth of FCs and E. coli during cake storage.

Antibiotic resistance in sludge bacteria

Recent studies have confirmed that the use of antimicrobials had created a large pool of antibiotic-resistance genes in bacteria that are detected in sewage sludge and effluent from sewage treatment plants. Antibiotic resistant bacteria were found in higher numbers downstream of sludge-treated farmland as compared to upstream.

Increased Frequency of Drug-resistant Bacteria and Fecal Coliforms in an Indiana Creek Adjacent to Farmland Amended with Treated Sludge. Shivi Selvaratnam and David J. Kunberger, 2004. Canadian Journal of Microbiology, 50(8):653-656

Abstract: Many studies indicate the presence of human pathogens and drug-resistant bacteria in treated sewage sludge. Since one of the main methods of treated sewage disposal is by application to agricultural land, the presence of these organisms is of concern to human health. The goal of this study was to determine whether the frequency of drug resistant and indicator bacteria in Sugar Creek, which is used for recreational purposes, was influenced by proximity to a farmland routinely amended with treated sludge (site E). Surface water from 3 sites along Sugar Creek (site E, 1 upstream site (site C) and 1 downstream site (site K)) were tested for the presence of ampicillin-resistant (AmpR) bacteria, fecal and total coliforms over a period of 40 d. Site E consistently had higher frequencies of AmpR bacteria and fecal coliforms compared with the other 2 sites. All of the tested AmpR isolates were resistant to at least 1 other antibiotic. However, no isolate was resistant to more than 4 classes of antimicrobials. These results suggest that surface runoff from the farmland is strongly correlated with higher incidence of AmpR and fecal coliforms at site E.

Potential ecological and human health impacts of antibiotics and antibiotic-resistant bacteria from wastewater treatment plants. S. Kim and D.S. Aga, 2007. Journal of Toxicology and Environmental Health-Part B-Critical Reviews, 10:559-573.

Abstract**:** The occurrence of antibiotics and other pharmaceuticals in the environment has become an increasing public concern as recent environmental monitoring activities reveal the presence of a broad range of persistent pharmaceuticals in soil and water. Studies show that municipal wastewater treatment plants (WWTPs) are important point sources of antibiotics and antibiotic-resistant bacteria in the environment. The fate of antibiotics and other pharmaceuticals in WWTPs is greatly influenced by the design and operation of treatment systems. Because knowledge on the fate of antibiotics and resistant bacteria in WWTPs is important in estimating their potential impacts on ecology and human health, investigations on occurrence, treatment, and observed effects are reviewed in this article. In addition, human health risk assessment protocols for antibiotic and resistant bacteria are described. Although data on other pharmaceutical compounds are also presented, discussion is focused on antibiotics in the environment because of the potential link to increased emergence of resistance among pathogenic bacteria. The applications of modern analytical methods that facilitate the identification of novel transformation products of pharmaceuticals in environmental matrices are also included to illustrate that the disappearance of the parent pharmaceuticals in WWTPs does not necessarily equate to their complete removal.

Effect of wastewater treatment on antibiotic resistance in Escherichia coli and Enterococcus sp. S. Garcia, B. Wade, C. Bauer, C. Craig, K. Nakaoka, and W. Lorowitz, 2007.Water Environment Research, 79:2387-2395

Abstract**:** The effects of wastewater treatment on the proportion of Escherichia coli and Enterococcus sp. resistant to specific antibiotics were investigated at two facilities in Davis

County, Utah, one of which received hospital waste. Samples were taken from the influent, effluent before disinfection, and secondary anaerobic sludge digester effluent. There was very little difference in antibiotic resistance among E. coli in the inflow waters of the plants but the plant receiving hospital waste had a significantly higher proportion of antibiotic resistant Enterococcus. The effect of wastewater treatment on antibiotic resistance was more pronounced on enterococci than E. coli. Although some increases in antibiotic resistance were observed, the general trend seemed to be a decrease in resistance, especially in the proportion of multidrug resistant Enterococcus sp.

Antimicrobial resistance in Enterococcus spp. isolated in inflow, effluent and sludge from municipal sewage water treatment plants. P.M. Da Costa, P. Vaz-Pires, and F. Bernardo, 2006. Water Research, 40:1735-1740

Abstract**:** Antimicrobial resistance of enterococci was investigated in 42 samples of crude inflow, treated effluent and sludge collected in 14 municipal sewage treatment plants of Portugal. A total of 983 enterococci were recovered and tested, using the diffusion agar method, regarding their sensitivity to 10 different antimicrobial drugs. Multidrug resistance was present in 49.4% of the isolates. Only 3.3% and 0.6% of the investigated strains were resistant to ampicillin and vancomycin, respectively. Resistances found against rifampicin (51.5%), tetracycline (34.6%), erythromycin (24.8%) and nitrofurantoin (22.5%), are causes for substantial concern. Almost 14% of isolates were resistant to ciprofloxacin. Wastewater treatment resulted in enterococci decrease between 0.5 and 4log; nevertheless, more than 4.4 x 10(5) CFU/100ml were present in the outflow of the plants. Our data indicate that the use of antimicrobials had created a large pool of resistance genes and that sewage treatment processes are unable to avoid the dissemination of resistant enterococci into the environment.

Prions

The potential for prions that might be present in wastewater to accumulate in sludges and to persist through treatment is a concern.

***Persistence of Pathogenic Prion Protein during Simulated Wastewater Treatment Processes*.** G.T. Hincklley, C.J. Johnson, K.H. Jacobson, C. Bartholomay, K.D. McMahon, D. McKenzie, J.M. Aiken, and J.A. Pederson, 2008. Environmental Science and Technology, 42(14):5254-5259.

Abstract: Transmissible spongiform encephalopathies (TSEs, prion diseases) are a class of fatal neurodegenerative diseases affecting a variety of mammalian species including humans. A misfolded form of the prion protein (PrPTSE) is the major, if not sole, component of the infectious agent. Prions are highly resistant to degradation and to many disinfection procedures suggesting that, if prions enter wastewater treatment systems through sewers and/or septic systems (e.g., from slaughterhouses, necropsy laboratories, rural meat processors, private game dressing) or through leachate from landfills that have received TSE-contaminated material, prions could survive conventional wastewater treatment. Here, we report the results of experiments examining the partitioning and persistence of PrPTSE during simulated wastewater treatment processes including

activated and mesophilic anaerobic sludge digestion. Incubation with activated sludge did not result in significant PrPTSE degradation. PrPTSE and prion infectivity partitioned strongly to activated sludge solids and are expected to enter biosolids treatment processes. A large fraction of PrPTSE survived simulated mesophilic anaerobic sludge digestion. The small reduction in recoverable PrPTSE after 20-d anaerobic sludge digestion appeared attributable to a combination of declining extractability with time and microbial degradation. Our results suggest that if prions were to enter municipal wastewater treatment systems, most would partition to activated sludge solids, survive mesophilic anaerobic digestion, and be present in treated biosolids.

Ecological impacts

Soil microorganisms play a critical role in the functions of soil as a source of plant nutrition and in the cycling of nutrients. Recent research shows that sludge application changes the soil microbial community and decreases its diversity. A number of human-use compounds (such as triclosan found in many personal care products such as antibacterial soaps) bioconcentrate in earthworms where soil has been amended with sewage sludges.

Computational Improvements Reveal Great Bacterial Diversity and High Metal Toxicity in Soil. Jason Gans, Murray Wolinsky, and John Dunbar, 2005. Science, 309:1387-1390.

Sewage sludge greatly reduced the diversity of bacterial species in soils.

Parallel Shifts in Plant and Soil Microbial Communities in Response to Biosolids in a Semi-Arid Grassland. Tarah S. Sullivan, Mary E. Stromberger, and Mark W. Paschke, 2006. Soil Biology and Biochemistry, 38 449-459.

Abstract: Approximately 70,150 dry Mg of biosolids from over 450 wastewater treatment facilities are applied to the semi-arid rangelands of Colorado every year. Research on semi-arid grassland responses to biosolids has become vital to better understand ecosystem dynamics and develop effective biosolids management strategies. The objectives of this study were to determine the long-term (~12 years) effects of a single biosolids application, and the short-term (~2 years) effects of a repeated application, on plant and microbial community structure in a semi-arid grassland soil. Specific attention was paid to arbuscular mycorrhizal fungi (AMF) and linkages between shifts in plant and soil microbial community structures. Biosolids were surface applied to experimental plots once in 1991 (long-term plots) and again to short-term plots in 2002 at rates of 0, 2.5, 5, 10, 21, or 30 Mg ha^{-1}. Vegetation (species richness and above-ground biomass), soil chemistry (pH, EC, total C, total N, and extractable P, NO_3-N, and NH_4-N), and soil microbial community structure [ester-linked fatty acid methyl esters (EL-FAMEs)], were characterized to assess impacts of biosolids on the ecosystem. Soil chemistry was significantly affected and shifts in both soil microbial and plant community structure were observed with treatment. In both years, the EL-FAME biomarker for AMF decreased with increasing application rate of biosolids; principal components analysis of EL-FAME data yielded shifts in the structure of the microbial communities with treatment primarily related to the relative abundance of the AMF specific biomarker. Significant (p%0.05) correlations existed among biomarkers for Gram-negative and

Gram-positive bacteria, AMF and specific soil chemical parameters and individual plant species' biomass. The AMF biomarker was positively correlated with biomass of the dominant native grass species blue grama (Bouteloua gracilis [Willd. ex Kunth] Lagasca ex Griffiths) and was negatively correlated with western wheatgrass (Agropyron smithii Rydb.) biomass. This study demonstrated that applications of biosolids at relatively low rates can have significant long-term effects on soil chemistry, soil microbial community structure, and plant community species richness and structure in the semi-arid grasslands of northern Colorado. Reduced AMF and parallel shifts in the soil microbial community structure and the plant community structure require further investigation to determine precisely the sequence of influence and resulting ecosystem dynamics.

Bioaccumulation of Pharmaceuticals and Other Anthropogenic Waste Indicators in Earthworms from Agricultural Soil Amended With Biosolid or Swine Manure. C.A. Kinney, E.T. Furlong, D.W. Kolpin, M.R. Burkhardt, S.D. Zaugg, S.L. Werner, J.P. Bossio and M.J. Benotti, 2008. Environmental Science and Technology, 42:1863-1870.

Abstract: Analysis of earthworms offers potential for assessing the transfer of organic anthropogenic waste indicators (AWIs) derived from land-applied biosolid or manure to biota. Earthworms and soil samples were collected from three Midwest agricultural fields to measure the presence and potential for transfer of 77 AWIs from land-applied biosolids and livestock manure to earthworms. The sites consisted of a soybean field with no amendments of human or livestock waste (Site 1), a soybean field amended with biosolids from a municipal wastewater treatment plant (Site 2), and a cornfield amended with swine manure (Site 3). The biosolid applied to Site 2 contained a diverse composition of 28 AWIs, reflecting the presence of human-use compounds. The swine manure contained 12 AWIs, and was dominated by biogenic sterols. Soil and earthworm samples were collected in the spring (about 30 days after soil amendment) and fall (140-155 days after soil amendment) at all field sites. Soils from Site 1 contained 21 AWIs and soil from Sites 2 and 3 contained 19 AWIs. The AWI profiles at Sites 2 and 3 generally reflected the relative composition of AWIs present in waste material applied. There were 20 AWIs detected in earthworms from Site 1 (three compounds exceeding concentrations of 1000 μg/kg), 25 AWIs in earthworms from Site 2 (seven compounds exceeding concentrations of 1000 μg/ kg), and 21 AWIs in earthworms from Site 3 (five compounds exceeding concentrations of 1000/μg/kg). A number of compounds that were present in the earthworm tissue were at concentrations less than reporting levels in the corresponding soil samples. The AWIs detected in earthworm tissue from the three field sites included pharmaceuticals, synthetic fragrances, detergent metabolites, polycyclic aromatic hydrocarbons (PAHs), biogenic sterols, disinfectants, and pesticides, reflecting a wide range of physicochemical properties. For those contaminants detected in earthworm tissue and soil, bioaccumulation factors (BAF) ranged from 0.05 (galaxolide) to 27 (triclosan).Thisstudydocuments that when AWIs are present in source materials that are land applied, such as biosolids and swine manure, AWIs can be transferred to earthworms.

International Standards for Heavy Metals

The USEPA standards for sewage biosolid contaminant concentrations (standards are set for 9 metals) are higher than those in other developed countries and higher than recommendations of scientists in the northeastern U.S. Switzerland has banned sludge application.

Since the 503 rule was promulgated by USEPA, there has been no reassessment of the heavy metal loading limits on agricultural soils set at that time. In fact, there has been no significant research effort in the US to test the assertion by EPA that the very high metal loading limits (by international standards) of the 503 rule have a high safety margin in protecting soil productivity and crop quality.

Two recent large multi-site field investigations measuring the long-term impacts of sludge metals on soil health and crop quality were undertaken independently in Australia and the UK. In the absence of a comparable study of this scale or longevity in the US, the results of the Australian and UK studies are highly useful in developing guidelines for heavy metals in the US.

The Australian study addressed the impact of Cd loading on food crop quality (levels of Cd in edible crops), and Cu and Zn impacts on crop production (phytotoxicity) and soil health (microbial processes). The recommended limits are much lower for most soils than the allowed soil concentrations of Cd, Zn and Cu based on metal loadings permitted by the USEPA 503 rule. However, the study revealed the high sensitivity of harmful metal effects in soils on soil properties such as pH, clay content and organic matter content. Therefore, the recommended limits for the heavy metals vary greatly by soil type, with acid sandy soils being the most sensitive soils to metal additions.

Ban on the Use of Sludge as a Fertiliser. Switzerland: Federal Office for the Environment, 2003. http://www.bafu.admin.ch/dokumentation/medieninformation/00962/index.html?lang=en&msg-id=1673.

Bern, 26.03.2003 – The use of sludge as a fertiliser is to be banned throughout Switzerland; in the future sludge will have to be incinerated using an environmentally friendly method. The Swiss Federal Council will modify the Ordinance on Materials accordingly on 1 May 2003. The ban will be introduced in stages: from May this year, sludge may no longer be used in the production of fodder crops and vegetables. A period of transition lasting until 2006 at the latest has been accorded for other types of cultivation which until now have been fertilised using sludge; in individual cases the cantonal authorities may extend this period until 2008. This decision is part of the Federal Council's implementation of precautionary provisions for the protection of soils and public health.

Although sludge contains plant nutrients such as phosphorus and nitrogen it also comprises a whole range of harmful substances and pathogenic organisms produced by industry and private households. For this reason, most farmers already avoid using sludge as a fertiliser since they are

aware of the risk of irreversible damage to the soil, the danger to public health and possible negative effects on the quality of the food they produce."

Australian recommendations on soil limits for cadmium, zinc and copper

Recommendations of the Australian National Biosolids Research Program on Biosolids Guidelines. Michael Warne, Mike McLaughlin, Diane Heemsbergen, Mike Bell, Kris Broos, Mark Whatmuff, Glenn Barry, David Nash, Deb Pritchard, Daryl Stevens, Grant Pu, and Craig Butler, 2007. Draft Position Paper.

Executive Summary: A set of soil specific maximum limits for copper and zinc in soils that have received biosolids were derived. These recommended limits state the amount of copper or zinc that can be added to a soil. In acidic, low carbon soils (pH 5, OC 1%) the recommended limit is 25 mg/kg added copper, which increases to 245 mg/kg added copper in alkaline soils (pH 8) irrespective of the organic carbon content. The recommended limits are, depending on the soil properties at a site, considerably smaller to considerably larger than the current limits of 100 – 200 mg/kg total copper. In acidic, low cation exchange capacity (CEC) soils (pH 5, CEC 3 cmolc/kg) the recommended limit for zinc in soils that have received biosolids is 20 mg/kg added zinc, which increases to 300 mg/kg added zinc when the soil pH is greater than or equal to 7.5 irrespective of the cation exchange capacity. Thus, the recommended limits can be considerably lower to marginally higher than the current limits of 200 – 250 mg/kg total zinc, depending on the properties of the soils at sites. Critical soil concentrations of cadmium that would lead to exceedance of the Food Standards Australian New Zealand (FSANZ) standard (0.1 mg/kg) for human consumption were determined across all NBRP sites. The critical values were affected by soil properties, principally soil pH and clay content. A set of recommended soil specific maximum cadmium concentrations in soils that have received biosolids were developed. The recommended limit for total cadmium at a soil pH of 5.5 is 0.6 mg/kg in sandy soils (5% clay or less). In alkaline (pH 7.5 or greater) and clayey soils (25% or greater) the recommended limit for total cadmium in soil is approximately 1 mg/kg or greater. Thus depending on the soil properties at a site the recommended cadmium soil concentration is considerably smaller to considerably greater than the value of 1 mg/kg previously recommended by the National Cadmium Management Committee. From the above recommended limits for cadmium, copper and zinc it is apparent that soils that are acidic combined with either low organic carbon, low clay content or low cation exchange capacity have low critical soil metal concentrations. The critical soil concentrations increased as the pH, organic carbon content, clay content or cation exchange capacity of soils increased. Based on the recommended soil limits, typical metal concentrations in biosolids and current land application practices example masses of biosolids that could be applied cumulatively to land were calculated. For high risk sites as little as 40 to 90 tonnes in total may be added, while at low risk sites between 280 and 970 tonnes in total may be applied. At typical current agronomic application rates of 10 t/ha this translates to 4 to 98 applications.

UK findings on the effect of sewage sludge metals on soil health

The UK study also addressed the impact of Cd loading on food crop quality (levels of Cd in edible crops), and Cu and Zn impacts on soil health (microbial biomass, rhizobium numbers, and microbial respiration). The results suggest that Zn is the metal responsible for the decrease in rhizobial population. It is important to stress that this study was designed to test the adequacy of existing UK limits for Cd, Zn and Cu in agricultural soils (e.g., 200-300 mg/kg for Zn). As some important detrimentral effects are being seen, at least in the early years of this long-term study, it is possible that UK limits for these metals will be adjusted lower. The present UK limits are well below those permitted in the US under the 503 rule.

Effects of Sewage Sludge Applications to Agricultural Soils on Soil Microbial Activity and the Implications for Agricultural Productivity and Long-Term Soil Fertility: Phase III, ADAS, Rothamsted Research, Water Research Centre (WRc), 2007.

Project synthesis: During the four years (2002-2006) of this project, significant ($P < 0.05$) responses in soil microbial properties (i.e. rhizobia numbers and microbial biomass size) and agricultural crop quality (i.e. grain Cd concentrations) were measured following the application of metal-rich sludge cakes and metal-amended liquid sludges during Phase I (1994-1997). The soil samples taken in spring 2003 and 2005 at all nine sites in Britain (and additionally in 1999 and 2001 during Phase II of the project) showed significant ($P < 0.05$) responses in rhizobia numbers on the Zn sludge cake treatments, and in soil microbial biomass size on the Zn and Cu sludge cake treatments. Further soil sampling and measurements during future years of this long term study will help to establish whether the effects measured so far are permanent and consistent over time.

Northeastern U.S. application guidelines

A review of published research by 9 scientists from 5 Northeastern states produced recommended limits for heavy metals that are substantially lower than those permitted under the USEPA 503 rule.

Guidelines for Application of Sewage Biosolids to Agricultural Lands in the Northeastern U.S., Ellen Z. Harrison and Uta Krogmann (Eds.), 2007. New Jersey Agricultural Experiment Station, Rutgers Cooperative Extension Bulletin, 36 pp.

Maximum recommended cumulative soil trace element concentration limits for sites to which sewage biosolids are applied are intended to address and protect the agricultural productivity under Northeast soil conditions and for Northeast farming practices and demographics some of which are unique to this region (Table 3).

Table 3. Recommended Maximum Soil Trace Element Concentrations for the Northeast US

Metal	Recommended Maximum Soil Concentration (mg/kg)		
	Sand to loamy sand	Sandy loam to silt loam	Silt to clay
cadmium	1.2	2	3
copper	50	75	120
nickel	30	40	60
lead	120	120	120
zinc	90	150	230

New Technologies as Alternative Beneficial Uses

Application of sewage biosolids is not the only option for recycling this material. New energy recovery technologies make use of the energy embedded in the sludge. Other technologies are in place to make construction material out of sludges.

***Emerging Technologies for Biosolids Management*, US EPA, 2006.**
http://www.epa.gov/OW-OWM.html/mtb/epa-biosolids.pdf

Preface: The U.S. Environmental Protection Agency (U.S. EPA) is charged by Congress with protecting the nation's land, air, and water resources. Under a mandate of environmental laws, the Agency strives to formulate and implement actions leading to a balance between human activities and the ability of natural systems to support and sustain life. To meet this mandate, the Office of Wastewater Management (OWM) provides information and technical support to solve environmental problems today and to build a knowledge base necessary to protect public health and the environment well into the future.

This publication has been produced under contract to the U.S. EPA by Parsons Corporation and provides information on the current state of development as of the publication date. It is expected that this document will be revised periodically to reflect advances in this rapidly evolving area. Except as noted, information, interviews and data development were conducted by the contractor. It should be noted that neither Parsons nor U.S. EPA has conducted engineering or operations evaluations of the technologies included. Some of the information, especially related to embryonic technologies, was provided by the manufacturer or vendor of the equipment or technology and could not be verified or supported by full-scale case study. In some cases, cost data were based on estimated savings without actual field data. When evaluating technologies, estimated costs, and stated performance, efforts should be made to obtain current information.

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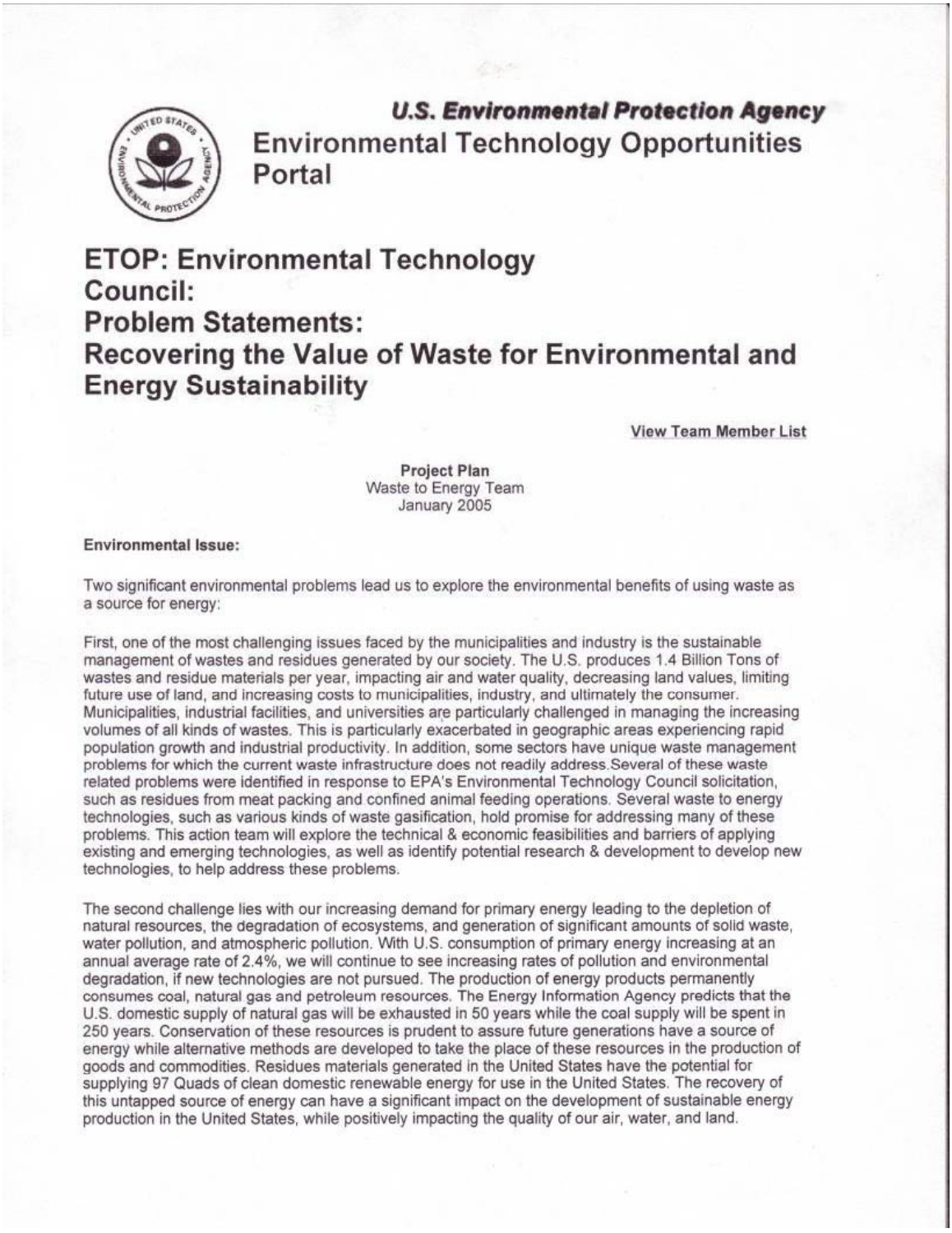
Energy alternatives

Combustion and Land Application Can Both be Beneficial? Roger Tim Haug, Deputy City Engineer City of Los Angeles, F. Michael Lewis, PE, Peter Brady, BE MIEI

Abstract: Both combustion and land application have played important roles in biosolids management practices for many decades. Land application in almost all of its forms has been proclaimed as beneficial use. By contrast, many have viewed combustion as a "disposal only" option, even if energy is recovered in the process and the resulting ash reused. These views and opinions are often proclaimed with no basis or criteria to support the conclusion. Five criteria are presented in this paper for judging whether a management practice is beneficial or not. When judged by these criteria, one can conclude that many combustion installations are beneficial. One can also conclude that land application is beneficial in most, but perhaps not all, installations."

Gasification presents an opportunity that EPA is promoting.



U.S. Environmental Protection Agency

Environmental Technology Opportunities Portal

ETOP: Environmental Technology Council: Problem Statements: Recovering the Value of Waste for Environmental and Energy Sustainability

View Team Member List

Project Plan
Waste to Energy Team
January 2005

Environmental Issue:

Two significant environmental problems lead us to explore the environmental benefits of using waste as a source for energy:

First, one of the most challenging issues faced by the municipalities and industry is the sustainable management of wastes and residues generated by our society. The U.S. produces 1.4 Billion Tons of wastes and residue materials per year, impacting air and water quality, decreasing land values, limiting future use of land, and increasing costs to municipalities, industry, and ultimately the consumer. Municipalities, industrial facilities, and universities are particularly challenged in managing the increasing volumes of all kinds of wastes. This is particularly exacerbated in geographic areas experiencing rapid population growth and industrial productivity. In addition, some sectors have unique waste management problems for which the current waste infrastructure does not readily address.Several of these waste related problems were identified in response to EPA's Environmental Technology Council solicitation, such as residues from meat packing and confined animal feeding operations. Several waste to energy technologies, such as various kinds of waste gasification, hold promise for addressing many of these problems. This action team will explore the technical & economic feasibilities and barriers of applying existing and emerging technologies, as well as identify potential research & development to develop new technologies, to help address these problems.

The second challenge lies with our increasing demand for primary energy leading to the depletion of natural resources, the degradation of ecosystems, and generation of significant amounts of solid waste, water pollution, and atmospheric pollution. With U.S. consumption of primary energy increasing at an annual average rate of 2.4%, we will continue to see increasing rates of pollution and environmental degradation, if new technologies are not pursued. The production of energy products permanently consumes coal, natural gas and petroleum resources. The Energy Information Agency predicts that the U.S. domestic supply of natural gas will be exhausted in 50 years while the coal supply will be spent in 250 years. Conservation of these resources is prudent to assure future generations have a source of energy while alternative methods are developed to take the place of these resources in the production of goods and commodities. Residues materials generated in the United States have the potential for supplying 97 Quads of clean domestic renewable energy for use in the United States. The recovery of this untapped source of energy can have a significant impact on the development of sustainable energy production in the United States, while positively impacting the quality of our air, water, and land.

Converting Biosolids to a Renewable Fuel. Michael Moore, Layne Baroldi, Deirdre Bingman, Ray Kearney, 2006. BioCycle, 47(10):32-35.

Orange County CA is working with EnerTech Environmental Inc on a facility to convert 1/3 of their biosolids to energy. The E-fuel is certified as a renewable fuel by CA Energy Commission.

Turning trash into energy in St. Lucie County. TCPalm newspaper editorial, December 1, 2006.

St Lucie County, FL is proceeding with plans to have Geoplasma INC build a plasma arc facility to deal with trash and sludge.

Green Production of Hydrogen from Excess Biosolids Originating from Municipal Waste Water Treatment. B. Bagchi, J. Rawlston, R.M. Counce, J.M. Holmes, and P.R. Bienkowski, 2006. Separation Science and Technology, 41:2613-2628

Rialto, CA OKs Energy Plant at Landfill Site. National Biosolids Partnership. 3/1/06 Weekly Biosolids Update. http://www.biosolids.org/news_weekly.asp?id=1911

Sewage turned into hydrogen fuel. NewScientist.com News Service, April 29, 2002.

RENEWABLE ENERGY: They hope to turn an array of biomass material into fuels by early 2008. John Welsh. The Press-Enterprise, Sept 14, 2006.

Bricks and glass

Sludge can be used to make construction materials including brick and aggregate.

Lightweight aggregate made from sewage sludge and incinerated ash. Ing-Jia Chiou, Kuen-Sheng Wang, Ching-Ho Chen, and Ta-Ting Lin, 2006. Waste Management, 26:1453-1461

Sewage sludge bulks up house bricks. Andy Cohlan, August 31, 2002. New Scientist

Advances in Envir Research. Chih-Huang Wend, I-Shou U in Kachsiung Co Taiwan.

Sewage vitrification. The Illinois North Shore Sanitary District has a new sludge recycling facility that is the first in the world to convert municipal biosolids into a reusable glass aggregate. Each day, up to 200 tons of municipal biosolids are transformed into 7.5 tons of glass.

Biosolids Reuse as Clear as Glass, 2006. Water Environment Federation, 18(11). http://www.wef.org/ScienceTechnologyResources/Publications/WET/06/06Nov/06NovemberProblemSolvers.htm