EREF’s Regional Summit on Sustainable Solid Waste Practices & Research

March 27 – 28, 2012
DoubleTree Suites by Hilton
Austin, Texas

PROGRAM

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AGENDA
EREF’s Regional Summit
on Sustainable Solid Waste Practices & Research

All presentations will take place in the Bluebonnet Room
Tuesday’s lunch will be served in the Houston Room

TUESDAY, MARCH 27 (9:00 a.m. - 5:00 p.m.)

Welcome/Introduction to the EREF
Bryan Staley, EREF

Biodegradation in Landfills: Why It Happens and Implications for Packaging Design
Mort Barlaz, NC State Univ.

BREAK/NETWORKING (10:00 a.m. - 10:30 a.m.)

Methane Oxidation Across Different Climates and Cover Types: the Stable Isotope Approach
Jeff Chanton, Florida State Univ.

Toward a Better Understanding of Gas Flow and Collection in Landfills
Paul Imhoff, Univ. of Delaware

An Improved Model to Predict Gas Generation from Landfills based on Waste Composition, Rainfall and Ambient Temperature
Richa Karanjekar/Melanie Sattler, Univ. of Texas-Arlington

LUNCH/NETWORKING (12:00 p.m. - 1:30 p.m.)

Performance-Based Evaluation of Post-Closure Care at MSW Landfills
Jeremy Morris, Geosyntec Consultants

Landfill Methane Emission Measurement: Method Development and Quantification
Roger Green, Waste Management

Emerging Contaminants and Special Wastes in MSW
Robert Ford, US EPA

BREAK/NETWORKING (3:00 p.m. - 3:30 p.m.)

Evaluating Human Behavior Using Culturally Relevant Technology in Solid Waste Management and Recycling
Kyle Johnsen, Univ. Georgia
Anaerobic Digestion of Organic Solid Wastes: the Impact of Process Conditions
Paige Griffin, Colorado State Univ.

MSW Conversion Technology Overview and Feasibility
Bryan Staley, EREF

SPECIAL CONVERSION TECHNOLOGY SESSION
WEDNESDAY, MARCH 28 (9:00 a.m. - 12:30 p.m.)

The Future of Waste
Carl Rush, Waste Management

Wet Waste... Problem or Profit?
Gary Luce, Terrabon, Inc.

BREAK/NETWORKING (10:30 a.m. - 11:00 a.m.)

Waste Conversion State of Practice in California
Ramin Yazdani, Yolo County Public Works Dept.

Small-Scale Gasification-Based Waste to Energy System
Santosh Gangwal, Southern Research

Life Cycle Environmental Analysis of Waste Conversion Technologies
Keith Weitz, RTI International

Lunch on your own
Biodegradation in Landfills: Why It Happens and Implications for Packaging Design

Mort Barlaz, NC State University

There is increasing interest in the use of biodegradable materials because they are believed to be “greener”. In a landfill, these materials degrade anaerobically to form methane and carbon dioxide. The fraction of the methane that is collected can be utilized as an energy source and the fraction of the biogenic carbon that does not decompose is stored in the landfill. A landfill life-cycle model was developed to represent the behavior of MSW components and new materials disposed in a landfill representative of the U.S. average with respect to gas collection and utilization over a range of environmental conditions (i.e., arid, moderate wet, and bioreactor). The behavior of materials that biodegrade at relatively fast (food waste), medium (biodegradable polymer) and slow (newsprint and office paper) rates was studied. Poly(3-hydroxybutyrate-co-3-hydroxyoctanoate) (PHBO) was selected as illustrative for an emerging biodegradable polymer. Global warming potentials (GWP) of 26, 720, -1000, 990, and 1300 kg CO$_2$e wet Mg$^{-1}$ were estimated for MSW, food waste, newsprint, office paper and PHBO, respectively in a national average landfill. In a state-of-the-art landfill with gas collection and electricity generation, GWPs of -250, 330, -1400, -96, and -420 kg CO$_2$e wet Mg$^{-1}$ were estimated for MSW, food waste, newsprint, office paper and PHBO, respectively. Additional simulations showed that for a hypothetical material, a slower biodegradation rate and a lower extent of biodegradation improve the environmental performance of a material in a landfill representative of national average conditions.

Methane oxidation across different climates and cover types: the stable isotope approach

Jeff Chanton, Florida State University

Methane oxidation in landfill covers was determined by stable isotope analyses over 37 seasonal sampling events at 20 landfills with intermediate covers over four years. Values were calculated two ways: by assuming no isotopic fractionation during gas transport, which produces a conservative or minimum estimate, and by assuming limited isotopic fractionation with gas transport producing a higher estimate. Thus bracketed, the best assessment of mean oxidation within the soil covers from chamber captured emitted CH$_4$ was 37.5 ± 3.5%. The fraction of CH$_4$ oxidized refers to the fraction of CH$_4$ delivered to the base of the cover that was oxidized to CO$_2$ and partitioned to microbial biomass instead of being emitted to the atmosphere as CH$_4$ expressed as a percentage. Air samples were also collected at the surface of the landfill, and represent CH$_4$ from soil, from leaking infrastructure, and from cover defects. A similar assessment of this data set yields 36.1 ± 7.2% oxidation. Landfills in five climate types were investigated. The fraction oxidized in arid sites was significantly greater than oxidation in Mediterranean sites, or cool and warm continental sites. Sub tropical sites had significantly lower CH$_4$ oxidation than the other types of sites. This relationship may be explained by the observed inverse relationship between cover loading and fractional CH$_4$ oxidation.

Toward a Better Understanding of Gas Flow and Collection in Landfills

Paul Imhoff, Univ. of Delaware

The efficient collection of landfill gas is important for reducing fugitive emissions and maximizing the economic benefit of landfill gas-to-energy facilities. I will discuss research we are conducting to assess the performance of existing and alternative gas collection systems. This work involves the development and application of mathematical models, which are used to evaluate the influence of refuse heterogeneity, barometric pressure, and alternative well designs on gas collection. In addition, field tests are conducted using gas tracers and measurements of gas composition and pressure to infer gas flow...
patterns and the collection efficiency of wells. In addition to providing a better understanding of gas flow in landfills, this work should result in more efficient well designs and well operating practices, as well as reduced fugitive emissions.

An Improved Model to Predict Gas Generation from Landfills based on Waste Composition, Rainfall and Ambient Temperature

Richa Karanjekar/Melanie Sattler, Univ. of Texas - Arlington

Landfills are the third largest human-related source of methane in the U.S., accounting for 17 percent of all methane emissions. Accurately estimating methane emissions from landfills is important to assess their potential for generating greenhouse gases (GHG), as well as to assess whether tapping a landfill's power generation potential is economically viable. Previous studies have shown that methane generation from landfills depends on waste composition, moisture content, temperature, pH and particle size. The goal of this research is to develop a model for predicting methane generation rates from landfills worldwide, which can be used by any country to estimate methane potential of its landfills, regardless of waste composition or climate. The improved model, “Capturing Landfill Emissions for Energy Needs (CLEEN),” will allow methane generation to be estimated for any landfill with basic information about waste composition, annual rainfall, and ambient temperature. Methane generation was studied from laboratory scale simulated landfill reactors. These reactors were installed at varying levels of rainfall, temperature and waste composition using a statistical incomplete block design. Based on the laboratory scale data, a comprehensive regression equation for predicting methane generation rate constant (k) is being developed and will be incorporated in the CLEEN model. Finally, the prediction efficiency of CLEEN model will be compared against the current landfill methane generation models (EPA’s LandGEM and the IPCC model).

Performance-Based Evaluation of Post-Closure Care at MSW Landfills

Jeremy Morris, Geosyntec Consultants

Between 2002 and 2006, Geosyntec worked with a multi-disciplinary team on an EREF funded project to develop the Evaluation of Post-Closure Care (EPCC) Methodology. The methodology provides a technically defensible, performance-based approach for evaluating the site-specific elements of post-closure care (PCC) at municipal solid waste (MSW) landfills regulated under RCRA Subtitle D. A modular approach for evaluating the functional stability of a landfill facility is adopted in which the four primary PCC elements of Subtitle D (i.e., leachate management, LFG management, groundwater monitoring, and final cover system maintenance) are sequentially addressed. The methodology can be used to demonstrate how and when operation, care, and/or monitoring within each module can be optimized or terminated. In the five years since publication of the EPCCM, critical experience has been gained from applying the methodology on a number of unique projects, including an EREF-funded multi-site case study to critically examine the methodology and expose potential weaknesses. The study, which was completed in March 2011, sought to: (1) determine if data prerequisites are presently available at a “typical” MSW landfill site; (2) identify data gaps and data collection needs; (3) assess whether data gaps constitute “fatal flaws” in the methodology or may be omitted, modified, or replaced by other data; and (4) critically appraise the methodology's usability in key areas of application, particularly with regard to its sensitivity to certain data requirements. Based on identified limitations, several improvements were made to the methodology to simplify its application and aid in development of proactive monitoring plans.

Landfill Methane Emission Measurement: Method Development and Quantification

Roger Green, Waste Management

Landfills present a number of challenges when quantifying greenhouse gas emissions due to their size and dynamic nature. Waste Management has worked collaboratively with others in the landfill industry, EPA and academic researchers to develop and apply cost-effective methods for quantifying methane emissions from landfills. This effort has resulted in the application of optical remote sensing and tracer
correlation approaches to the complex problem of quantifying landfill methane emissions. This presentation will provide field data obtained using two measurement methods, EPA OTM 10 using tunable diode lasers for measuring a section of the landfill surface and a tracer correlation approach that has the potential of determining whole-landfill emissions. Plans for future work in the area of landfill emissions measurement will also be discussed.

**Emerging Contaminants and Special Wastes in MSW**

*Robert Ford, US EPA*

Salt cake is the byproduct of secondary aluminum production and is often disposed of in the United States using landfills. A systematic study was undertaken to characterize the solid phase characteristics and water reactivity of a set of salt cake samples collected from operating Secondary Aluminum Processing (SAP) facilities. Thirty-eight (38) salt cake samples were collected from 10 SAP facilities across the U.S. using a double-blind approach via a third party. The facilities were identified by the Aluminum Association to cover a range of material processing approaches. Characteristics that were evaluated for the salt cake samples included water- and acid-extractable contents of inorganic constituents, semi-quantitative mineral phase identification, and heat and gas production during reaction with water. It was confirmed that the chemical composition, mineral phases, leachability of metals, and reactivity of salt cake with water was highly variable for the range of tested samples. All samples demonstrated heat and gas production during reaction, and hydrogen was identified as the dominant gas component. Significant correlations were identified between hydrogen production, temperature increase, and metallic aluminum content for the tested samples.

**Evaluating Human Behavior Using Culturally Relevant Technology in Solid Waste Management and Recycling**

*Kyle Johnsen, Univ. Georgia*

Advancements in technology only tackle part of the problem of sustainability. Human behavior must also be considered, and is especially relevant in the case of solid waste management where reducing, reusing and recycling of waste all require human engagement. We present research into enhancing the recycling ecosystem with smart, internet-connected, social technology. Our project seeks to create and understand how culturally relevant technology such as Web 2.0, RSS, and smartphones can be leveraged to promote, increase awareness of, and create engagement in recycling activities. Smart recycling bin technology, a smart-phone recycling app, and a social web-portal that binds the two together and presents information to the community will be discussed, as well as the future of such technology for solid-waste management and recycling.

**Anaerobic Digestion of Organic Solid Wastes: the Impact of Process Conditions**

*Paige Griffin, Colorado State Univ.*

Anaerobic digestion (AD) is an environmentally sustainable technology to manage organic waste (i.e., food, yard, agricultural, industrial wastes). Economic profitability, however, remains a key barrier to widespread implementation of AD for the conversion of the organic fraction of solid waste to energy in the United States. Specifically, high capital and operating costs and reactor instability have continually deterred the use of AD. In order to develop AD systems that are highly efficient and more cost-effective, it is necessary to optimize the microbial activity that mediates the digestion process.

Currently, our research team is utilizing a multi-stage AD system that allows for separate process optimization of each stage of the digestion process (hydrolysis, acido/acetogenesis, and methanogenesis). Leachate is recycled through the system, which reduces heating and pumping costs, as well as conserving water. The leachate recycle, however, leads to an increase in total dissolved solids (TDS) and ammonia (by-product of AD) concentrations. At this time, the impact of reactor conditions (TDS and ammonia concentrations) on hydrolysis is not well understood. As hydrolysis is one rate-limiting
step of the process in conversion of refractory wastes (e.g., lignocellulosic materials including branches and fruit rinds), optimization of hydrolysis has the potential to radically improve the economic profitability of AD. The specific objectives of this research are to: 1) determine the effects of operating conditions on hydrolysis efficiency for municipal solid waste; 2) determine hydrolysis kinetic parameters as a function of the operating conditions; and 3) identify the microbial inoculum source/microbial source processing required for optimum hydrolysis.

To this end, small-scale batch reactors were used to determine hydrolysis efficiency and kinetic rates. Each reactor was inoculated with AD sludge (from the Drake wastewater treatment plant in Fort Collins, CO), waste (supplied from Colorado State University dining facilities), and nutrient solution under the appropriate operating conditions. To determine the extent of waste hydrolysis, dissolved COD was tracked throughout the digestion period, and methane generation was measured.

Initially, the AD sludge inoculum was exposed directly to the high TDS and ammonia concentrations (10, 20, 30 g/L NaCl, 1, 2.5, 5 g/L NH₃-N) as would occur in a reactor treating organic waste with leachate recycle. Results demonstrated a need to acclimate, or adapt, the microorganisms to high concentrations, as methane generation was significantly inhibited with high concentrations. Thus, the batch studies were repeated after two and four month acclimation periods to these testing conditions, and results demonstrated substantial improvement in hydrolysis efficiency and methane generation. The two lowest concentrations of each operating condition (10, 20 g/L NaCl, 1, 2.5 g/L NH₃-N) demonstrated similar hydrolysis kinetics rates, but kinetic rates for the highest concentrations (30 g/L NaCl, 5 g/L NH₃-N) were significantly lower.

Results from this study are expected to contribute to overall process design and operation for a range of AD systems, ultimately increasing economic viability and profitability.

Additionally, molecular biology tools are being used to track changes in the microbial communities of the inoculum pre- and post-acclimation via terminal restriction length polymorphism from extracted DNA. Ultimately, the key organisms required for optimal hydrolysis will be identified to help guide engineering decisions for reactor operations.

**MSW Conversion Technology Overview and Feasibility**

*Bryan Staley, EREF*

With rising prices for petroleum-derived fuels, improving the economic and technological feasibility of alternative fuel sources has become a key research priority. Unlike dedicated energy crops, fuels derived from waste products incur minimal land use burdens and may add economic value to existing waste disposal processes. This presentation will provide a brief overview of the conversion technologies being considered by the solid waste industry to divert various components of the waste stream from traditional end-points like landfills or WTE facilities to facilities that generate high-value end products such as biofuels or chemicals. The talk will also highlight operational challenges and the feasibility of waste conversion technologies from and operations standpoint based on work being conducted via a grant from the NC Biofuels Center with partners NC State University, Waste Industries and Maverick Biofuels.

**The Future of Waste**

*Carl Rush, Waste Management*

Over the past few years there has been a dramatic increase in the development of new and innovative waste management technologies to extract the economic value in the waste stream. Waste Management estimates that the waste stream it manages is valued at $8 to $10 billion and has been an industry leader in the investment and development of a wide range of recycling, renewable energy, conversion technologies with the goal of increasing the beneficial reuse of materials, creating electricity and fuel and green chemicals. Carl Rush will speak to the company's development pipeline and associated issues such as feedstock, end markets and technology challenges.
Wet Waste... Problem or Profit?

Gary Luce, Terrabon, Inc.

Wet waste (i.e food and restaurant wastes) has been a pinch point in the waste industry for some time. It is mostly water, the first to decay and cause odor issues, that is the primary contributor to green house gases and contributes to the leachate problem in landfills. Other issues have been scale, local composting solutions and anaerobic digestion to methane makes it difficult to aggregate enough scale to change the supply chain economics in a way to draw a significant amount of wet waste into the transportation system. With Terrabon's technology, both of these issues can be addressed and enough scale can be created to fundamentally change the supply chain approach to making wet waste profitable vs. problematic.

Waste Conversion State of Practice in California

Ramin Yazdani, Yolo County Public Works Dept.

The California's Renewable Energy and Fuels Polices are the main drivers in the implementation of conversion technologies in California. The Global Warming Solutions Act of 2006 (AB 32) and the Low Carbon Fuel Standards of California (RFS 2) in addition to AB 341, which requires 75% waste diversion by 2020, in California are also encouraging cities and counties to develop various demonstration, pilot and full scale project to convert waste to energy. Various guidance documents for new and emerging conversion technologies have been prepared by California Department of Resources Recycling and Recovery (CalRecycle) to assist the California State Legislature develop policies in support of conversion of waste to energy. Many of the large cities and counties are evaluating thermochemical and biochemical conversion technologies and considering pilot projects to demonstrate their success. Many municipalities are pursuing the biochemical route, such as anaerobic digestion of food waste at an existing Publicly Owned Treatment Works (POTW) and some are planning to construct a privately owned and operated liquid and/or high solid anaerobic digester. Given the complexity and the cost associated with the thermochemical conversion technologies the European anaerobic digester model has attracted the attention of many companies and jurisdiction. Anaerobic digestion of residual organic waste seems to be the leading technology to help achieve the goal of California's renewable energy portfolio for now. This presentation will focus more on the biochemical conversion technology state of practice in California.

Small-Scale Gasification-Based Waste to Energy System

Santosh Gangwal, Southern Research Institute

Gasification is a clean energy technology that can convert a variety of low-value feedstocks such as biomass and municipal solid waste (MSW) into electricity, fuels, and chemicals. Compared to combustion that is suited only to large-scale systems, gasification can be effectively used for distributed energy generation using small-scale conversion systems. Southern Research is engineering and building a small-scale MSW and biomass gasification system to produce renewable power and liquid fuels. Commissioning and trials of a 3 ton/day plant representative of Southern's scalable, modular process is underway. At the heart of the process is a simple, low cost gasifier system that can efficiently convert minimally processed feed to a clean syngas. The syngas can be either converted to power using an engine or microturbine, or to liquid fuel using a catalyst. Southern is targeting the development of the process at 3 scales: 1-3 ton/day for U.S. DoD forward operating bases and other small generators, 10-50 ton/day for U.S. DoD fixed installations, other institutional waste generators, and municipal landfills, and 100 ton/day micro-refinery for producing liquid fuels. Discussions are underway for the first installation of the system at a military base. A suitable site has been located at the base.
In this research, RTI International investigated the range of emerging waste conversion technologies that use municipal solid waste (MSW) as all or a portion of their feedstock. The focus of the study was to report on the state-of-practice and environmental aspects of the technologies, using a life cycle type approach. Conversion technologies analyzed included pyrolysis, gasification, plasma arc treatment and anaerobic digestion. This study was designed to include real-world case examples characterized by data and information from open literature and complemented by informal surveys of technology vendors. The goals of the research were to develop a better understanding of the range of technologies available for MSW, to identify and profile specific technology vendors, and to identify and quantify the potential life-cycle environmental burdens/benefits of the technologies as compared to existing landfill disposal. In this presentation, waste conversion technology categories are described, potential benefits and impediments per each technology category identified, and life cycle environmental inventory results summarized.
JEFF CHANTON is a Gulf Coast Native, born in New Orleans, Louisiana. He received his PhD from the University of North Carolina at Chapel Hill. Chanton joined the faculty at Florida State University in the Department of Oceanography in 1989. Awards include the title of Distinguished Research Professor and the John Winchester Professorship. Chanton works on a variety of research problems that involve fluxes of greenhouse gases methane and carbon dioxide and isotopic chemistry. Current projects include studies of gas hydrate stability, the effect of permafrost decomposition on methane release from boreal regions, developing methods to determine methane oxidation in landfill covers and the study of ecosystem respiration in pine forests and peat bogs.

MORTON BARLAZ is Professor and Head of the Department of Civil, Construction, and Environmental Engineering at North Carolina State University. He received a B.S. in Chemical Engineering from the University of Wisconsin. He has been involved in research on various aspects of solid waste since 1983. Over this time, he has conducted research on biological refuse decomposition, methane production, and the biodegradation of hazardous wastes in landfills. He has participated in two state-of-the-practice reviews of bioreactor landfills. His research forms the basis for much of the work done to assess the impact of landfills on methane emissions inventories. Dr. Barlaz is also recognized for his research on the use of life-cycle analysis to evaluate environmental emissions associated with alternate solid waste management strategies. Dr. Barlaz is the author of over 90 peer-reviewed publications and has made over 200 presentations at conferences throughout the world. In 1992 he was awarded a Presidential Faculty Fellowship from the National Science Foundation. Dr. Barlaz has been active in service throughout his career. He is an Associate Editor for two journals (Waste Management and Journal of Environmental Engineering) and serves as co-chair of the biannual Intercontinental Landfill Research Symposium. He has served as chair of the Government Affairs Committee and the Lectures Committee for the Association of Environmental Engineering and Science Professors. Finally, he serves on the Science Advisory Committee for the International Waste Working Group.

ROBERT FORD is a Research Environmental Scientist for the U.S. Environmental Protection Agency’s Office of Research and Development at their research facility in Cincinnati, OH. He holds a B.S. in Civil Engineering (1989) from the Missouri University of Science and Technology (formerly University of Missouri-Rolla), and a Ph.D. in Environmental Engineering and Earth Sciences (1997) from Clemson University with emphasis in Aquatic and Soil Chemistry. Prior to joining EPA in 1999, he served in research positions at the Savannah River Ecology Laboratory in Aiken, SC and the Department of Plant and Soil Sciences at the University of Delaware in Newark, DE. His research is focused towards developing approaches to characterize and remediate sites with recalcitrant contaminants such as metals and radionuclides. Dr. Ford has been actively involved in providing technical support to EPA Regional and Headquarters Offices, including the development of technical guidance and training for the application of Monitored Natural Attenuation as a component of groundwater cleanup. He has conducted field research efforts at Superfund sites to support site characterization and selection of appropriate remedies for remediation of groundwater and sediments impacted by subsurface releases from historical industrial and mining/milling operations.

SANTOSH GANGWAL, Senior Chemical Engineer, Southern Research Institute has over 35 years of experience in coal / biomass / municipal solid waste gasification / pyrolysis, syngas conditioning / conversion, catalyst / sorbent preparation-evaluation-scale-up, fuel desulfurization, combined-cycle power systems, solar-PVT, low grade heat utilization, energy storage, fuel cells, and carbon capture. He is presently leading the effort at Southern Research on the development and commercialization of a small-scale gasification-based waste to energy system. He has managed complex multimillion dollar, multiple team member research programs totaling over $40 million for the Federal Government and private industry in energy technology research and development. His work has appeared in a book chapter, 15 U.S. patents and over 175 refereed publications and proceedings.
ROGER GREEN is a scientist with Waste Management, Inc., in Cincinnati, Ohio. His responsibilities include: the development and evaluation of chemical and biological processes for waste treatment and remediation and providing technical support to the company's soil bioremediation facilities and bioreactor landfill projects. He is involved in the company's work on greenhouse gas emission quantification and modeling and biologically active landfill cover systems. Mr. Green has been employed by Waste Management since 1993. He earned Bachelor of Science and Master of Science degrees from the University of Cincinnati.

PAIGE GRIFFIN is a graduate research assistant at Colorado State University in Fort Collins, CO. Paige has been researching the anaerobic digestion of a variety of substrates for the past three years. Specifically, she works to optimize the hydrolysis stage of the AD process to increase overall process efficiency. Prior to attending CSU for a master's degree in Environmental Engineering, Paige earned a bachelor's degree in Environmental Science from Lipscomb University in Nashville, TN.

PAUL IMHOFF is an Associate Professor in the Department of Civil and Environmental Engineering at the University of Delaware, Newark, DE, USA. Dr. Imhoff received his degrees in Civil and Environmental Engineering at the University of Cincinnati (BS), University of Wisconsin (MS), and Princeton University (MA, PhD). Dr. Imhoff is a recipient of the National Science Foundation Career Award, the Editors Award from the Journal of Environmental Engineering, and outstanding reviewer awards from Waste Management. Dr. Imhoff’s teaching and research interests are in several areas of environmental engineering, but in general focus on the movement of fluids and mass transfer processes in porous media. He has worked for over 15 years on the impact of nonaqueous phase liquids (NAPLs) (e.g., gasoline) on groundwater. In the last 7 years he has employed field, laboratory, and computer modeling techniques to understand and describe the movement of gas and liquid in landfills and to advance technologies for improved capture of landfill gas. Methane oxidation in biologically active cover soils and measurements of airborne methane emissions are the focus of ongoing research projects. Dr. Imhoff's research is supported by the National Science Foundation (NSF), Department of Energy (DOE), California Department of Resources Recycling and Recovery, Environmental Research and Education Foundation (EREF), and the Delaware Department of Transportation.

KYLE JOHNSEN is an assistant professor in the Faculty of Engineering at the University of Georgia. He also holds an adjunct position in the Department of Computer Science and a research appointment at the Medical College of Georgia. His research focuses on the engineering of technology-infused educational and outreach solutions, with an emphasis on virtual environments and the human-computer interface. Dr. Johnsen received his Ph.D. (2008), M.S. (2007), and B.S (2003) in computer engineering from the University of Florida. His early work on immersive training with virtual patients is currently in the process of being incorporated into four major medical schools in the southeastern United States, with plans to commercialize towards national training and evaluation in medical education. Currently, he is working towards engineering the next generation of mobile, hand-held, and wearable solutions to a broad range of problems within medical and veterinary education, environmental monitoring and outreach, entertainment, immersive visualization, and music education, to name a few. By leveraging off-the-shelf technology, such as smart-phones and consumer-entertainment devices, his approach enables ubiquitous solutions that are accessible to the general population, and inherently robust, portable, and low-cost.

RICHA KARANJEKAR is a currently pursuing her Ph.D at the University of Texas at Arlington (UTA). Her research interests include landfill gas modeling and climate change. Richa received bachelor’s degree in Civil Engineering from the University of Pune, India. Subsequently, she obtained master’s in Environmental Engineering from University of Mumbai, India. Her bachelor’s and master’s thesis focused on removal of heavy metals from industrial wastewater. After completing her master’s degree, Richa worked as a proposal and design engineer for 3 years in a multinational company in India. She enjoys reading, painting and travelling in her spare time.

GARY LUCE has served on Terrabon’s Board since June 2007 when he arranged and closed an investment in the Company on behalf of Global Energy Horizons, LLC and is currently Terrabon’s Chief Executive Officer. In 1982, Mr. Luce graduated summa cum laude from Texas A&M University and Stephen F. Austin State University with degrees in chemical engineering and physics. In 1987, he received an MBA from Houston Baptist University. Mr. Luce has over 25 years of senior management strategic planning and operating experience in the energy sector. He has serve in senior leadership roles with McKinsey & Company,
EOTT Energy and Reliant Energy. From 2002 to 2007, Mr. Luce worked in the private equity area, primarily with K-L Energy Partners, LLC, a firm that he co-founded early in 2004, which focuses on investments in the midstream and downstream sectors of the energy industry. Since June 2007, Mr. Luce has been the principal architect of the Company's technology deployment, and has led its financial and management transition from a development-stage entity to a stand-alone, operating technology company.

**Jeremy Morris** has over 16 years of professional and academic experience in the field of solid waste management, with particular expertise in issues relating to waste disposal by landfill. His Ph.D. research work involved investigating methods for enhancing waste degradation and landfill gas generation at water deficit landfills in South Africa, and field measurement and modeling of fugitive greenhouse gas emissions through landfill covers. Since joining Geosyntec in 2001, he has provided technical design and project management services during permitting and construction of new landfills and lateral or vertical landfill expansions at numerous sites around the country and internationally. His technical specialties include landfill closure and post-closure care, waste characterization, and leachate characterization and treatment. He also has experience with landfill gas management and utilization, feasibility analyses for landfill-based renewable energy technologies, and sustainable approaches to landfill development and long-term management and remediation of closed sites. From 2002-2006, Jeremy led Geosyntec’s work on developing the EPCC Methodology for EREF. Since 2007, he has conducted ongoing assignments for EREF and EREF’s industry members to critically assess and improve the methodology for application in the U.S. and Europe.

**Carl Rush** is Senior Vice President of Organic Growth for Waste Management, where he is charged with finding growth opportunities that leverage the company's current asset base. On February 13, 2010, Carl joined the company's senior leadership team. Waste Management, based in Houston, Texas, is a FORTUNE 200 company with revenues of approximately $11.79 billion and 43,000 employees. Carl joined the company in 2001 as Director of the In-Plant Services Group, now called Sustainability Services. After several years serving in that role, he became Vice President of Sustainability Services in early 2005, and a year later accepted the position of Vice President of Organic Growth. Over the years, Carl has overseen the development of several business opportunities for the company. Some of these include partnering with Linde North America to convert landfill-gas into liquefied natural gas (LNG), partnering with S4 Energy Solutions to expand plasma gasification technology, and founding a new organics offering with Harvest Power. Carl serves as a board member for several companies, including 1-800-Pack Rat, Agilyx, Terrabon, Inc, Harvest Power and Enerkom. Before joining Waste Management, he was President and CEO of The GNI Group for 15 years. He received a bachelor’s degree in business and a master’s degree in business administration from Texas Christian University.

**MELANIE SATTLER** serves as an Associate Professor of Civil Engineering at the University of Texas at Arlington, where she teaches courses and conducts research related to air quality and sustainable energy. Her research has been sponsored by the National Science Foundation, Texas Commission on Environmental Quality, Luminant Power, and the Defense Advanced Research Projects Agency. She has published over 60 peer-reviewed papers and conference proceedings. Dr. Sattler received her Ph.D. in environmental engineering in 1996 from the University of Texas at Austin. She is a registered professional engineer in the State of Texas.

**Bryan Staley** currently serves as President and CEO of the Environmental Research and Education Foundation. He joined the EREF 4 years ago, where he started as vice-president of environmental programs, and has 18 years of experience in the environmental engineering field. He is a technical expert in sustainable solid waste management issues and obtained a Ph.D. in solid waste research at North Carolina State University. He is also a licensed professional engineer. Dr. Staley has held key positions in consulting firms as a project manager and vice-president of engineering where he managed projects ranging from solid waste management, wastewater treatment system design, to retail/commercial land development and large-scale livestock operations.

**Keith Weitz** is manager of the Sustainability and Environmental Assessment program at RTI International. He specializes in solid waste management, energy technology assessment, global climate change research, and life cycle assessment. Mr. Weitz has been working with the U.S. EPA and others to analyze the cost and environmental aspects of solid waste management systems since the early 1990’s. Mr. Weitz holds a Master of Environmental Management from Duke University (1992) and a B.A. in Economics and Business Administration from Augustana College (1990).
RAMIN YAZDANI is the Senior Civil-Environmental Engineer in the Division of Integrated Waste Management at the Yolo County Planning and Public Works Department. Dr. Yazdani received his Ph.D. in Civil & Environmental Engineering from the University of California at Davis. He is a registered Professional Civil Engineer in California. He conducts research and operates commercial scale controlled landfill bioreactor facility. His research work is in the areas of waste to energy, with emphasis on anaerobic digestion, aerobic composting, landfill methane emission reduction, and biogas. He has over 22 years of experience in environmental engineering applied research, plant design, construction and operation of various solid waste management and waste to energy processing facilities. He has conducted numerous research and demonstration projects for the California Energy Commission, the Department of Resources Recycling and Recovery (CalRecycle), and the U.S. Department of Energy-NETL. He has published numerous project reports and articles in leading environmental engineering and science journals.