ENABLING THE FUTURE

Advancing Resource Recovery from Biosolids

NATIONAL biosolids PARTNERSHIP

WERF
Water Environment Research Foundation
Collaboration. Innovation. Results.

Water Environment Federation®
the water quality people®

Enabling the Future:
Advancing Resource Recovery from Biosolids

by:

Lynne H. Moss, P.E., BCEE
John F. Donovan, P.E., BCEE
Scott Carr, P.E., BCEE
CDM Smith Inc.

Lori Stone, P.E.
Christine Polo
Black & Veatch

Wendell O. Khunjar, Ph.D.
Ron Latimer, P.E.
Hazen and Sawyer

Samuel Jeyanayagam, Ph.D., P.E., BCEE
CH2M HILL

Ned Beecher
North East Biosolids and Residuals Association

Lisa McFadden
Water Environment Federation

2013

Acknowledgments

The Project Team would like to thank WEF, the NBP, and WERF for their support of this project. We also extend our thanks to the Project Advisory Committee for their valuable guidance and assistance throughout the development of this document.

Report Preparation

Editor

Lynne H. Moss, P.E., BCEE, *CDM Smith Inc.*

Authors

Ned Beecher*, North East Biosolids and Residuals Association*

Scott Carr, P.E., BCEE, *CDM Smith Inc.*

John F. Donovan, P.E., BCEE, *CDM Smith Inc.*

Samuel Jeyanayagam, Ph.D., P.E., BCEE, *CH2M HILL*

Wendell O. Khunjar, Ph.D.*, Hazen and Sawyer*

Ron Latimer*,* P.E.*, Hazen and Sawyer*

Lisa McFadden, *Water Environment Federation*

Lynne H. Moss, P.E., BCEE, *CDM Smith Inc.*

Christine Polo*, Black & Veatch*

Lori Stone, *Black & Veatch*

Advisory Committee

Robert Bastian, Ph.D., *U.S. Environmental Protection Agency*

Vince de Lange, *East Bay Municipal Utility District*

Alicia Gilley, *Metro Wastewater Reclamation District*

Chris Hornback, *National Association of Clean Water Agencies*

John Novak, Ph.D., *Virginia Tech*

Dave Taylor, *Madison Metropolitan Sewerage District*

Todd Williams, *CH2M HILL*

Project Staff

Barry Liner, Ph.D., P.E., *Water Environment Federation*

Lisa McFadden, *Water Environment Federation*

Amit Pramanik, Ph.D., *Water Environment Research Foundation*

Dan Woltering, Ph.D., *Water Environment Research Foundation*

List of Acronyms

Acronyms

BNQ	Bureau de normalisation du Québec
BPR	biological P removal
Btu/lb	British thermal units per pound
CHP	combined heat and power
CNG	compressed natural gas
DOE	Department of Energy
FBI	fluid bed incinerator
FOG	fats, oils, and grease
GGE	gallon gasoline equivalent
GTW	grease trap waste
GHG	greenhouse gas
IC engines	internal combustion engines
kWh	kilowatt per hour
LNG	liquid natural gas
mgd	million gallons per day
MHI	multiple-hearth incinerator
MW	megawatt
N	nitrogen
O&M	operation and maintenance
P	phosphorus
PPCP	pharmaceuticals and personal care products
PPP	pollution prevention program
REC	renewable energy credit
scfm	standard cubic feet per minute
SCW	supercritical water
SCWO	supercritical water oxidation
SGIP	self-generation incentive program
TS	total solids
VS	volatile solids
VSr	volatile solids reduction
WAS	waste activated sludge
WRRF	water resource recovery facility

Table of Contents

List of Tables and Figures

Executive Summary

Over the past several years, there has been a paradigm shift in how wastewater solids are perceived, and today, biosolids are viewed as a renewable resource too valuable to waste. This perception reflects the widespread interest in sustainability, energy, climate change, resource depletion, materials cycling, and zero-waste goals.

The evolving view of biosolids was highlighted in the Water Environment Federation (WEF) and the National Biosolids Partnership (NBP) 2011 report *Charting the Future of Biosolids Management*, which identified current trends, as well as the trajectory of change stemming from those trends.

The journey toward meaningful change is further explored with *Enabling the Future: Advancing Resource Recovery from Biosolids*. Specifically, the document examines the unprecedented opportunities that now exist and are emerging for the organics, energy, and nutrients in biosolids. Lessons learned and documented experiences have also been captured in this publication as part of an effort to provide practical guidance for utilities embarking on the road to resource recovery.

A first step on that journey is defining regulatory and policy requirements that might promote or hinder resource recovery. While regulations at the federal level do not appear to actively support resource recovery from biosolids, some states are developing regulations and policies that remove barriers to resource recovery. These activities are driven, in part, by “zero-waste initiatives” in many cities, which seek to maximize the diversion of recyclables away from landfills. Key examples include Massachusetts regulations and policies intended to facilitate co-digestion and California’s recent efforts to encourage composting. This regulatory evolution will need to continue to support resource recovery, and may soon need to address a portfolio of new products such as biosolids-derived bioplastics.

In the absence of regulatory drivers, policies and market needs help shape resource recovery opportunities. With respect to policy and planning, the overarching driver for resource recovery is the broader focus on sustainability, viewed through the perspective of triple bottom line (TBL) analyses that reflect environmental, economic, and social concerns. This focal shift is reflected in the increasing use of TBL analyses for solids planning, but is also driving research, voluntary programs, and a renewed interest in the environmental benefits of biosolids. Many TBL focal points – which are actually tools to forward resource recovery – address multiple elements in the sustainability trifecta.

The new view of a traditional beneficial use – land application – provides an example of our changing focus. Once viewed primarily as an approach to add nutrients and organics for soil improvement only, we now understand that biosolids can play a critical role with respect to climate change through a variety of mechanisms. First, the organic matter provided by biosolids can replenish soil organic carbon (SOC) lost through climate change-induced wind and water erosion. Additionally, biosolids can reduce agricultural carbon footprints through both fertilizer production offsets and biosolids use to meet plant nutrient requirements. A better understanding of the role that biosolids can play in carbon footprint reduction will serve as a catalyst for their recognition as a valued resource.

Biosolids also play a key role in carbon footprint reduction through the conversion of the energy in solids to a useable form (heat or fuel) via biological or thermal processes. Energy recovery options range from mature, well established systems, such as anaerobic digestion and incineration, to emerging technologies, such as Supercritical Water Oxidation (SCWO) and hydrothermal gasification. Solids treatment provides the greatest potential for energy recovery and production, with the chemical energy embedded in biosolids greater than the energy needed for treatment. Recovering that energy is an opportunity for wastewater utilities to reduce costs and increase sustainability.

In addition to organic and energy resources, nutrients in biosolids are also a focus for resource recovery, going beyond recycling of nutrients through land application to nutrient extraction and recovery. Extractive nutrient recovery provides a mechanism to both effectively remove nutrients from liquid streams and create a marketable product. At present, commercial technologies for extractive nutrient recovery primarily produce chemical nutrient products that are used in agricultural applications (because 85% of all nutrient products are associated with agriculture). Since food demand is expected to rise with an increasing global population, it is expected that demand for chemical nutrient products will also increase. This represents an opportunity for the wastewater treatment market to develop niche products that can be used in this field.

In exploring technologies to recover any of the resources discussed here, it is important to note that the evolutionary path for emerging technologies is not an easy one. New technologies must overcome tremendous obstacles to travel from “emerging” to “established” status. Incentives to utilities by state and federal programs to test and implement innovative technologies would facilitate the development and application of these technologies by reducing the economic risk. To that end, a joint WEF/Water Environment Research Federation (WERF) initiative, the Leaders Innovation Forum for Technology (LIFT) program, was developed to help move innovation into practice in the water quality industry. The LIFT Technology Evaluation Program Working Group provides facility owners a forum for technology prioritization and evaluation. To date, the Working Group has selected five technology areas for evaluation: short-cut nitrogen removal (e.g., deammonification); phosphorus recovery; biosolids to energy; electricity from wastewater; and predigestion.

Enabling the future will require enhancing the capacity, skills, and knowledge in the public and private sectors involved in biosolids management. As the focus on resource recovery from biosolids intensifies, the importance of the distributed network of support for biosolids professionals becomes even greater. Communication of research findings – both historic and new – is a specific pressing need, as it appears that existing research has been underutilized as a tool to communicate the safety of biosolids to the public. The increased complexity of biosolids management and the need for increased communications with more diverse audiences requires that these support mechanisms continue to grow and evolve to meet future needs.

Engaging in effective communication continues to be a key tenet to successfully developing systematic, proactive response and education strategies in which public outreach ensures appropriate developmental materials and biosolids curriculums are in place, as well as ensuring that working relationships with key environmental and public health organizations are cultivated. The biosolids sector should also continue to leverage and build upon the existing communication structure, which includes WEF, NBP, WERF, regional associations, and utilities, and to emulate successful outreach programs (such as the documentary “Liquid Assets”, which was co-funded by WEF).

The theme of biosolids as a renewable resource is perhaps the key to repositioning both the role and value of biosolids. This document highlights ongoing activities in this area, existing and emerging opportunities, potential challenges, and activities required to fully leverage biosolids potential.

Section 1

Introduction

Today, our concept of "beneficial use" for biosolids is being redefined – both philosophically and literally – reflecting an expanded vision of the resource recovery potential of municipal wastewater solids. This new perspective is reflected in the following WEF 2011 policy statement:

> *"The Water Environment Federation supports a comprehensive approach to wastewater treatment and solids management that ensures the recycling and recovery of valuable resources including water, nutrients, organic matter, and energy."*

The paradigm shift in our view of beneficial use offers an unprecedented opportunity to reposition biosolids as a community resource too valuable to waste in the context of not only renewable energy needs, but also in terms of urban sustainability interests and soil depletion.

Resource recovery was a focal point of the 2011 WEF/NBP report, titled *Charting the Future of Biosolids Management,* which identified both opportunities and challenges for resource recovery in biosolids. This report builds upon the findings of that 2011 effort, further exploring the frameworks, technologies, and outreach needed to fully leverage the resource potential of municipal wastewater solids. (It should be noted, however, that some of the principles and even technologies addressed in this report could be applied to other biomass sources, such as manures.)

Specific areas of focus for this report include the following resources explicitly noted in WEF's definition above: organics (carbon), nutrients, and energy. New technologies, however, are extracting further value from biosolids – using them as feedstock, for example for bioplastic production and other materials. These innovative biosolids-derived products are also discussed in the report.

Section 2

Building a Framework for Resource Recovery: Regulations and Policy

A sound regulatory framework and supporting policies are essential to leverage resource recovery potential. The impact of a strong regulatory foundation, especially, cannot be underestimated, as evidenced by the impact of 40 CFR 503 regulation (and its underpinning policies) on biosolids' beneficial use in the U.S. As shown in the figure below, the proportion of solids directed to beneficial use more than doubled from 1984 to 1998. While a variety of factors contributed to the shift away from disposal, the 503 rule created incentives for beneficial use and reflected the U.S. Environmental Agency (U.S. EPA) position that biosolids are an important resource (U.S. EPA, 1984).

Figure 1: Historic proportion of solids to land application or other beneficial use (million dry tons/year)

Conversely, regulations can constrain resource recovery as well: "legitimacy criteria" for renewable fuels is a current example.

This section explores regulatory and policy issues that have the potential to impact the trajectory of biosolids resource recovery in the U.S. and, based upon those issues, identifies foundational changes needed to advance the role of biosolids as a renewable resource.

Regulatory Overview

On the federal level, current regulatory trends and policies appear to constrict resource recovery, but other governmental agencies and voluntary efforts appear to be moving in the opposite direction, as described below.

Federal Regulations and Policy

Two recent changes at the federal level – one in regulation and the other in policy – appear to limit the full recovery potential in biosolids in some cases: the U.S. EPA clarification of the wastewater sludge definition and the adoption of a new U.S. Department of Agriculture (USDA) nutrient management standard.

U.S. EPA Sludge Definition and Legitimacy Criteria

In March 2011, U.S. EPA clarified the definition of wastewater sludge to expressly define sludge as a nonhazardous solid waste when used in a combustion unit. This clarification is of concern for processes that would combust wastewater solids to recover their energy and U.S. EPA "legitimacy criteria" for consideration as a renewable fuel are at the heart of industry concerns. To meet these criteria, sludge must:

- Have meaningful heating value and be used as a fuel in a combustion unit that recovers energy,
- Be managed as a valuable commodity, and
- Contain contaminants at levels comparable to or lower than those in traditional fuels which the combustion unit is designed to burn.

Per the U.S. EPA, wastewater sludge does not meet these criteria and is defined as a solid waste. Wastewater professionals contend that some sludges do, in fact, meet these criteria (especially sludges that have been dried) and that the use of sludge and biosolids as a renewable fuel should be encouraged as part of the nation's effort to promote green energy.

While U.S. EPA has not made a blanket determination that wastewater solids are renewable fuels when burned, the Agency recently promulgated a new, categorical non-waste determination rulemaking process that could potentially be used to seek a nationwide exclusion for wastewater solids burned for energy recovery (U.S. EPA, 2013).

Additionally, some utilities have sought – and received – U.S. EPA approval of their solids as renewable fuels via a separate "non-waste petition process" (a process available for other solid wastes as well). This process allows generators or managers to demonstrate to U.S. EPA That their solids meet the legitimacy criteria, providing a pathway for individual solids to be classified as a renewable fuel. In some instances, where the generator and combustor are the same entity, the legitimacy criteria and non-waste determination process can be "self-implemented" and do not require U.S. EPA approval (Hornback, 2012).

The potential role of solids as a fuel lies not only in the hands of U.S. EPA but, potentially, in the hands of state regulators as well. States have the ability to set more stringent requirements than U.S. EPA, and the potential impacts of any state-specific requirements, as well as the potential basis of such requirements – remain in question. Moreover, some states adopt policies that shape solids management strategies (as rulemaking can be a long and arduous process) and informal policies (that discourage incineration, for example) could also limit the role of wastewater solids as a renewable fuel.

Nutrient Management Standard Revision

A recent standard issued by USDA exemplifies both the potential constraints and complexities facing biosolids managers that wish to include land application in their resource recovery tool box. In January 2012, the USDA Natural Resources Conservation Service (NRCS) revised its Code 590 Nutrient Management Standard (available at http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1046433.pdf). This federal standard, essentially a template that states were to modify for their unique conditions by January 2013, defines approaches to manage nutrient sources such as manures and biosolids that are applied to the land. The new revision reflects USDA's effort to bring more uniformity to state standards, most especially in the development and application of the primary tool used to assess risks from the over application of phosphorus (P): the Phosphorus Index (PI). And for the first time, the new standard explicitly includes biosolids in the materials that it covers.

Although Code 590 was originally intended for use by farmers participating in NRCS assistance programs, it has been incorporated into regulations governing manure management and in some states, into biosolids land application regulations and/or permits as well. Thus, the standard has taken on the weight of law for biosolids applications in some states, especially those in the mid-Atlantic region; in these states, biosolids application rates generally reflect phosphorus management requirements.

In general, the move toward P-based management poses a significant challenge to biosolids land application programs, as it can result in reduced application rates and, consequently, an increase in the land area required for such programs. The issue is exacerbated by the fact that most PIs do not account for the differing P availability from nutrient sources; this is especially critical, as research has shown that many biosolids products have lower P availability than fertilizers and manures. The following figure illustrates the differing P availability for these materials, as measured by Water Extractable Phosphorus.

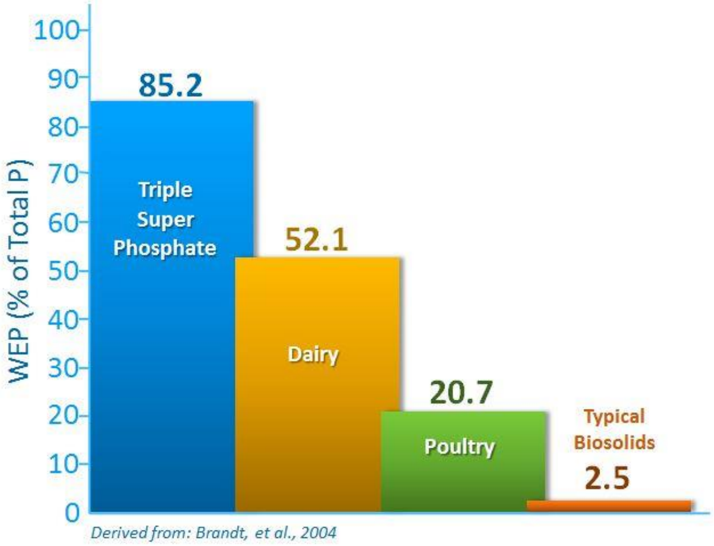
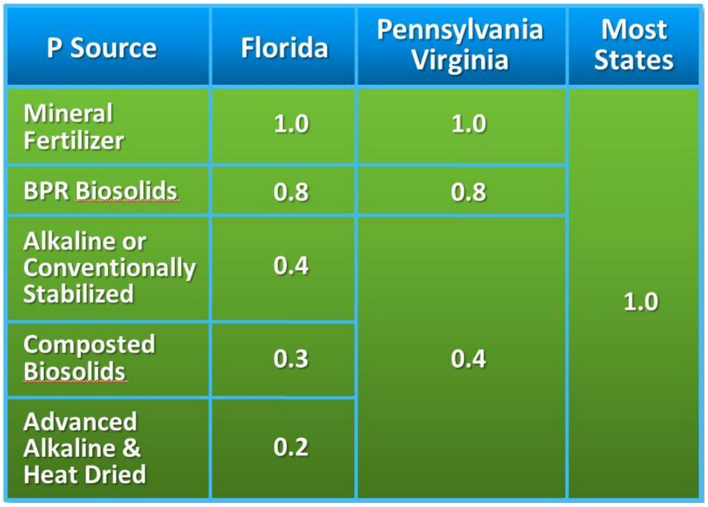


Figure 2: Relative phosphorus availability of biosolids and other nutrient sources

Phosphorus availability in biosolids should be – and in some cases, already has been – reflected in PIs through "P source coefficients". The P source coefficient (PSC) "quantifies the environmental availability of a P source relative to inorganic P fertilizer", which has a PSC = 1 (Elliot, 2012). Incorporating a product-specific PSC can both improve the predictive capability of a PI and keep P management requirements from being overly restrictive. As such, the adoption of source coefficients into Code 590 PIs is a critical element in sustainable nutrient management planning for biosolids. A dozen states now incorporate source coefficients in their PIs, and several of those states include a biosolids PSC of some kind. Additionally, Pennsylvania and Maryland allow for water extractable P testing to determine product-specific PSCs. The following table shows approaches to PSCs used in P Indices.



P Source	Florida	Pennsylvania Virginia	Most States
Mineral Fertilizer	1.0	1.0	1.0
BPR Biosolids	0.8	0.8	
Alkaline or Conventionally Stabilized	0.4	0.4	
Composted Biosolids	0.3		
Advanced Alkaline & Heat Dried	0.2		

Table 1: Select phosphorus source coefficients used in P indices

It is important to note that the difference in states' approaches to nutrient management extends well beyond their approach to PIs. Some states practicing P management rely on soil P threshold values to manage P in land-applied biosolids. Still others have no P-based requirements at this time and retain nitrogen-based application rates for nutrient management. This varied approach is expected to continue for the foreseeable future and should be considered when assessing potential impacts of P-based management in various locales.

Regulatory Status of Biosolids-derived Products

The focus on renewable-sourced products in general, coupled with an industry-specific need to diversify biosolids outlets, has led to innovative solids-derived products such as biodegradable plastics, which were never envisioned when the 503 rule was promulgated (Section 6 provides additional detail on "nontraditional" products). While these products fall well within the paradigm of beneficial use, some diverge significantly from "traditional" biosolids in both form and function: accordingly, the applicability of the 503 rule is in question and the regulatory status of these products is far from certain.

Because of the relatively early development status for some of these products, the regulatory framework for their use has not been defined, but vendors of such products are seeking feedback from regulators to guide them as they seek to enter the marketplace. As the portfolio of new solids-derived products expands, defining an approach to regulations that reflects the diversity of these products will become increasingly important.

State Regulation and Policy

While ongoing federal regulatory activity does not generally appear to support resource recovery from biosolids, some state-level regulatory actions and policies are specifically attempting to remove regulatory barriers to resource recovery. These activities are driven, in part, by "zero-waste initiatives" in many cities, which seek to maximize the diversion of recyclables away from landfills. Key examples of state-based regulations and policies intended to facilitate co-digestion and California's recent efforts to encourage composting, are discussed below.

Co-Digestion Regulations

The trend toward digesting fats, oils, and grease (FOG) and source-separated organics (SSOs) such as food scraps at water resource recovery facilities (WRRFs) has created a regulatory conundrum: should WRRF digesters processing these materials be treated as solid waste or wastewater processing facilities? The conflict stems from the traditional handling of FOG and food waste treatment under solid waste regulations (specifically the Resource Conservation and Recovery Act Subtitle D, which covers nonhazardous solid wastes, and 40 CFR Part 258, which covers landfills) versus biosolids digestion, which is typically regulated by Clean Water Act requirements. In some states, the processing of food waste and other organics in a WRRF digester may result in the designation of the digester as a solid waste processing facility.

The question of how to permit such facilities is complicated by the fact that neither solid waste nor water-quality regulations were intended – or are well equipped – to accommodate mixed biomass recovery in digesters.

Because solid waste and wastewater permitting are generally state-level activities, solutions to this conundrum are appearing at a state level as well. States can also be more agile and flexible than the federal government, and are better positioned to enact changes to support local conditions and demands.

Although many states are believed to be grappling with this issue, several have already identified paths to facilitate resource recovery in digesters. As described below, the approaches vary, but all reflect a recognition of the opportunities to meet both solid waste reduction and biogas optimization goals through mixed biomass digestion.

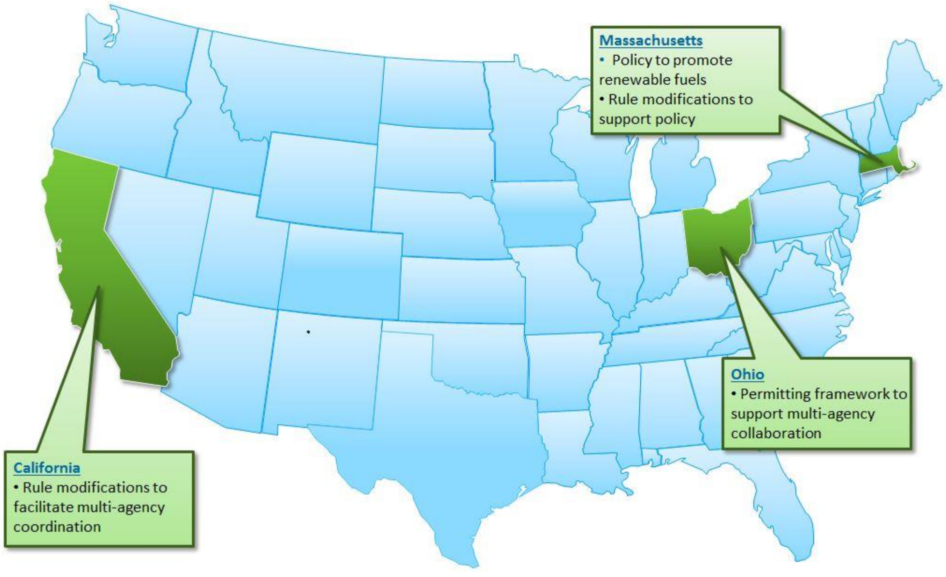


Figure 3: State regulatory approaches to mixed biomass digestion

Ohio: Multi-Agency Permitting Framework

The digestion of wastewater solids at Ohio WRRFs is regulated by the Ohio Environmental Protection Agency's Division of Surface Water through the National Pollutant Discharge Elimination System (NPDES) program, while foodwaste processing is regulated through the Division of Solid Waste and Infectious Waste Management. Faced with requests to process foodwaste in WRRF digestion facilities, the state has assigned primacy to the Surface Water Division for permitting involving biosolids, but provides for feedback from other relevant divisions during the permitting process. This general permitting framework (primacy for one agency, in collaboration with others) is also applied for digesters at Concentrated Animal Feeding Operations, with the Department of Agriculture leading the permitting effort; facilities digesting other materials (i.e., that do not include biosolids or manures) are usually permitted through the Solid Waste Division (BioCycle, 2009).

Massachusetts: Policy-Driven Rule Modifications

The Massachusetts Department of Environmental Protection (DEP) is now focusing a great deal of attention on SSOs and, as part of the

Massachusetts Organics Action Plan, the agency has announced its intention to ban certain large scale (e.g., institutional) SSO from landfills in 2014. While waste diversion is a primary goal, a cornerstone of its policy is supporting renewable energy in the state through its Clean Energy Results Program. Through this program, the state hopes to have 50MW of biogas-derived power in place by 2020. The processing of SSOs in digesters is a primary tool to accomplish these objectives.

Toward this end, two significant regulatory changes were enacted in November 2012, one to the solid waste regulations and one to the wastewater regulations. The solid waste rules were changed to allow for streamlined siting of facilities that process SSO (e.g., compost or anaerobic digestion facilities). The wastewater rules were changed to allow for WRRFs with anaerobic digesters to accept and process SSO (Beecher, 2012).

State-level Programs to Advance Energy Recovery: The Massachusetts Clean Energy Results Program

This program is a "first-of-its-kind partnership" between Massachusetts DEP (MassDEP) and the Massachusetts Department of Energy Resources. Launched in November 2011, it "builds on MassDEP's unique regulatory expertise and authority to support the Massachusetts Department of Energy Resources in advancing the permitting and development of renewable energy and energy efficiency projects across the Commonwealth". For more information, see: http://www.mass.gov/dep/energy/cerpprogram.htm.

Advancing renewable energy & energy efficiency in the Commonwealth
CLEANENERGYRESULTS

California: Rule Modifications to Eliminate Regulatory Overlap

CalRecycle, the primary solid waste regulatory agency in California, is proposing to exclude WRRFs that process select organics from its solid waste transfer/processing and in-vessel digestion regulations. The proposal recognizes that the Regional Water Quality Control Board oversight may "adequately address the receipt, handling, anaerobic digestion and residual solids management of specific types of organic material for co-digestion". Proposed revisions exempt a "Publicly Owned Treatment Works Treatment Plant that receives vehicle-transported solid waste that is an anaerobically digestible material for the purpose of anaerobic co-digestion with POTW wastewater" (CalRecycle, 2012). The definition of "anaerobically digested material" includes inedible kitchen grease and specific vegetative food material. CalRecyle may approve other organic feedstocks on a case-by-case basis, via a multi-agency process that includes consultation with the State Water Resources Control Board and the California Department of Food and Agriculture. Additional details on the changes, which were proposed in September 2012, can be found at http://www.calrecycle.ca.gov/laws/Rulemaking/Compost/1stDiscDraft/Issue5.pdf.

Policy and Planning

With respect to policy and planning, the overarching driver for resource recovery is the broader focus on sustainability, viewed through the perspective of TBL analyses that reflect environmental, economic, and social concerns. This focal shift is reflected in the increasing use of TBL analyses for solids planning, but is also driving research, voluntary programs, and a renewed interest in the environmental benefits of biosolids. As shown in the figure below and described below, many of these focal points – which are actually tools to forward resource recovery – address multiple elements in the sustainability trifecta.

Figure 4: Biosolids sustainable management focal

Partnerships

The paradigm shift to resource recovery is being thwarted by the harsh economic reality that capital funding budgets are being stretched to the breaking point and that economics continue to influence (if not dominate) decision-making and, in some cases, prevent the investment in biosolids management choices that offer the greatest long-term environmental benefit. One trend that has developed in response to these dual pressures is the growth of partnerships that benefit all participants. Partnership opportunities can take several forms, including private enterprise funding; collaboration with Energy Service Companies; and the development of synergistic relationships between wastewater utilities and other municipal departments, industry, and manufacturers of new technologies.

Case Study: The USCC Seal of Testing Assurance (STA) Program Role in Texas Compost Market Development

STA testing is the foundation requirement for all composts used by the Texas Department of Transportation (TxDOT). Soon after the STA program was developed, TxDOT, working with the Texas Commission on Environmental Quality (TCEQ) incorporated STA testing requirements into new specifications for a variety of compost products used in their projects. To ensure that they had access to the large TxDOT market, nearly all Texas compost producers joined the STA program, participating in required testing. The stringent quality requirements in the specifications were critical to TxDOT and to contractors bidding on TxDOT projects, as they provided them with the assurance that the composts they purchased would be suitable for their needs. Today, TxDOT is believed to be the largest user of compost in the nation, purchasing about 300,000 cubic yards annually for its construction projects.

Product Marketability Criteria

Diversity is a key tenet of sustainable solids management, and toward that end, utilities are seeking multiple outlets for their renewable-sourced products, which today include biosolids, biogas, and specialty fertilizers. For biogas, access to markets such as vehicle fuel is a function of gas cleaning and compression, while specialty fertilizers (such as the phosphorus fertilizer resulting from Ostara's Pearl process) generally are marketed by process vendors. Requirements for entering retail biosolids markets (typically with a composted or heat-dried biosolid) are more complicated, however, as utilities need to satisfy customers that range from homeowners to farmers. Toward that end, biosolids products must meet not only regulatory criteria, but also "marketability criteria" – i.e., those characteristics that are critical to targeted customers.

Biosolids marketability criteria include two basic parameters: consistency (of both supply and quality) and product characteristics. Desired characteristics generally vary by product and are highlighted in the table below. Additional information on specific criteria can be found in *Design of Municipal Wastewater Treatment Plants* (WEF, 2011).

Compost	Heat-dried Product
pH Soluble salts/Salt index Nutrient content Water-holding capacity Bulk density Moisture content Organic matter content Particle size Maturity (phytotoxicity) Stability Odor	Particle size Nutrient content Durability (hardness) Dust Odor Bulk density Soluble salts Heating value

Table 2: Product quality criteria (Source: Derived from WEF, 2010)

Few of the parameters noted are regulatory in nature, although stability and odor criteria in some respects are intended to be addressed by the 503 rule's Vector Attraction Reduction (VAR) requirements. VAR requirements are not market-based, however, and for composts, at least, a robust approach to measure – and uniformly compare products with respect to – marketability criteria has been developed by the U.S. Composting Council (USCC). The USCC effort, which culminated in its Seal of Testing Approval (STA) program and the testing method manual that supports the program, Test Methods for the Examination of Composting and Composts (USCC, 2002). The USCC effort, many years in the making, was initiated on the simple principles that: (1) material testing is needed to verify product market (and safety) claims and (2) that product data should be truly comparable for all customers in order to be meaningful. The resulting program is an example of criteria – and, critically, associated testing – developed to support product markets that might serve as a model for other biosolids products.

In Québec, the Bureau de normalisation du Québec (BNQ) offers a biosolids quality certification program for biosolids composts and pellet fertilizer. Several biosolids programs in Québec (and other provinces) have had their biosolids products certified. The Québec environment ministry removes all regulation from the use of any product certified by BNQ.

Research (Odor and Safety)

Public acceptance is critical to maximizing the recovery of nutrients, organics, and other resources through land application. Two key impediments to public acceptance are odors and the perceived safety of biosolids, and WERF recently brought research addressing these issues together into a single comprehensive project known as the Regrowth, Odors, and Sudden Increase Project. The project is comprised of two separate but interrelated research trains:

- *Biosolids Odors* – Building on a decade of research on biosolids odors, the research team is investigating short-term and long-term odor characteristics and approaches to reduce those odors. The researchers found that odors do, in fact, change with time, reflecting the release of different compounds (WERF, 2012). Volatile organic sulfur compounds are largely responsible for odors after dewatering, but indole, skatole, p-cresol, and butyric acid contribute to odors that might be emitted over the long term during storage. The research further found that shear during dewatering and conveyance contributes to short-term odors and that higher shear operations (centrifuge dewatering, screw conveyance) and polymer can have an impact as well. Lastly, the researchers determined that while digestion in general decreases odors, the improvement may not meet odor reduction objectives. The project team is currently working with utilities to assess mitigation measures for broader future application.

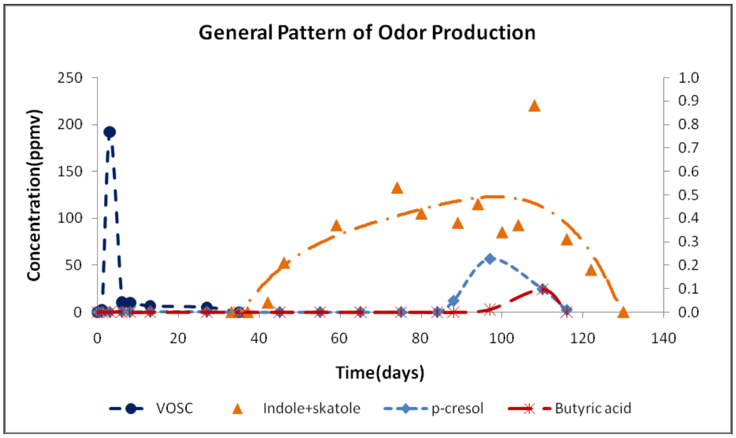


Figure 5: Biosolids odor production over time (WERF, 2012)

- *Sudden Increase/Regrowth* – The terms "sudden increase" and "regrowth" refer to increases in fecal coliform counts observed in some types of dewatered and anaerobically digested biosolids. Specifically, sudden increase (SI) is defined as an increase observed in freshly dewatered cake, while regrowth is defined as an increase observed in stored biosolids. Researchers found that the higher shear that contributes to cake odors is also a factor in both SI and regrowth in digested cake (WERF, 2012). Digestion processes had differing impacts on SI, however, with the phenomenon observed more frequently with thermophilically digested (and centrifuged) biosolids (WERF, 2012). The project team has identified strategies to address both SI and regrowth, and is currently assessing the effectiveness of those strategies in the field.

Because of the importance of odor and perceived safety concerns to the sustainability of land application as a biosolids recycling approach, WERF has invested and continues to invest in additional research in these issues. Appendix A lists additional research in these areas. As noted in the appendix, the research extends into emerging issues such as trace organics and nanoparticles.

Carbon Footprint

Some have noted that climate change may be a key driver of biosolids management strategies in the future. While neither the federal government nor most states require greenhouse gas (GHG) reductions at this time, there is nonetheless an increased focus on both quantifying and reducing carbon footprints from biosolids operations, and a corresponding emphasis on renewable fuels. This interest may reflect a sense that regulations are pending, as well as a growing awareness of our role in a sustainable urban ecology. The term "carbon footprint" is often used to discuss GHG impacts, as their emission rates are typically quantified in terms of carbon dioxide (CO_2) equivalents. This measure reflects the varying global warming potential of different greenhouse gases.

GHG (tons)	CO_2 Equivalents (tons)
Carbon Dioxide	1
Methane	23
Nitrous Oxide	296

Table 3: Carbon dioxide equivalents of greenhouse gases

Solids treatment and disposal/use operations are potential emitters of GHGs, but biosolids management programs also offer opportunities to reduce net greenhouse gas emissions through the use of biosolids as a resource. Biosolids themselves do not impact a carbon footprint, as they are "new" carbon, created from photosynthesis and biogenic in origin. (Biogenic CO_2 originates from the decomposition of organic matter that was created by recent photosynthesis; the emission of biogenic CO_2 does not create a net increase in CO_2 since the carbon is recently derived from atmospheric CO_2.)

Biosolids processing and management activities can reduce or increase a facility's carbon footprint, however, as shown in the figure below. Chemicals, fuel, and electricity used in processing can increase GHG impacts if they require the combustion of fossil fuel. Another source of GHG impacts from biosolids operations is the conversion of CO_2 or nitrogen into more potent GHGs. This might occur via the conversion of biogenic carbon to methane in digesters (if the methane escapes), or via the release of nitrous oxide from the application of biosolids to soils or biosolids combustion. Biosolids management can provide significant opportunities for GHG reductions through the generation and use of biogas, replacing mineral fertilizer, and sequestering carbon in the soil (carbon sequestration and fertilizer replacement are discussed further in Section 3).

Utilities are increasingly scrutinizing their operations to assess ways to reduce their carbon footprints but, to date, a consistent approach for estimating GHG emissions has proven to be elusive. A number of organizations around the world have developed protocols for GHG estimates, and although many follow the general approach adopted in the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories (IPCC, 2006), the protocols vary in many ways. In North America, it appears that efforts may be focusing on a protocol published by The Climate Registry (TCR) General Reporting Protocol (2008), which attempts to integrate several existing state protocols.

Based upon the TCR protocol, the Canadian Council of Ministers of the Environment (CCME) has developed an emissions model specifically for biosolids management programs, the Biosolids Emissions Assessment Model, or BEAM (SYLVIS, 2009). To our knowledge, this is the first government agency-sponsored model for biosolids GHG estimates that has been developed. CCME (2009) notes that the BEAM can be used to define existing GHG emissions, assess GHG reduction opportunities, and document GHG reductions for emerging carbon markets (with independent verification).

The desire to take advantage of emerging carbon markets has presented a quandary for some utilities. At present, the value of carbon credits is low. Some utilities may choose to postpone proposed GHG reduction measures until those markets mature, fearing that implementing them earlier would change their baseline footprint and make them ineligible for such credits. That being said, the general push for sustainability and resource recovery has minimized the focus on credits at this time, but an improved credit value could incentivize utilities to pursue resource recovery programs.

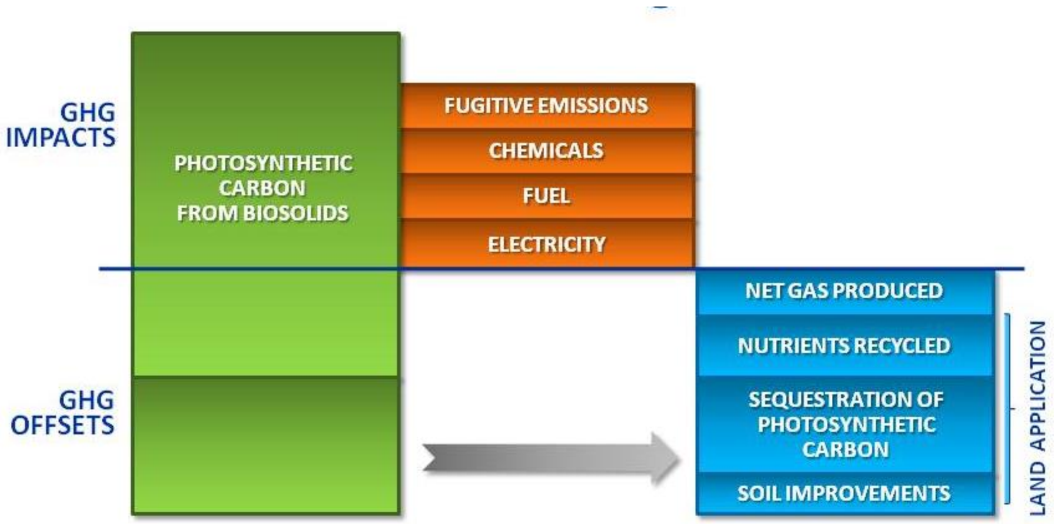


Figure 6: Biosolids carbon accounting

Voluntary Programs

As indicated by the discussions above, meeting existing regulatory requirements is not always sufficient to ensure public acceptance. Toward that end, several programs have been developed that focus on optimized biosolids quality, management practices, and/or public outreach, with the goal of alleviating public concerns. Through improved public acceptance, these programs advance the goal of resource recovery. Examples of programs that fall into this category are the National Biosolids Partnership (NBP) Environmental Management System (EMS) and voluntary programs to divert pharmaceuticals and personal care products (PPCPs) from wastewater and biosolids.

National Biosolids Partnership BMP (EMS)

The NBP Biosolids Management Program (BMP) (EMS) is a voluntary program that uses a flexible framework to help public and private sector organizations improve the quality of their biosolids management programs. The BMP framework is designed to accommodate all types of biosolids management practices and is based on elements that encompass all levels of a program, including policy-making, management planning, program implementation, measurement and corrective action, and management review.

Organizations that achieve BMP certification are committed to the use of best management practices and conform to the NBP's Code of Good Practice. Over 30 organizations, representing more than 12% of the biosolids generated in the U.S., have achieved certification.

One of the key features of the BMP program is the use of third-party audits to improve the credibility of the biosolids program with the public. The audits also help participants identify areas of strength as well as areas of weakness that can be improved upon.

Though initially offered as a certification program only, the BPM now offers a tiered system that includes recognized programs (bronze through gold) as well as the traditional platinum-certified programs. This change was made to recognize, in particular, those organizations that that have committed to and trained for NBP goals, but have not had the ability to meet financial commitments for the program. The following table provides an overview of the different BMP tiers.

NBP BMP Tier Summary

Tier Requirement	Platinum Certification	Gold Recognition	Silver Recognition	Bronze Recognition
Third Party Verification Audit	Every 5 years	Initial and at 5 years	Ready per NBP-approved audit	Goal
Interim Internal Audits	Annual, some third party	Annual	Annual	Not required
17 BMP Elements	Implement	Implement	Implement	Goal
NBP Code of Good Practice	Implement	Implement	Implement	Commit

Table 4: BMP tier summary

It should be noted that while the NBP program was developed primarily to focus on environmental and social issues, the program can also offer financial benefits to participants in terms of improved and more efficient operations.

Additional information on the program can be found at: http://www.wef.org/Biosolids/page.aspx?id=7554&ekmensel=c57dfa7b_127_0_7554_3.

Product Stewardship Programs

Concerns regarding microconstituents (originating from pharmaceuticals and personal care products) persist among the public, although research to determine the effects of biosolids-borne microconstituents is still underway. Moreover, research-based regulations are likely years away. In the interim, product stewardship and pollution prevention programs (PPPs) offer an approach to minimize microconstituents entering the wastestream and maximize both biosolids quality and resource recovery potential.

The "SMAR$_x$T Disposal^{TM}" campaign is an example. Created by the U.S. Fish and Wildlife Service, the American Pharmacists Association, and the Pharmaceutical Research and Manufacturers of America, the program promotes environmentally protective alternatives to flushing medications or pouring them down the drain. Wal-Mart is a participating partner in the program and is promoting the campaign through its pharmacies. Additional information on the program can be found at: http://smarxtdisposal.net/index.html.

The Product Stewardship Institute, a Boston-based nonprofit group, is also promoting environmentally protective disposal, but is also working to encourage manufacturers, legislators, and others to support such programs as part of a broader initiative to reduce the health and environmental impacts of a variety of consumer products.

Summary of Needs

As evidenced above, a wide range of actions are required on regulatory and policy levels to advance resource recovery in biosolids.

The theme of biosolids as a renewable resource is perhaps the key to repositioning both the role and value of biosolids. This could involve recognizing biosolids as a source of recyclable nutrients (N, P), as well as achieving formal designation as a renewable fuel resource on a federal level – a critical step not only to expanded use of wastewater solids as a renewable fuel, but also to positioning utilities to take advantage of Renewable Portfolio Standards.

Other critical activities include

- *Continued efforts to promote and facilitate multi-agency coordination,* which will be critical to addressing overlapping regulations and responsibilities as the lines between solid waste management and wastewater treatment blur. Additionally, coordination will be required to emphasize the concept of "maximum environmental benefit" in regulatory development to minimize regulations that shift pollutant issues from one medium to another (i.e., air to water), rather than effectively and holistically managing pollutants.
- *Collaboration between experienced biosolids practitioners and regulators* as new products emerge from wastewater and biosolids processing (such as fertilizer derived from struvite) and questions arise as to how (or if) those products should be regulated.
- *The development of "marketability criteria" for value-added products* using the USCC Seal of Testing Approval and BNQ program as a model. Previous WERF studies on the subject of biosolids stability (Switzenbaum et al., 1997; Switzenbaum et al., 2002) could provide a springboard for test methods and protocols that will be required.
- Continued expansion of voluntary programs that support biosolids quality such as the NBP EMS and PPPs.
- *Continued research to address public uncertainties regarding biosolids safety*. Though this research is critical, it is equally important to ensure the research findings are effectively disseminated to practitioners and the public. Specific education and outreach needs and potential solutions are addressed in Section 7 of this report.

References

Beecher, N.; Crawford, K.; Goldstein, N.; Kester, G.; Lona-Batura, M.; Dziezyk, E. (2007) *National Biosolids Regulation, Quality, End Use, and Disposal*; North East Biosolids and Residuals Association: Tamworth, New Hampshire.

Beecher, N. (2012) Personal communication.

BioCycle (2009) Regulating Codigestion Plants. *BioCycle*, **50** (8), 35.

CalRecycle (2012) *Proposed Rulemaking: Regulatory Coordination of Publicly Owned Treatment Works (POTWs) Accepting Food Waste, Fats, Oils and Grease (FOG)*, September. http://www.calrecycle.ca.gov/laws/Rulemaking/Compost/1stDiscDraft/Issue5.pdf (accessed May 10, 2013).

Canadian Council of Ministers of the Environment (2009) *Biosolids Emissions Assessment Model: User Guide*. PN 1430; http://www.ccme.ca/assets/pdf/beam_user_guide_1430.pdf (accessed May 10, 2013).

Elliot, H. A. (2012) *Science and Policy Updates on Biosolids Phosphorus.* Presented at: Challenges and Solutions for Managing Biosolids Nutrients, Mid-Atlantic Biosolids Assoc., Nov 20; Mid-Atlantic Biosolids Assoc.: Philadelphia.

Hornback, C. (2012) Personal communication.

IPCC (2006) *Guidelines for National Greenhouse Gas Inventories*. Intergovernmental Panel on Climate Change, Task Force on National Greenhouse Gas Inventories. http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html (accessed May 10, 2013).

Metcalf and Eddy (1978) *Wastewater Engineering Treatment and Disposal*; McGraw-Hill: New York.

Rios, R. (1992) Development of a Sludge Disposal Plan for Puerto Rico. http://prwreri.uprm.edu/publications/Development%20of%20the%20Sludge%20Disposal%20Plan%20for%20Puerto%20Rico.pdf (accessed May 10, 2013).

Switzenbaum, M. S.; Moss, L. H.; Pincince, A. B.; Donovan, J. F; Epstein, E. (1997) *Defining Biosolids Stability: A Basis for Public and Regulatory Acceptance;* Water Environment Research Foundation: Alexandria, Virginia.

Switzenbaum, M. S.; Pincince, A. B.; Donovan, J. F.; Epstein, E.; Farrell, J. B. (2002) *Developing Protocols for Measuring Biosolids Stability;* Water Environment Research Foundation: Alexandria, Virginia.

SYLVIS (2009) The Biosolids Emissions Assessment Model (BEAM): A Method for Determining Greenhouse Gas Emissions from Canadian Biosolids Management Practices, Project No. 1432; Prepared for the Canadian Council of Ministers for the Environment; SYLVIS: New Westminster, British Columbia, Canada.

The Climate Registry (2008) General Reporting Protocol. http://www.theclimateregistry.org/resources/protocols/general-reporting-protocol/ (accessed May 10, 2013).

U.S. Composting Council (2002) *Test Methods for the Examination of Composting and Composts;* U.S. Composting Council Research and Education Foundation: Bethesda, Maryland.

U.S. Environmental Protection Agency (1984) *Environmental Regulations and Technology: Use and Disposal of Municipal Wastewater Sludge;* EPA-625/10-84-003; U.S. Environmental Protection Agency: Washington, D.C.

U.S. Environmental Protection Agency (1999) *Biosolids Generation, Use, and Disposal in the United States;* EPA-530/R-99-009; U.S. Environmental Protection Agency: Washington, D.C.

U.S. Environmental Protection Agency (2013) The Commercial and Industrial Solid Waste Incineration (CISWI) Units: Reconsideration and Final Amendments; Non-Hazardous Secondary Materials That Are a Solid Waste; Final Rule February 7. *Fed. Reg.,* **78** (26), 9112–9213. http://www.gpo.gov/fdsys/pkg/FR-2013-02-07/pdf/2012-31632.pdf (accessed May 10, 2013).

Water Environment Federation; American Society of Civil Engineers; Environmental & Water Resources Institute (2010) *Design of Municipal Wastewater Treatment Plants,* 5th ed.; WEF Manual of Practice No. 8; ASCE Manuals and Reports on Engineering Practice No. 76; Water Environment Federation: Alexandria, Virginia.

Water Environment Research Foundation (2012) Design and Operational Modifications to Minimize Odor and Pathogens at Wastewater Treatment Facilities; WERF 2012 Webinar Series; Sept 5.

Section 3

Organics Recycling: A New Perspective

The recycling of organics through application to the land has been practiced for millennia, with farmers long recognizing the benefits of the organic matter and nutrients in manures, night soil – and more recently, biosolids – to soil and crop systems. While these benefits are still a focal point, our perspective has expanded to include benefits associated with carbon footprint and climate change, as biosolids provide opportunities for GHG reductions through carbon sequestration and fertilizer production offsets. They can also play a role in sustainable soil management by building better soils. This section explores these relationships.

Soils and Climate Change

The relationship between biosolids applied to the land and climate change is best viewed in the broader context of sustainable soil management, considering not only how our soils have changed with intensive cultivation, but also predicted soil impacts due to climate change. One soil parameter impacted by both agricultural practices and climate change is SOC. SOC comprises about 50% of soil organic matter (SOM), which also includes materials from plants, animals, or microorganisms (living or dead) (Overstreet and DeJong-Hughes, 2009).

Agriculture takes a heavy toll on SOM, and thus studies indicate that the heavily farmed Midwestern U.S. soils have lost 30 to 50% of their SOC level since they have been cultivated (Lal, 2002). As shown in the figure, intensive agricultural practices can lead to a “soil degradation spiral”: increasing cultivation can ultimately lead to poor soils and declining crop yields, and therefore ever increasing cultivation needs, which further degrade soils.

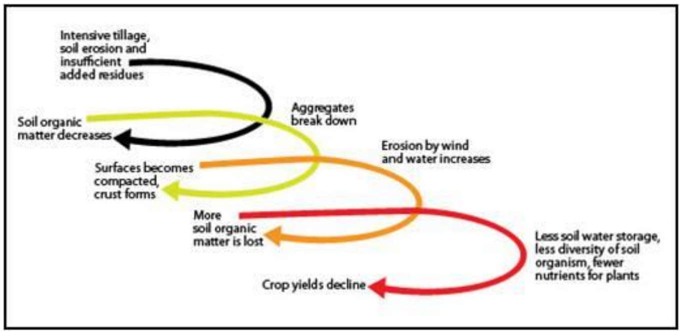


Figure 8: Soil degradation spiral (adapted from Magdoff and Van Es, 2009)

As shown below, climate change can exacerbate soil degradation via three mechanisms: higher temperatures can increase microbial decomposition of SOM, drought can lead to wind erosion and loss of SOM, while flooding can scour the soil surface and reduce SOM (van den Born et al., 2000). Of these degradation processes, erosion – by wind or water – has the most severe impact on soil SOC content (Lal, 2004).

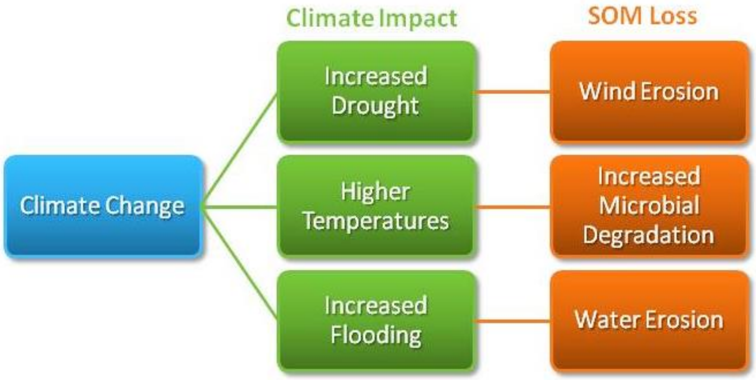


Figure 7: Climate change impacts on soil organic matter (SOM)

The impact of erosion on soils cannot be underestimated. Erosion can remove the most fertile part of soil, reducing productivity up to 50% and in the U.S. alone, the annual cost of erosion loss is estimated to be $44 billion/per year (Eswaran et al., 2001).

Climate change impacts on soil are not limited to loss of fertility: soil compaction is also a critical issue. Compacted soils can increase energy costs for tillage by 50% (Raper et al., 2000) and can reduce yields by 10 to 20% (Iowa State University, 2009).

Biosolids can play a critical role with respect to climate change and its impacts on soil by providing the SOC and organic matter to build soils.

The addition of biosolids can also sequester carbon in the soil. Lal (2002) estimates that about 60 to 70% of the SOC lost from U.S. mid-western soils could be re-sequestered through the adoption of recommended soil and crop management practices, such as the conversion from plow till to no till, the “liberal use of biosolids”, and other practices.

In addition to SOC loss, the increased reliance on fertilizers to maintain soils productivity has a strong carbon footprint impact, as fertilizer production, distribution, and use contribute 2.5% to global GHG emissions (IFA, 2009). As shown in the figure below**,** biosolids contain macronutrients (nitrogen, phosphorus, potassium) – albeit in lower concentrations than mineral fertilizers – and their use can offset fertilizer requirements (biosolids also contain micronutrients, such as iron and zinc).

The potential role of biosolids in carbon footprint reduction – via fertilizer replacement and carbon sequestration – is described below.

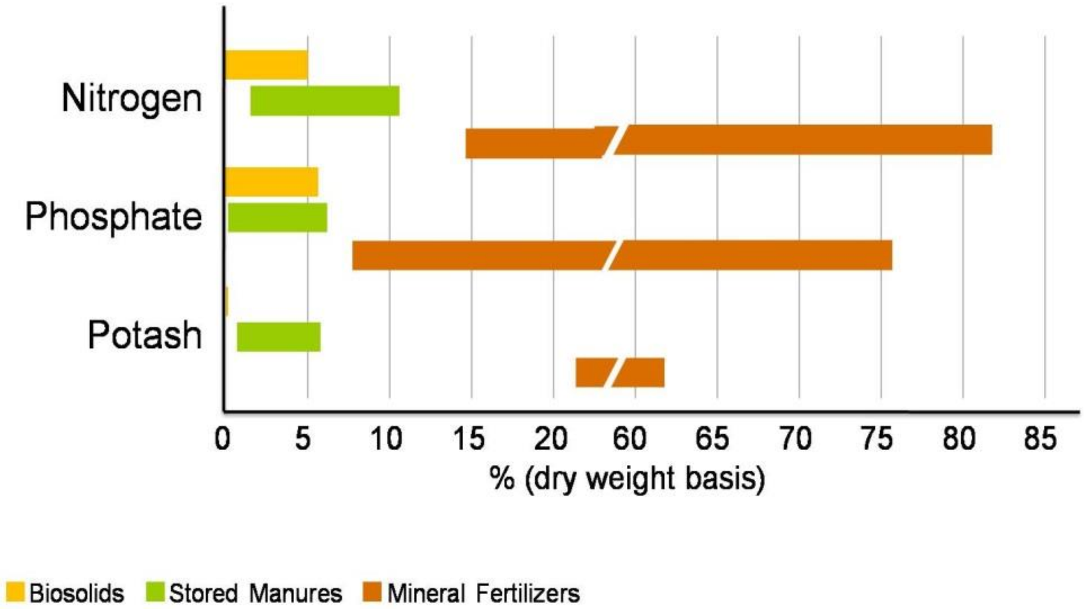


Table 5: Biosolids, manure, and fertilizer macronutrient content

Biosolids and Carbon Accounting

As noted in Section 2, protocols to estimate GHG emissions from biosolids processes are still evolving, but the development of BEAM provides a strong foundation for such assessments. Developed at the request of the CCME, BEAM can be used to define existing GHG emissions, assess GHG reduction opportunities, and document GHG reductions for emerging carbon markets (SYLVIS, 2009). Key processes addressed in the model are shown in the following figure, which also indicates GHG impacts and offsets associated with solids processing.

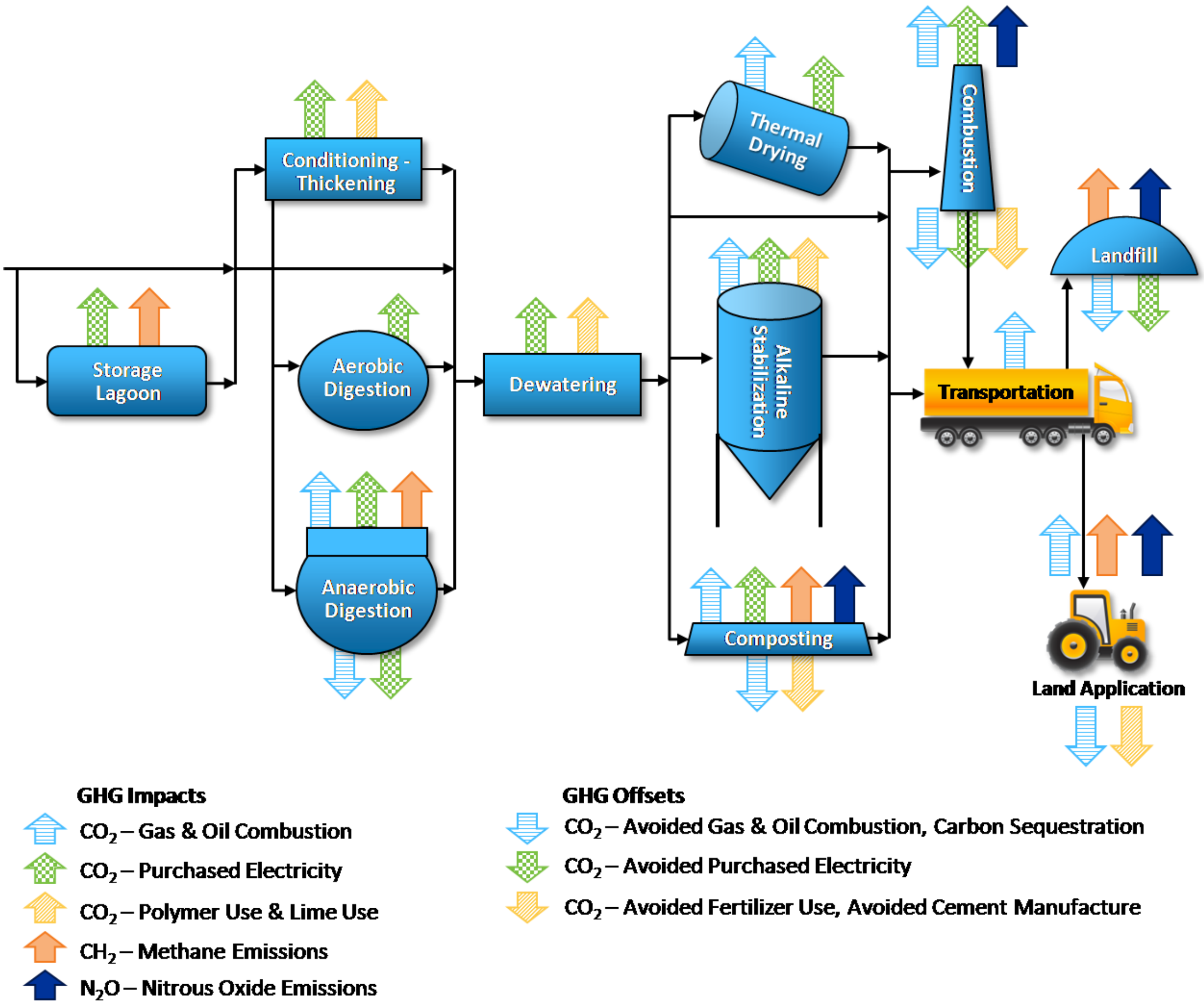


Figure 9: Biosolids GHG impacts and offsets (Brown et al., 2010)

For the purposes of this report, key areas of focus include fertilizer replacement and carbon sequestration, both described below.

Fertilizer Replacement

Biosolids can reduce agricultural carbon footprints through fertilizer production offsets to meet plant nutrient requirements. The reported GHG offset values for fertilizer replacement vary in literature, but based upon the data presented in Table 6, the BEAM model assumes values of 4 and 2 kg CO_2e/kg for nitrogen (N) and P, respectively (Brown et al., 2010). The default values are expected to be conservative, as they do not distinguish between plant available and total nutrient content and do not account for the micronutrients (and macronutrients such as potassium) that are present in biosolids (Brown et al., 2010).

Carbon Sequestration

Atmospheric CO_2 has increased by more than 30% since 1750, with losses of SOC contributing significantly to the increase: of the estimated 240 to 300 billion tons of CO_2 emitted since the industrial revolution, and an estimated 66 to 80 billion tons have been contributed by the SOC pool (Lal, 2004).

Author	Title	Journal	Nitrogen	Phosphorus	Comments
Brown and Leonard (2004)	Biosolids and global warming: Evaluating the management impacts	*BioCycle*, **Aug**.		3 g CO_2 per g P	Used sitting 1979 to calculate energy required for P production, and IPCC factor used for N for multiplier to take into account transport and production inefficiencies
Murray et al. (2008)	Hybrid life-cycle environmental and cost inventory of wastewater sludge treatment and end-use scenarios: a case study from China	*Environ. Sci. Technol.* Published online 3/20/08	3.6 g CO_2 per g N	4.86 g CO_2 per g P	
Kim and Dale (2008)	Effects of nitrogen fertilizer application on greenhouse gas emissions and economics of corn production	*Environ. Sci. Technol.*, **42,** 6028–-6033	3.1-4.7 g of CO_2 per g N		Total emissions from all other fertilizer use (P, K, S, lime, pesticides and herbicides) similar to N fertilizer emission
Intergovernmental Panel on Climate Change (IPCC) (2006)	Guidelines for National Greenhouse Gas Inventories	http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html	1.3 g of CO_2 per g N		Manufacture only
Recycled Organics Unit (2006)	Life-cycle inventory and life-cycle assessment for windrow composting systems	University of New South Wales, Sydney, Australia. http://www.recycledorganics.com/publications/reports/lca/lca.htm	3.96 g of CO_2 per g N	1.76 g of CO_2 per g P	Potassium, factor of 1.36 given
Schlesinger (1999)	Carbon sequestration soils: some cautions amidst optimism	*Agriculture, Ecosystems Environ.* ,**82,** 121–127	4.5 g CO_2 per g N		1.436 moles of CO_2-C per mole of N

Table 6: Reported values for energy required to produce, transport, and apply synthetic fertilizers (Brown et al., 2010)

In his comprehensive report on soil carbon sequestration and climate change, Lal (2004) cited replenishing the soil's carbon supply as a strategy to offset (but not eliminate) increases in atmospheric CO_2, and estimated the cumulative potential of soil carbon sequestration to be 30 to 60 billion tons over 25 to 50 years. Because other factors – specifically fossil fuel use – contribute so heavily to CO_2 emissions, however, he also notes that carbon sequestration has a limited (albeit critical) potential to impact climate change; nonetheless, because it also improves soil quality, soil "C sequestration is something that we cannot afford to ignore".

Recognizing the role that biosolids can play in sequestering carbon, research on this topic has intensified over the last decade or so and, while information remains sparse, data were identified and included in the BEAM model (see below).

Land use	Summary	Change in Soil C Storage (Mg CO_2 per dry Mg biosolids)
Dryland wheat, conventional tillage	Cumulative loading rate of 18–40 Mg ha-1 . Site 14 years old	1.25–1.6
Surface application to fescue	Annual application from 1993–2000, sampled in 2008, cumulative loading rates 67–201 Mg ha-1	0.15–0.3
Roadside, incorporated	Single 147 Mg ha—1 application 2 years prior to sampling	1.74

Table 7: Carbon sequestration in biosolids-amended soils (Kurtz, 2010)

The table illustrates a critical consideration when quantifying carbon sequestration from biosolids amendments: the amount of carbon sequestered will vary according to land use and management practices, with surface applications apparently yielding lower C storage than single one time applications (such as might be seen for vegetation establishment on roadway embankments or reclamation).

C storage is also impacted by climate and soil type (Lal et al., 2007). The following figure illustrates the impact of differing climates and soils on sequestration.

Figure 10: Impact of differing climates and soils on sequestration

Generally, depleted soils (those with low SOM) and disturbed lands offer particular promise for C sequestration, and the use of biosolids on reclaimed lands has therefore been a focus. Studies of three U.S. and two Canadian mines demonstrated that biosolids addition enhanced carbon storage in reclaimed mine soils, finding that every Mg of biosolids applied resulted in 0.03 to 0.31 Mg of carbon stored in soil. (Trlica, 2010). In a longer term study covering decades of biosolids applications for land reclamation in Fulton County, Illinois, Tian et al. (2009) found that the mean net C sequestration in amended fields was 1.73 Mg C/ha^{-1} yr^{-1}, compared to values ranging from -0.7 to 0.17 Mg C/ha^{-1} yr^{-1} in fertilizer control fields.

Despite the promising role of biosolids for sequestering carbon, additional research is needed to better support carbon footprint accounting tools such as the BEAM model and to reflect the broad diversity of biosolids management practices currently employed. Additionally, GHG impacts from land application must be considered when considering the overall carbon footprint of this practice. These include transportation impacts (which can be minimal in many cases) and nitrous oxide emissions.

It is also critical to remember that even if carbon accounting tools show that land application does not offer the greatest carbon footprint reductions (or lowest cost), the value of biosolids for improving soil SOC, SOM, and soil tilth should not be ignored.

Enabling Organics Recycling

Fully leveraging the resource potential of biosolids applied to the land requires the following key areas of focus:

- Research to address persistent uncertainties regarding biosolids safety,
- Further demonstration of the benefits of biosolids as amendments, with a focus on their role in restoring depleted and disturbed soils,
- Further research and documentation of the carbon footprint impacts of land application activities, and
- Broad-based and effective communications regarding all of the above.

Research to Address Uncertainties

Focusing on land application (rather than product marketability issues discussed in Section 2), research is required to address both existing and emerging concerns regarding biosolids safety.

Specific research areas requiring attention include:

- *Odor* – Continued research into processes to reduce biosolids odor, a primary public concern and a driver of resistance to biosolids use, is warranted. This information would supplement the significant work done by WERF over the last decade or so on the mechanisms of odor generation.
- *Stability* – Stability is closely related to odor and is therefore a recommended focus going forward. Key focus areas for further investigation should build upon existing research and, as noted in Section 2, result in new stability measurements and methods.
- *Emerging Pollutants* – Interest in the future will continue to center on the fate and significance of emerging contaminants, including personal care products, pharmaceuticals, emerging pathogens, and nanoparticles.
- *Surrogate Indicators* – Research is also needed to support the development of new surrogate indicators (for pathogens), as research in this area, described in *Charting the Future of Biosolids Management* (WEF and NBP, 2011) reveals potentially improved approaches to demonstrate effective pathogen reduction.

Demonstrating Biosolids Benefits

Recycling of biosolids to the land is clearly not new, yet the demonstrated benefits that biosolids provide to our soils do not seem to be well understood by the public. Moreover, these benefits are often overshadowed by persistent uncertainties about the safety of biosolids. While additional research to demonstrate benefits to the soil could be helpful, effective dissemination of the multiple success stories and research regarding biosolids benefits is essential. The need to communicate what we know about biosolids in order to foster resource recovery is critical enough to be the topic of a separate discussion, and is the focus of Section 7 of this report.

Carbon Footprint Documentation

The BEAM model discussed above provides a solid foundation for quantifying the carbon footprint of biosolids operations, but additional data are needed to expand and strengthen the model. Specifically, additional data on carbon sequestration, reflecting the depth and breadth of biosolids practices across the continent, are needed. Additionally, additional information regarding nitrous oxide emissions from land application and combustion are needed to strengthen the model.

References

Brown S.; Beecher N.; Carpenter, A. (2010) Calculator Tool for Determining Greenhouse Gas Emissions for Biosolids Processing and End Use. *Environ. Sci. Technol.,* **44** (24), 9509–9515.

Eswaran, H.; Lal, R.; Reich, P. F. (2001) *Land Degradation: An Overview*: In *Responses to Land Degradation; Proceedings of the Second International Conference on Land Degradation and Desertification*; Khon Kaen, Thailand; Oxford Press: New Delhi, India. http://soils.usda.gov/use/worldsoils/papers/land-degradation-overview.html (accessed May 11, 2013).

International Fertilizer Industry Association (IFA) (2009) *Fertilizers, Climate Change and Enhancing Agricultural Productivity Sustainably,*1st ed.; IFA: Paris, France, July. http://www.fertilizer.org/ifa/HomePage/LIBRARY/Publication-database.html/Fertilizers-and-Climate-Change.-Enhancing-Agricultural-Productivity-and-Reducing-Emissions.html (accessed May 11, 2013).

Iowa State University (2009) *Resource Conservation Practices: Understanding and Managing Soil Compaction.* Iowa State University Extension PM 1901b. http://www.extension.iastate.edu/Publications/PM1901B.pdf (accessed May 11, 2013).

Kurtz, K. (2010) Quantification of the Long-Term Effects of Organic Soil Amendment Use: Carbon, Nitrogen, Bulk Density, and Water-holding Capacity. Master's Thesis, University of Washington, College of Forest Resources, Seattle, Washington.

Lal, R. (2002) Soil Carbon Dynamics in Cropland and Rangeland. *Environ. Pollut.,* **116** (3), 353–362.

Lal, R. (2004) Soil Carbon Sequestration Impacts on Global Climate Change and Food Security. *Science*, **304,**1623–1627.

Lal, R.; Follett R. F.; Stewart, B. A.; Kimble, J. M. (2007) Soil Carbon Sequestration to Mitigate Climate Change and Advance Food Security. *Soil Sci.,* **172** (12).

Magdoff, F.; Van Es, H. (2009) *Building Soils for Better Crops: Sustainable Soil Management,* 3rd ed.; Sustainable Agriculture Research and Education (SARE). http://www.sare.org/Learning-Center/Books/Building-Soils-for-Better-Crops-3rd-Edition (accessed May 11, 2013).

Overstreet, L. F.; DeJong-Hughes, J. (2009) *The Importance of Soil Organic Matter in Cropping Systems of the Northern Great Plains.* University of Minnesota Extension Publication M1273. http://www.extension.umn.edu/distribution/cropsystems/M1273.html (accessed May 11, 2013).

Raper, R. L.; Reeves, D. W.; Burmester, C. H.; Schwab, E. B. (2000) Tillage Depth, Tillage Timing, and Cover Crop Effects on Cotton Yield, Soil Strength, and Tillage Energy Requirements. *Appl. Eng. Agric.*, **16** (4),379–385.

SYLVIS (2009) The Biosolids Emissions Assessment Model (BEAM): A Method for Determining Greenhouse Gas Emissions from Canadian Biosolids Management Practices, Project No. 1432; Prepared for the Canadian Council of Ministers for the Environment; SYLVIS: New Westminster, British Columbia, Canada.

Tian, G.; Granato, T. C.; Cox, A. E.; Pietz, R. I.; Carlson, C. R.; Abedin, Z. (2009) Soil Carbon Sequestration Resulting from Long-Term Application of Biosolids for Land Reclamation. *J. Environ. Qual*., **38,** 61–74.

Trlica, A. (2010) Mitigation of Climate Change Through Land Reclamation with Biosolids: Carbon Storage in Reclaimed Mine Soils, Life Cycle Analysis of Biosolids Reclamation, and Ecosystem Services with Reforestation. Master's Thesis, University of Washington, Seattle, Washington.van den Born, G. J.; de Haan, B. J.; Pearce, D. W.; Howarth, A. (2000) *Technical Report on Soil Degradation*; RIVM Report No. 481505018. http://ec.europa.eu/environment/enveco/priority_study/pdf/soil.pdf (accessed May 11, 2013).

Water Environment Federation; National Biosolids Partnership (2011) *Charting the Future of Biosolids Management.* Water Environment Federation: Alexandria, Virginia. www.wef.org/cfbm_finalreport/ (accessed May 11, 2013).

Section 4

Energy Recovery

Because the energy contained in wastewater and biosolids exceeds the energy needed for treatment by a factor of 10, energy neutrality isn't just a pipe dream. It is a challenging, yet reachable, goal when wastewater facilities are designed and operated for this objective through a combination of energy efficiency best practices and energy production technologies. Solids treatment provides the greatest potential for energy recovery and production, with the chemical energy embedded in biosolids greater than the energy needed for treatment. Recovering that energy is an opportunity for wastewater utilities to reduce costs and increase sustainability. Recognizing this potential, the number of utilities recovering energy is growing rapidly; today, nearly 300 of the more than 1200 WRRFs equipped with anaerobic digestion convert their biogas to electricity (Beecher and Qi, 2013).

The expanded resource recovery potential of biosolids is reflected in the North East Biosolids and Residuals Association's (NEBRA) definition of beneficial use:

> *"Putting a particular biosolids product to its best and highest use by maximizing the utilization of nutrients, organic matter, moisture and/or other qualities – including extracting the maximum amount of energy possible."*

This chapter focuses on energy recovery. It presents the extensive menu of technologies available to optimize, extract, and use energy from biosolids, their benefits and limitations, and research and implementation initiatives that are needed to realize biosolids' energy potential.

Drivers

Energy is the second or third most expensive item in a wastewater utility's operations and management budget. Any effort to reduce purchased energy requirements benefits the utility by not only lowering operational costs, but also by decreasing its carbon footprint and increasing the sustainability of the operations. The impacts go beyond the utility; when a utility decreases its net energy use, the local and national communities also benefit from increased energy security and fewer greenhouse gas emissions. The following figure illustrates the numerous factors driving utilities to reduce their net energy demand.

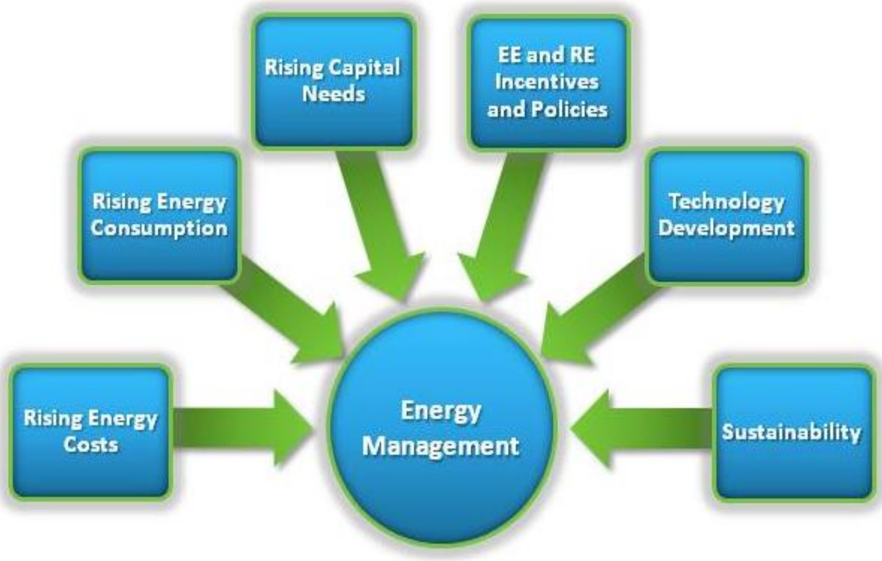


Figure 11: Factors driving utilities to reduce net energy consumption (Fillmore et al., 2011)

Energy in Wastewater and Biosolids

As noted earlier, the energy contained in wastewater and biosolids has been estimated to exceed the energy needed for treatment by a factor of 10. Based on this premise, WERF has developed an initiative to achieve net-zero energy in WRRFs.

The energy contained in wastewater and biosolids exceeds the energy needed for treatment by a factor of 10.

The energy in wastewater exists in three forms: thermal energy, hydraulic energy, and chemical or calorific energy. The following table illustrates the energy content of wastewater. **Thermal energy** is controlled by the temperature of the wastewater entering the plant. Heat can be recovered from the raw influent using heat exchangers and the resulting low-grade heat energy can be used to satisfy some of the building and process heating needs of the plant. **Hydraulic energy** is the energy of the moving water. Low head turbines on gravity flow can be used to convert kinetic energy into electricity (WERF Fact Sheet, 2012).

Constituent	Value	Unit
Average heat in wastewater	41,900	MJ/10 °C•$10^3 m^3$
Chemical oxygen demand (COD) in wastewater	250–800 (430)	mg/L
Chemical energy in wastewater, COD basis	12–15	MJ/kg COD
Chemical energy in primary solids, dry	15–15.9	MJ/kg TSS
Chemical energy in secondary biosolids, dry	12.4–13.5	MJ/kg TSS

Table 8: Energy in wastewater (Tchobanoglous and Leverenz, 2009)

The embedded **chemical energy** in wastewater is on average 2-10X times the energy needed for treatment, with the values ranging from 0.4 to 6.3. In many cases, recovering the chemical energy in solids alone is sufficient to achieve energy neutrality.

Energy in Biosolids

There are many opportunities to convert the chemical energy in solids to a useable form (heat or fuel) through biological or thermal processes. Biosolids typically contain approximately 6500 to 9500 British thermal units per pound (Btu/lb) on a dry weight basis (2.3 kWh/lb), which is similar to the energy content of low-grade coal. The following table shows a comparison of the energy in biosolids to the energy in other fuels. For comparison, the average daily residential energy use in the U.S. is 31 kWh per home, which would require the energy equivalent of 13.4 lb of dry biosolids (Stone et al., 2010).

Fuel	Energy (Btu)
1 lb dry biosolids	8000
1 kWh electricity	3412
1 cu ft natural gas	1028
1 cu ft biogas	600–700

Table 9: Biosolids energy in perspective (Stone et al., 2010)

Energy Optimization and Recovery Technologies

Energy recovery options range from mature, well established systems, such as anaerobic digestion and incineration to emerging technologies, such as SCWO and hydrothermal gasification. This section provides a description of optimization and recovery technologies, including advantages and disadvantages, and the current status of each technology (stated as embryonic, innovative, or established).

Bioconversion: Anaerobic Digestion

The bioconversion of biosolids energy is typically accomplished using anaerobic digestion. In high rate anaerobic digestion (AD), the readily biodegradable portion of the volatile solids in sludge is converted into biogas by microorganisms in the absence of oxygen. The biogas is composed primarily of methane (60 to 65%) and carbon dioxide (30 to 40%), with small concentrations of nitrogen, hydrogen sulfide, and other constituents. The methane portion of the biogas is a valuable fuel and, with conditioning, can be used in place of natural gas for many energy needs.

As shown in a recent WEF Survey (Beecher and Qi, 2013), approximately 10% of all U.S. WRRFs employ this process. Section 8 provides additional information on the WEF survey. Anaerobic digestion is more common in plants larger than 5 mgd.

There are a variety of technologies to recover energy from the biogas generated by AD systems, as well as multiple uses for that gas.

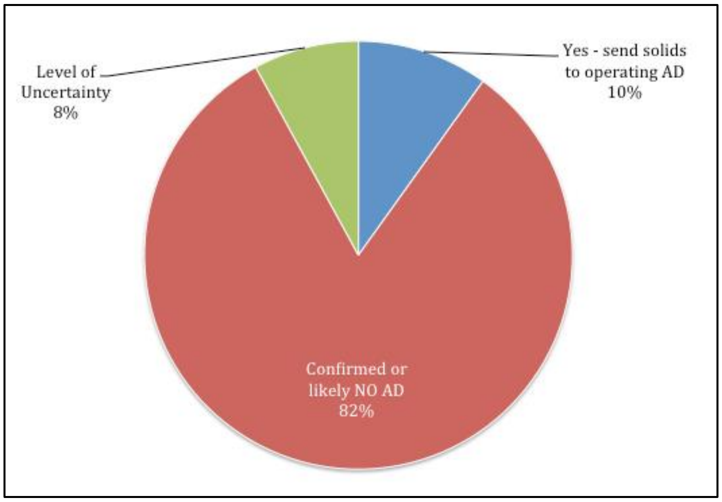


Figure 12: Percentage of facilities sending solids to AD, including an indication of the level of uncertainty in the survey data (comparing WEF 2012 survey data to Clean Watershed Needs Survey [CWNS], 2008, total WRRFs)

Maximizing Biogas Production

Biogas production through anaerobic digestion is limited to conversion of the readily biodegradable portion of the solids. To overcome this limitation, and thus maximize biogas production, pretreatment processes and co-digestion have become rapidly growing practices in recent years. Pretreatment processes break open the bacterial cells in the waste activated solids (WAS), releasing the cell contents, making them available to the anaerobic bacteria for conversion to biogas. Co-digestion, on the other hand, consists of adding readily biodegradable feedstocks directly into the digester, to co-digest them with the biosolids. FOG, for example, are readily biodegradable by anaerobic bacteria. Other high-strength wastes can also be co-digested to increase biogas production. Co-digestion of high-strength wastes and digester pretreatment technologies are discussed in the following sections.

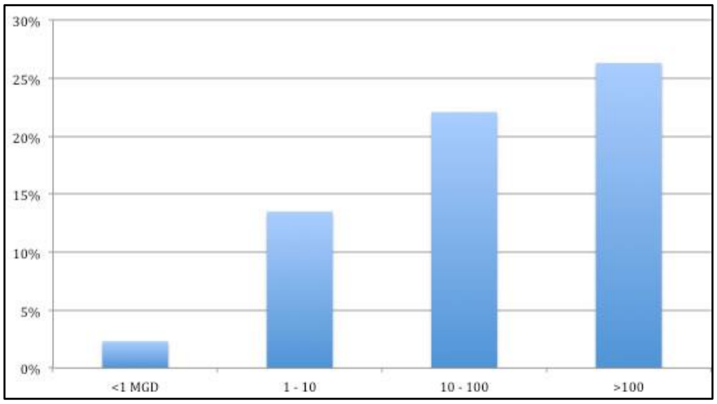


Table 10: Percentage of facilities of different flow sizes that send solids to AD (based on total number of U.S. WRRFs in each size grouping according to CWNS, 2008)

Co-Digestion

Co-digestion of high-strength wastes in anaerobic digesters has been a rapidly growing practice to meet WRRF goals of maximizing biogas production for energy recovery. Approximately 17% of U.S. WRRFs with anaerobic digestion take in outside wastes and feed them directly into the digesters. FOG is the most common high-strength organic waste co-digested with biosolids. High-strength wastes from food processing, breweries, cheese production, animal farming, biodiesel production, and de-icing operations (glycols) can also be co-digested to increase biogas production in anaerobic digesters with spare capacity. Aside from increased biogas production, the plant benefits from the tipping fees that can be charged for the service of processing the waste.

Since co-digestion increases biogas production, it can improve the economies of scale for on-site power generation, especially at small facilities. At the Village of Essex Junction Wastewater Treatment Plant in Vermont, co-digestion improves biogas production, allowing this small 2-mgd plant to run a successful combined heat and power (CHP) system. Fueling two 30-kW microturbines with biogas, the plant has reduced its electricity costs by 30% and is receiving renewable energy credits (RECs) for the electricity it generates (Willis et al., 2012).

> *"DC Water chose to implement an innovative technology and is building a thermal hydrolysis system that will be the first in North America and the largest in the world. This decision, along with the choice to go with a design-build model to compress the schedule and the calculated future savings ($28 M/yr) has given our board the confidence to fund this discretionary project and set a precedent for renewable energy production, resource recovery, and sustainability."*
>
> *– Chris Peot, Biosolids Manager at DC Water*

Digestion Pretreatment

Digestion pretreatment processes improve the digestibility by making internal cellular matter of biological solids more available for digestion. This increases the volatile solids reduction (VSr) achieved in anaerobic digestion and consequently increases the biogas production. Since pretreatment typically results in little improvement in digestion of primary solids, many of these processes are applied only to the WAS portion. Pretreatment processes modify the microbial cells by making the cell walls "leaky" or by completely lysing (breaking apart) the cells.

Pretreatment technologies include thermal hydrolysis (THP) (Cambi, Biothelys, Exelys), sonication, mechanical disintegration (Crown Biogest. MicroSludge), and electrical pulse treatment (OpenCEL). Pretreatment technologies have the potential to more than double the readily biodegradable fraction of the volatile solids (VS), resulting in a 30 to 60% increase in biogas production compared to digestion without pretreatment. With the exception of thermal hydrolysis, most digester pretreatment technologies are relatively simple and have small footprints, making them fairly easy to retrofit into an existing facility. A summary of pretreatment technologies is presented below.

	THP	Sonication	Crown Biogest	Micro Sludge	OpenCEL
Development Status	Established	Innovative	Established	Innovative	Innovative
Reported Improvement in VSr and Biogas Production	Yes	No	Yes	No	Yes
Complexity	High	Low	Low	Medium	Low
Dewatering Benefits	Yes	No	Unknown	Unknown	Yes
Class A Product	Yes	No	No	No	No

Table 11: Comparison of digester pretreatment technologies (from Qi, 2011)

Cost estimates for the various technologies are based on vendor-provided information for thermal hydrolysis, Crown Biogest , and OpenCEL treatment. MicroSludge estimated costs are based on information from literature (Gary et al., 2007). Costs are based on equipment costs only.

Thermal Hydrolysis (THP)

Thermal hydrolysis involves injecting steam at high temperature and pressure to rupture cells and improve the conversion of organic matter to biogas in the digestion process. THP is a proven and reliable technology with full-scale installations that date back to 1995. There are 24 installations of the Cambi® THP system in Europe and the UK. There are five installations of the Veolia process (marketed under the Biothelys name) in operation or under construction in

Europe, with the oldest installation in operation since 2004. In addition, there is one Exelys installation. With a total of 30 facilities, THP is a well-established pretreatment technology.

Based on THP experience in Europe, digesters receiving THP-treated solids can operate at higher organic loading rates than conventional digestion, significantly reducing the tank volume required for digestion. The digesters achieve VSr of 60% or greater, and biogas production increases by 20 to 30%. The THP conditioning significantly improves the dewaterability of the biosolids after digestion, producing a drier cake. The drier cake and the improved VS destruction result in a substantial reduction in the volume of biosolids, providing plants significant annual hauling and land application cost savings. Lastly, bench scale testing has shown that THP biosolids cake has a lower odor production than digested biosolids from non-THP systems. The largest drawbacks of THP are its high capital cost and operational complexity. THP is the most complex of the digester pretreatment technologies, mainly because of the high-pressure reactors.

DC Water's Blue Plains Advanced Wastewater Treatment Plant is installing the first thermal hydrolysis plant in North America. The biogas from the digestion process downstream of thermal hydrolysis will produce 10 MW net energy when the system comes online in 2015, meeting nearly one-half of the plant's total power demand. This will reduce DC Water's carbon footprint by 40% (Willis et al., 2012).

Sonication

Ultrasound is sound above the range of human hearing, with frequencies between 20 kHz and 10 MHz. At these frequencies, sound waves produce microbubbles, which then collapse (a phenomenon known as cavitation), causing high mechanical shear forces that can disintegrate bacterial cells.

There are several full-scale installations of the technology in Europe, but none in the U.S. to date.

Sonication tests in the U.S. have shown inconsistent results. At the Orange County Sanitation District, sonication increased biogas production by 50%, while at the Joint Water Pollution Control Plant in Los Angeles County, tests showed a 1% increase in VSr and 7.9% increase in biogas production (Gary et al., 2007).

Crown Biogest

The Crown disintegration system is a mechanical cell lysing system consisting of a high-speed mixer, a homogenizer, two progressive cavity pumps, a recirculation tank, and a disintegration nozzle. Pressurized solids are forced through a disintegration nozzle, resulting in a sudden pressure drop that causes cavitation. The shear forces resulting from the implosion of the microbubbles cause the cell walls to rupture.

Pretreatment through the Crownsystem appears to improve solids destruction and biogas production during anaerobic digestion, as well as reduce foaming potential by disrupting filamentous bacteria. There are 21 Crowndisintegration system installations, mostly in Germany and one in New Zealand. The first installation in the U.S. has been contracted by the City of Visalia, CA.

MicroSludge

The MicroSludge process uses caustic solution to weaken the bacterial cell walls, followed by screening and high-pressure homogenization (cell disrupters). The cell disrupters are high-pressure positive displacement pumps that force the solids through a valve, causing a sudden pressure drop. The pressure drop results in cavitation, which ruptures the cell membranes. Because it is a combined physical and chemical pretreatment process, MicroSludge is relatively complex.

The first full-scale MicroSludge plant was installed at the Chilliwack Wastewater Treatment Plant, near Vancouver, British Columbia, in 2004. Following pretreatment, the average VSr improved from 40 to 50% to 78%. The technology has since been tested on a pilot scale at the Los Angeles County Sanitation District's Joint Water Pollution Control Plant and at the Des Moines, Iowa, Wastewater Treatment Plant. The Los Angeles testing indicated only a slight increase in biogas production – of less than 5% (Gary et al., 2007). There are currently no full-scale systems in operation.

OpenCEL

OpenCEL is a physical pretreatment technology that uses pulsed electric field technology to disrupt cell walls. The applied electric field disrupts the lipid layer and proteins in the cell membranes, making the cell wall porous, eventually causing rupturing and release of intercellular material for better digestion.

The first full-scale installation of OpenCEL will start up in early 2013 at the 22-mgd Racine Wastewater Treatment Plant in Wisconsin. A second full-scale installation is under construction in Riverside, CA, and is expected to start up in 2014. A demonstration system has been in operation since 2007at the Mesa Northwest Water Reclamation Plant in Arizona.

Biogas Use

The biogas generated by AD systems is an extremely versatile fuel and can replace natural gas for heating and power generation needs. According to the WEF Biogas Survey, as of 2012, 85% of the WRRFs with AD beneficially used their biogas. Beneficial use as heat for process needs or conversion to electricity or fuel was found to be more common in larger plants, with more smaller plants burning generated biogas in flares. Biogas has long been used to fuel boilers for process heat, such as for anaerobic digestion. As shown in the figure below, about one-half of WRRFs use their biogas for digester heating, either directly through combustion in a boiler, or through recovery of waste heat from another process, such as CHP systems. The figure also shows other biogas uses employed at WRRFs.

> *85% of WRRFs with anaerobic digestion beneficially use their biogas.*
>
> *WEF, 2012*

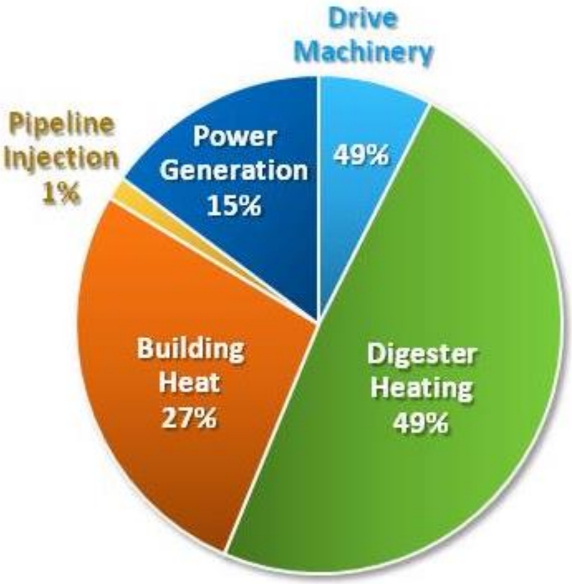


Figure 13: How common each use of biogas is at U.S. WRRFs with operating anaerobic digestion (Beecher and Qi, 2013)

The following sections describe in more detail the various uses of biogas as a renewable fuel.

Heat/Boiler

Heat recovery is by far the most common use of biogas, with a majority of facilities using biogas in boilers or recovering heat from CHP to heat digesters and/or buildings. The primary use of biogas at most facilities is digester heating. Biogas production is usually more than adequate for digester heating needs for all but the coldest months in colder climates; surplus biogas is often available during most months. Surplus gas can be used for building heat or other needs, including thermal drying or CHP. Surplus biogas can also be used in absorption chillers to cool buildings during the summer.

Combined Heat and Power (CHP)

With increasing fuel costs and sustainability concerns, many plants are trying to maximize the use of biogas in place of purchased energy. Increasingly, plants are using biogas in CHP systems to generate electricity from the biogas. Waste heat from the prime mover (turbine or engine) is used in the treatment processes or for building heat. The WEF Biogas Survey confirmed that 270 out of 1238, corresponding to 22%, of plants with anaerobic digestion use their biogas to generate power. This number is almost three times that reported by the U.S. EPA Combined Heat & Power Partnership (U.S. EPA – CHPP, 2011); that estimate was 104. Power generation from biogas is particularly attractive in areas with high electricity rates.

	Internal Combustion Engines	Combustion Gas Turbines	Micro Turbines	Fuel Cells	Stirling Engines
Development Status	Established	Established	Established	Emerging	Established
Size (kW)	110–3700	1200–4700	30–250	200–1200	~15–43
Electrical Efficiency (%)	30–42	26–37	26–30	36–45	~27
Thermal Efficiency (%)	35–49	30–52	30–37	30–40	~48
Equipment Cost ($/kW)	465–1600	1100–2000	800–1650	3800–5280	4000–10000
Maintenance Cost ($/kWh)	0.01–0.025	0.008–0.014	0.012–0.025	0.004–0.019	N/A
Biogas Cleaning Requirements	Medium	Low	High	High	Low
Emissions	Medium	Low	Low	Low	Medium

Source: Arespachaga et al., 2012, for Stirling engine data; Wiser et al., 2012, for IC engine, gas turbine, microturbine, and fuel cell data.

Table 12: Comparison of CHP technologies

Many CHP technologies are available. Some established technologies, such as microturbines, are available in smaller capacities suitable for a range of WRRF sizes. The WEF survey found that 88% of the 292 WRRFs using biogas for CHP use either internal combustion engines or microturbines. Other CHP technologies, such as combustion gas turbines, are only economically feasible at the largest plants and are used by only 7% of WRRFs. Some locations with strict air quality regulations have turned to fuel cells (5% of WRRFs), with their clean emissions; however, current fuel cell economics often require financial incentives to make this technology attractive.

In addition to current CHP technologies, innovative technologies may become competitive in the future by reducing the need for biogas cleaning prior to use, therefore reducing overall complexity and equipment cost. Established and innovative CHP technologies are described in the following sections.

Internal Combustion Engines

Internal combustion (IC) engines are the most widely used CHP technology. They are often the most economical CHP technology for WRRFs and have combined electrical and heat recovery efficiencies higher than any other currently available CHP technology. Heat can be recovered from the engine jacket water and from the exhaust gas. The available size range for IC engines matches biogas production rates of most WRRFs. The technology is reliable and available from a number of reputable manufacturers. IC engines are less sensitive to biogas contaminants than most other CHP technologies, reducing the gas cleaning requirements; however, cleaning is recommended to remove moisture, hydrogen sulfide, and siloxanes. One disadvantage of IC engines is their relatively high emissions, as compared to other CHP technologies, such as microturbines and fuel cells. IC engine emissions can cause permitting difficulties in areas with strict air quality limits and may require additional emissions control, such as selective catalytic reduction to meet emission requirements.

Most IC engines installed since 2005 are lean-burn engines, with higher fuel efficiency and lower emissions than rich-burn engines, which were more commonly used before the 1970s. IC engine technology continues to improve. In 2001, national research laboratories, in collaboration with three large engine manufacturers, received contracts from the U.S. Department of Energy (DOE) to make further improvements to lean-burn engines. This resulted in a new generation of engines with even lower emissions and higher fuel efficiency (Wiser et al., 2012).

Combustion Gas Turbines

Combustion gas turbines are often a good fit for the largest WRRFs. Like IC engines, combustion gas turbines are a reliable, well-proven technology available from several manufacturers. Large WRRFs in the U.S. use biogas-fueled combustion gas turbines for CHP. Heat can be recovered from the exhaust gas. Combustion gas turbines are relatively simple, containing few moving parts, and consequently requiring little maintenance. While infrequent, the maintenance of combustion gas turbines requires specialized service (Wiser et al., 2012).

The 370-mgd DC Water Blue Plains WRRF is installing combustion gas turbines that will produce 10 MW net energy, providing energy for nearly one-half of the plant's total power demand. A rendering of the digester pretreatment and CHP system is shown below (CDM Smith, 2012).

Figure 14: Cambi thermal hydrolysis and gas turbine CHP system at the Blue Plains facility

Microturbines

As the name suggests, a microturbine is a much smaller version of a combustion gas turbine. Microturbine capacities range from 30 to 250 kW and are often a good fit for smaller WRRFs with anaerobic digestion. Microturbines are relatively new, introduced about 15 years ago. Despite their somewhat recent development, microturbines have become the second most widely used CHP technology at WRRFs due to their small capacity and clean emissions. However, microturbine electrical efficiency is considerably lower than that of IC engines. Microturbines require relatively clean fuel, increasing the performance requirements and cost of biogas treatment, but their exhaust emissions are among the lowest of all CHP technologies. Microturbines are currently available from two manufacturers (Wiser et al., 2012).

The Sheboygan Regional Wastewater Treatment Plant in Wisconsin has been successfully operating microturbines since 2006. The 10.5-mgd plant started with a generation capacity of 300 kW in 2006. In 2010, the plant added an additional 200 kW in order to use the increased biogas production resulting from their co-digestion program. The Sheboygan CHP installation is an example of positive collaboration with the electric utility. With the goal of adding biogas to their renewable energy portfolio, the local, privately owned power utility funded 80% of the capital cost of the microturbines (Willis et al., 2012).

Figure 15: Microturbine installation at the Sheboygan Regional facility

> *"With energy costs increasing each year, we were actively looking at different ways to reduce our total energy cost. Since we were wasting excess biogas, it became evident that we could use it as fuel for microturbines and reduce our energy costs."*
>
> *– Dale Doerr, Wastewater Superintendent,*
> *City of Sheboygan*

The Combined Heat & Power Partnership (CHPP) has estimated that additional capacity for biogas generation at U.S. WRRFs could generate up to 400 additional MW of electricity (although their estimate was based on an underestimate of current electricity production at such facilities). CHPP equations indicate that 400 MW could provide the electricity for 300,000 homes. (Speaking practically, however, electricity generated at WRRFs is usually used most cost-efficiently to offset WRRF electricity use, saving other grid electricity for powering homes.) By any measure, the potential for future growth of CHP at WRRFs is significant.

Fuel Cells

Fuel cells are unique in that they do not combust biogas to produce power and heat. Instead, fuel cells convert chemical energy to electricity using electrochemical reactions. Their benefits include high electric efficiency and extremely clean exhaust emissions. However, fuel cells are one of the most expensive CHP technologies in terms of both capital and operation and maintenance (O&M) costs. In addition, they are extremely sensitive to impurities in the biogas, requiring the highest level of biogas cleaning of all CHP technologies. For these reasons, fuel cell installations are typically limited to locations with strict air quality regulations and fuel cell-specific grants or incentives. For example, several installations in California have benefited from the Self-Generation Incentive Program, which subsidizes the capital cost of fuel cells by $4,500/kW. Fuel cells suitable for use with biogas are currently available from only one manufacturer (Wiser et al., 2012).

Stirling Engines

While Stirling engine technology is established, their application to biogas is innovative. There has been increased interest in this CHP technology in recent years due to its reduced biogas cleaning requirements. A Stirling engine is an *external* combustion process. Biogas is combusted outside of the prime mover. The heat generated by the combustion process expands a working gas (generally helium), which moves a piston inside a cylinder. Because combustion occurs externally to the cylinder and moving parts, very little biogas cleaning is required (Arespachaga et al., 2012).

A 35-kW Stirling Engine has been running on biogas at the Niederfrohna Wastewater Treatment Plant in Germany since 2010. Despite the biogas being rich in siloxanes, only sulfur and moisture removal are required (Stirling DK, 2012). In the U.S., a 43-kW Stirling Biopower demonstration facility has been operating since 1995 in Corvallis, Oregon (Arespachaga et al., 2012).

Figure 16: Stirling engine installation at the Niederfrohna facility in Germany

Biogas Upgrading

Currently, only 1% of the biogas beneficially used is upgraded to natural gas quality for injection to the natural gas transmission system. Biogas is also upgraded to compressed natural gas (CNG) for use as fuel for CNG vehicles.

Pipeline Injection

Pipeline quality biogas has extremely low concentrations of contaminants and must be compressed to match the natural gas transmission line pressure. Biogas contaminants that must be removed include foam, sediment, water, siloxanes, hydrogen sulfide, and carbon dioxide. Technologies used for removal are listed in the following table. Following cleaning, biogas must be compressed for pipeline injection.

Contaminant	Removal Technology
Moisture	Water chiller
Siloxanes	Activated carbon vessels
Hydrogen sulfide	Vessel with iron sponge or proprietary media
Particulates	Particulate filters
Carbon dioxide	Pressure swing absorption, cryogenic, membrane

Table 13: Biogas treatment technologies

Biogas cleaning to pipeline quality has high capital and O&M costs. In most situations, generation of pipeline quality biogas is not cost-competitive with CHP. This biogas use is a better fit for large WRRFs (to take advantage of economies of scale) that are near a natural gas pipeline. If financial incentives are available, pipeline injection can become attractive. As of 2008, there were at least four WRRFs cleaning biogas to pipeline quality in the U.S.: San Antonio, Texas; Newark, Ohio; Dayton, Ohio; and Renton, Washington.

CNG or LNG Vehicle Fuel

Biogas can be upgraded to displace CNG or liquid natural gas (LNG) in vehicles capable of using these fuels. In Europe, upgrading biogas to fuel vehicular fleets is an established practice. In the U.S., there are only a few installations. Purity requirements for vehicular fuel are lower than those for pipeline injection. The biggest barriers to CNG or LNG conversion are the lack of a widespread infrastructure for gas filling stations and the cost of vehicle conversion for CNG or LNG use.

Small-scale packaged CNG conversion systems and filling station equipment are available from a single manufacturer and includes sulfur removal in a vessel with proprietary media, siloxanes removal in an activated carbon vessel, and membrane carbon dioxide removal. There are currently three biogas CNG installations in the U.S.: the Dane County, Wisconsin, landfill; St. Landry Parish, Louisiana, Wastewater Treatment Plant; and the Janesville, Wisconsin, Wastewater Treatment Plant. Two more facilities are currently in design stage. The system in the photograph has a 50-scfm capacity and can produce up to 275 gasoline gallon equivalents per day (BioCNG, 2012).

Figure 18: BioCNG installation at Janesville, Wisconsin, facility (BioCNG, 2012)

Use of biogas in industrial processes

There are several examples of efficient use of biogas by industries sited in proximity to WRRFs. In these situations, biogas that is untreated or minimally treated is provided to an industrial facility that utilizes the gas in its processes. For example, the Des Moines Metropolitan Wastewater Reclamation Authority sells 40% of the biogas it produces from co-digestion of wastewater solids, FOG, and other high-strength organic residuals to a neighboring industrial facility (Greer, 2011).

Thermal Conversion

In contrast to biological conversion (anaerobic digestion), thermal conversion of wastewater solids can make use of all of the chemical energy embedded in the solids, regardless of degradation potential. While the theoretical energy available through thermal conversion is higher, a significant amount of the energy is used to drive off moisture in the incinerator feed, which is typically in the form of dewatered cake. Consequently, net energy recovery from incineration can be lower than experienced from anaerobic digestion. Biosolids generally need to be dewatered to 26 to 35% total solids (TS) to result in autogenous incineration, that is, incineration without the need of auxiliary fuel. Gasification is another thermal conversion technology that has gained interest in recent years for solids treatment. Before feeding biosolids to a gasifier, it is usually necessary to dry them to 80 to 90% TS. The need for drying, be it in the incinerator or in a dryer prior to a gasifier, reduces the potential net energy output of the system.

Given the high moisture content of wastewater solids, there has been much interest in developing innovative technologies for thermal conversion suitable to a liquid medium, such as SCWP or hydrothermal catalytic gasification. These technologies are in their early stages of development, but are promising in that they are developed for treatment of solids with solids concentrations ranging from 1 to 10% and allow the recovery of heat, nutrients, and marketable gases (SCWP) or syngas and nutrients (hydrothermal catalytic gasification).

The following sections describe thermal conversion technologies suitable to dewatered or dry solids: incineration, gasification, and pyrolysis, as well as the more innovative thermal conversion technologies suitable for a liquid medium. The equipment required for the three technologies is relatively similar. The difference among the technologies is the amount of oxygen available for the combustion reaction, which controls the oxidation of the fuel (solids). The incineration process uses excess oxygen, resulting in oxidation of all carbonaceous matter and generating ash. Gasification is performed in a sub-stoichiometric condition, with oxygen limited to 25% of the oxidation requirement. Pyrolysis is performed in a zero oxygen environment.

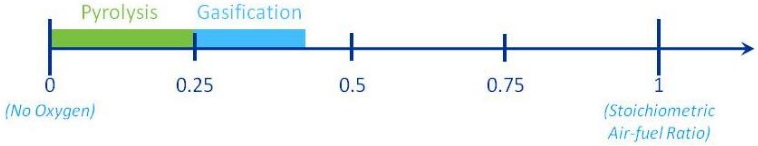


Figure 17: Thermal conversion oxygen requirements

Incineration

Incineration is the most established biosolids thermal conversion technology. It involves the complete oxidation of all organic material by applying heat in the presence of excess oxygen. The volatile fraction of the feed material is converted to hot flue gases, while the nonvolatile or inert fraction becomes ash. Thermal energy is often recovered from the high temperature flue gas and may be used to generate electricity using a steam turbine. The flue gas contains contaminants that must be removed prior to emission to meet regulatory limits; consequently, air pollution control devices are integral parts of incineration facilities.

Biomass + Excess O_2 → Heat + Ash

Incineration has been used for wastewater plant solids since the 1930s. Incineration is used throughout the world, with approximately 17 to 25% of solids produced in the U.S. incinerated. Biosolids generally need to be dewatered to 26 to 35%TS to support autogenous incineration. The dominant incineration technologies are multiple-hearth incinerators (MHI) and fluid bed incinerators (FBI). MHIs are being phased out in many areas in favor of more efficient FBIs.

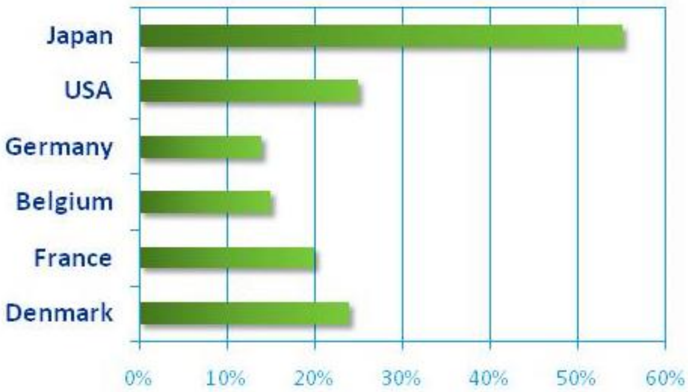


Figure 20: Prevalence of biosolids incineration

While sludge incineration has been practiced for almost a century, it is only in the last decade that energy recovery from incineration has become a well-established practice in the U.S. Forward-thinking utilities with incineration energy recovery systems include the Metropolitan Council of Environmental Services (MCES), the Northeast Ohio Regional Sewer District (NEORSD), the Metropolitan District of Connecticut (Hartford), and the Green Bay Metropolitan Sewerage District. MCES has operated 3 FBIs with energy recovery for a number of years; Hartford's incineration facility started up in 2013; the NEORSD incineration facility is about to be commissioned; and the Green Bay facility is in design phase.

The following figure shows a typical schematic of an energy recovery system. A portion of the heat available in the exhaust gases is first recovered in a primary heat exchanger to preheat the fluidizing air fed to the incinerator. Another portion of the heat is then recovered in a waste heat boiler, producing super-heated steam. The steam is then used to run a steam turbine, generating electricity. The electricity generated can be significant, with some installations generating about 50% of the total plant electricity usage.

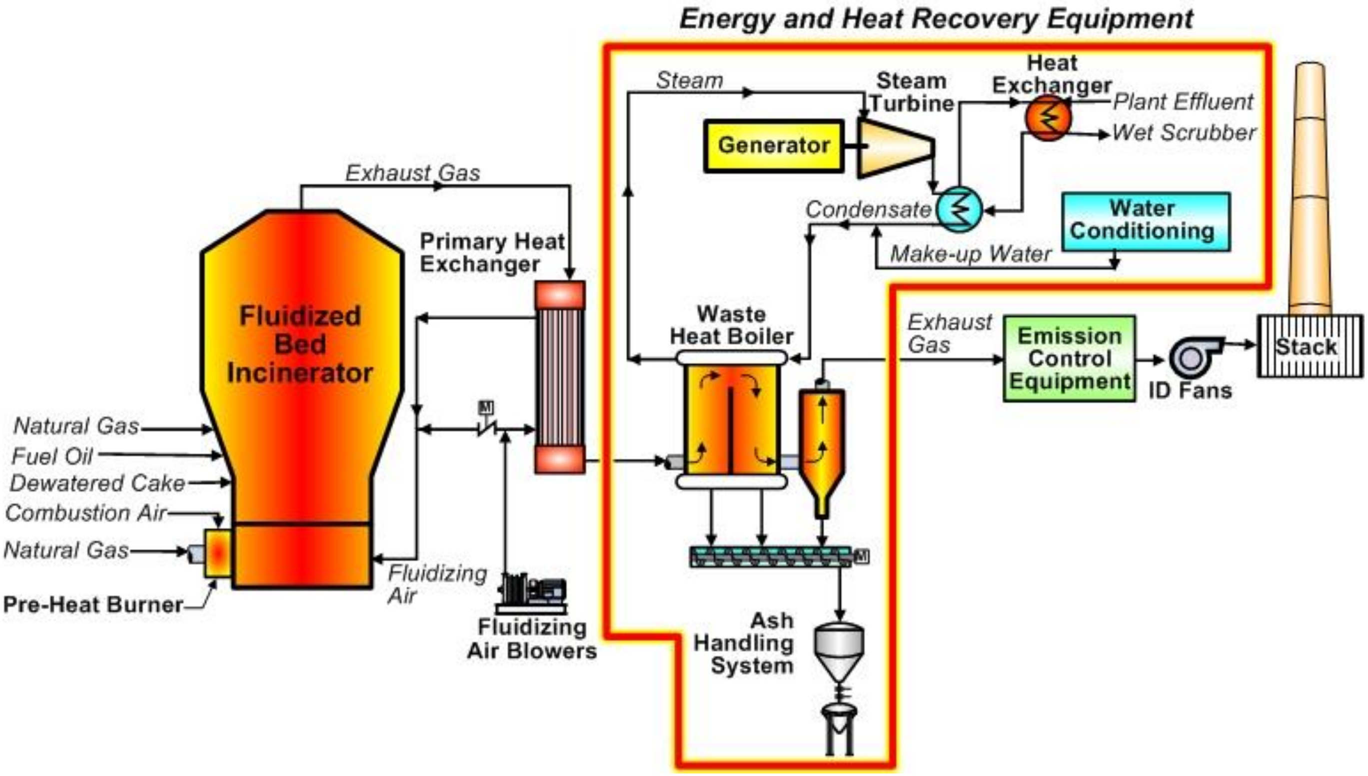


Figure 19: Energy recovery system schematic

The Hartford Water Pollution Control Facility in Connecticut is an example of one of the progressive utilities that are currently implementing power production from incinerator waste heat. The Hartford facility, an 80-mgd plant, processes dewatered solids in three MHIs, each rated at 2.5 dry tons per hour. Limited by air permit, the plant can only run two of the three incinerators at any one time. Exhaust gases from the incinerators are induced through the waste heat boilers to produce steam. The steam generated in the waste heat boilers is used to produce nearly 2 MW of electricity with a steam turbine-generator, which is equivalent to approximately 45% of the current plant demand.

The new incinerator energy recovery facility at the Hartford facility will produce 2 MW in a steam turbine from waste heat, providing approximately 45% of the current plant demand.

Off-site Co-Combustion

Instead of incinerating biosolids at the treatment plant, biosolids can be used to supplement or replace coal in cement kilns and coal-fired power plants. Biosolids must typically be dried to 90% TS or greater to make co-firing attractive to those industries.

Co-firing of dried biosolids is currently performed by the cement industry in a number of locations in Europe and in two locations in North America. Lehigh Cement owns a 2 million metric ton per year cement production facility in Maryland, which burns approximately 14,000 metric tons of dried biosolids annually, with plans to increase capacity to 36,000 metric tons per year. This represents approximately 3 to 5% of its average daily fuel use and is reported to have no adverse impacts to product quality (Maestri, 2009).

Gasification

Gasification is the thermal conversion of carbonaceous biomass into syngas, a gaseous fuel composed mainly of hydrogen and carbon monoxide, and impurities including carbon dioxide, water, methane, nitrogen gas, and tars. The conversion is accomplished by heating the biomass to temperatures of 500 to 1600 °C under pressures ranging from 1 to 60 bar in the presence of a controlled supply of oxygen (Yassin et al., 2005). Directly heated gasifiers are heated by combusting a portion of the feedstock. Alternatively, gasifiers can be indirectly heated with electric heating elements.

$$\text{Biomass} + \text{Limited } O_2 \rightarrow \text{Syngas} + \text{Heat} + \text{Ash}$$

While the gasification of biomass is a commercial technology with many installations worldwide, there are only a few commercial-scale biosolids gasifiers, making it innovative with respect to biosolids. The following table describes the existing commercial, demonstration, and testing biosolids gasification facilities.

Summary of Biosolids Gasification Facilities

Vendor	Installation	Dry lb/hr	Description
KOPF	Commercial facility in Balingen, Germany, operating since 2004	375	Solar-dried digested solids (75 to 85% solids) are fed to fluid bed gasifier. Gas is used in IC engines. Of the 0.5 kWh of electricity produced per kg of solids treated, 0.1 kWh is used to run the gasifier, and 0.4 kWh is used to displace electricity use of the WRRF.
Nexterra/ Stamford, Connecticut WPCA	Testing facility in Kamloops, Canada	1354	Thermally dried biosolids (93% TS) fed to fixed-bed updraft gasifier. Tested solids from Stamford, Connecticut, WPCA in 2009.
Maxwest	Commercial facility in Sanford, Florida, operating since 2009	1800	Dewatered solids are received from several plants at an average dryness of 16% TS. Solids are thermally dried and fed to a fluid bed gasifier. Syngas is combusted in a thermal oxidizer, from which heat is recovered to supply the dryer.
M2Renewables/ Pyromex	Demonstration facility in Emmerich, Germany, operating since 2009	83	Solids are dewatered mechanically to 55%, then thermally to 80%. Ultra-high temperature gasifier operates in the absence of oxygen. The source of oxygen and hydrogen for the syngas comes from the moisture in the feed. Gasifier is indirectly heated, producing high-quality syngas (63% hydrogen, 30% carbon monoxide)
Tokyo Bureau of Sewerage	Commercial facility in Kiyose, Japan, operating since 2010	8000	Thermally dried biosolids (80% TS) fed to a fluid bed gasifier. Heat from the syngas is recovered to dry the feedstock. Syngas is converted to motor power via an aeration blower or to electricity via an IC engine.

Source: Greenhouse Gas Technology Center, 2012.

The moisture in biosolids can make it difficult to gasify without the addition of energy. Before feeding biosolids to a gasifier, it is usually necessary to dry them to 50 to 90% TS, depending on the technology. Mechanical dewatering is preferred over heat drying, due to the high energy use of thermal drying. However, mechanical processes can only dewater to about 20 to 30% TS. The need for thermal drying reduces the potential net energy output of the system. The Maxwest facility in Sanford, Florida, for example, is not a net energy producer. The syngas supplies 80% of the energy for drying. However, if the dewatered cake concentration were increased from the current average of 16 to 23%, the gasification facility (but not the entire WRRF) would be energy neutral.

Pyrolysis

Pyrolysis is the thermal conversion of carbonaceous biomass in the absence of oxygen. Three products are generated through pyrolysis: a liquid fuel or bio-oil, a solid char, and combustible gas (Zhang et al., 2010). Pyrolysis processes are typically carried out at atmospheric pressure and temperatures ranging from 300 to 600 °C (Venderbosch and Prins, 2010). The temperature and reaction time affect product generation. Slow pyrolysis, which occurs at low temperatures and low heating rates, maximizes char production; fast pyrolysis, involving moderate temperatures, fast heating rates, and short residence times, maximizes bio-oil production (Yurtsever et al., 2009).

Similar to incineration, supercritical water oxidation (SCWO) is the complete oxidation of organic matter. The key difference is that SCWO occurs in supercritical water.

Biomass + no O_2 → Bio-oil + Char + Syngas + Ash

Three fast pyrolysis facilities have tested the production of bio-oil from biosolids, with two installations in California and one in Australia. However, all three have ceased operations. Additional development is necessary to address technology limitations and costs that currently limit commercial implementation. One slow pyrolysis process has been operating successfully in Japan since 2007 (Oda, 2007).

Thermal Conversion in Supercritical Water

The concept of applying thermal conversion to liquids is attractive, since it eliminates the need for moisture removal and therefore reduces process energy requirements. Supercritical water (SCW) is a state in which water behaves as both a gas and a liquid and occurs at high temperatures (greater than 374 °C) and pressure (greater than 221 bar). The gas-like properties of the SCW promote mass transfer, while the liquid-like properties promote solvation (dissolution). These properties, combined with high temperatures that increase reaction rates, result in a medium in which chemical reactions occur extremely rapidly.

Supercritical Water Oxidation

Supercritical water oxidation is the complete oxidation of organic matter. SCWO achieves high destruction efficiencies of organics (greater than 99.99%) in short reaction times (less than 1 minute). However, the properties that make SCW a good reaction medium can also be a disadvantage, increasing the potential for corrosion in the reactor.

The SCWO process has been used since the 1980s for military hazardous waste destruction. In the SCWO process, carbon is converted to carbon dioxide, hydrogen to water, and nitrogen to nitrogen gas or nitrous oxide. Inert, non-reactive materials remain as particulate matter. The effluent from the SCW oxidizer is fed to a cyclone that separates the particulate solids from the liquid. Heat can be recovered from the high-temperature, high-pressure liquid effluent for process needs or in a steam turbine to generate electricity. Carbon dioxide and nitrogen gas can be recovered as byproducts for commercial sale (Gidner and Stenmark, 2001; O'Regan, 2008).

The use of SCWO technology for biosolids applications is still in developmental stages. There are currently two operating biosolids SCWO facilities in the world, in Orlando, Florida, and in Ireland. The 1-dtpd facility in Ireland has been operating successfully since 2008. A second, larger (10-dtpd) facility has been installed in Ireland and is expected to start operating in 2014 (O'Regan, 2012).

Figure 21: Supercritical water oxidation facility in Cork, Ireland

Green Chemistry: KORE Infrastructure, LLC has operated a pilot project at a major WRRF in Southern California for the past four years that uses a thermo-chemical process to convert biosolids into market-ready, drop-in, No. 2 diesel fuel. This process uses pyrolysis to reduce biosolids by 90% and then utilizes the Fischer-Tropsch process to transform syngas into advanced biofuels without the use of outside energy. The KORE Infrastructure technology will lower the GHG profile of the wastewater utility by reducing truck traffic for biosolids disposal and offer other sustainable economic, environmental and community benefits.

Environmental Awards in the Pacific Southwest,
U.S. EPA 2012

Enabling Energy Recovery

Driven by rising energy costs and sustainability concerns, utilities are recovering previously wasted resources – flared biogas and waste heat – to increase their energy self-sufficiency. A variety of well-proven energy recovery technologies is available for on-site energy production, and innovative technologies are poised to expand the options. While the shift in the biosolids industry from waste disposal to resource recovery is already happening (albeit slowly), utilities face economic and regulatory barriers to implementing sustainable energy recovery systems. An economic and regulatory environment that facilitates and promotes energy recovery is needed to hasten this shift towards an economically and environmentally sustainable biosolids industry.

Barriers

Many of the barriers to energy recovery from biosolids are shared with the renewable energy industry at large. Primarily legislative and economic, these barriers are based on the enormous difficulties that come from having to **compete with the established fossil fuel industry**. Legislative support through consistent, reliable financial incentives could turn this around, giving renewable energies the opportunity to have a competitive starting point in the energy race. For biosolids in particular, the barriers can be higher. As noted earlier, federal and state legislation does not clearly **recognize biosolids as a renewable energy source**. This makes it difficult or impossible for biosolids-to-energy projects to benefit from existing state and federal renewable energy incentives.

A survey of over 200 wastewater treatment utilities conducted in 2011 by WERF and NYSERDA sheds light on the barriers to biogas use (Willis et al., 2012). While the survey focuses on biogas use, most of these barriers are common to those faced by other energy recovery technologies. The survey found that the most important barrier to biogas use was economic, related to higher priority demands on limited capital resources or to perceptions that the economics do not justify the investment. Of the 10 barrier categories introduced (see figure below), all but “complication with the liquid stream” were deemed significant. However, the economic barriers were dominant; given sufficient funding, the other barriers can be overcome. Strategies to overcome the barriers were developed during focus group meetings, and are shown in and highlighted at the end of this section. Section 8 contains further details on strategies identified at the meetings.

Initiatives and Research Needed

Government initiatives to incentivize energy recovery, continued research to further improve established technologies and develop new ones, and education and outreach efforts are necessary steps to maximize the renewable energy potential of biosolids. Recommended actions are listed below.

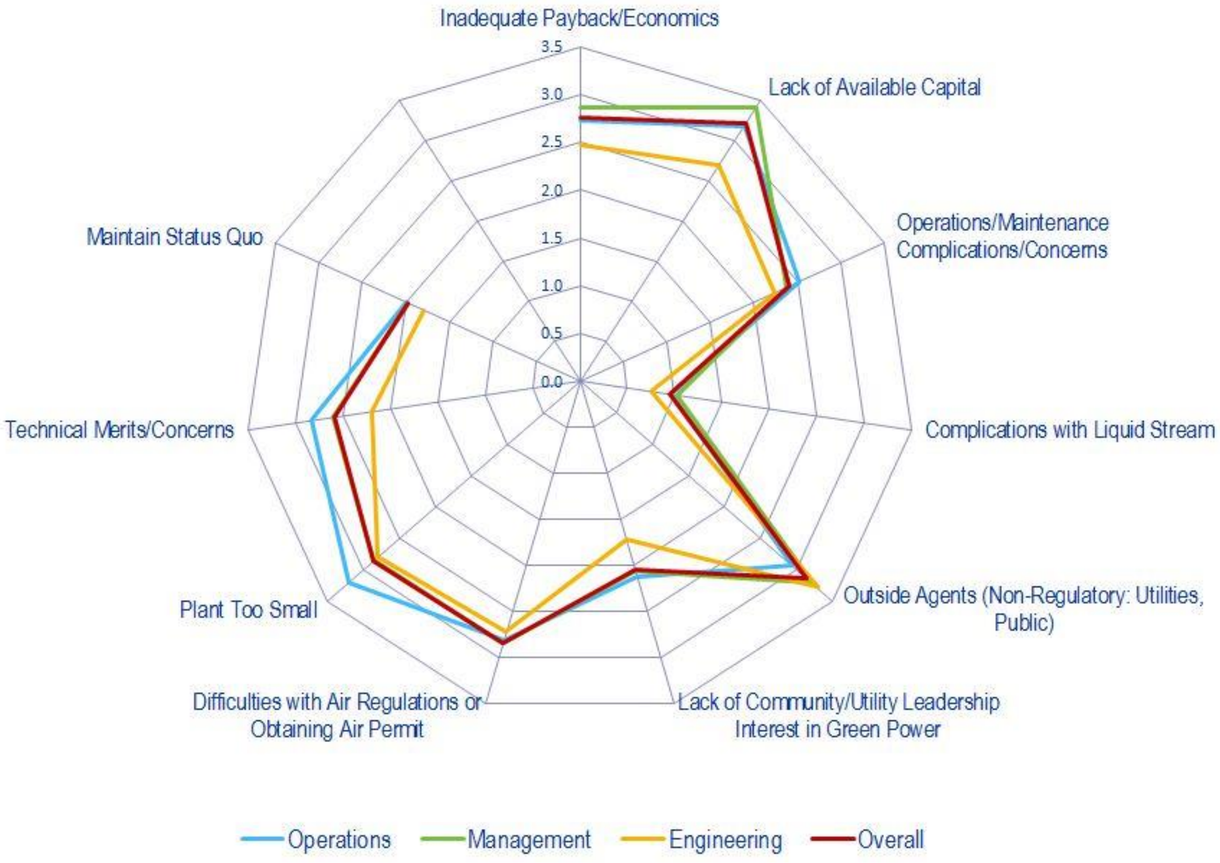


Figure 22: Key barriers to biogas use, as perceived by WRRF operators, managers, and engineers (Willis et al., 2012)

Government Initiatives

Government initiatives promoting new renewable energy technologies have the greatest potential to help wastewater utilities overcome the economic barriers to energy recovery. Three key initiatives are:

- Incentivize renewable energy generation by providing grants or RECs for biosolids-to-energy recovery projects.
- Put a price on carbon that accounts for the negative environmental and social effects of greenhouse gas emissions, as demonstrated by California and the European Union Cap-and-Trade programs.
- Support the WEF renewable energy statement to move biogas and biosolids to the DOE list of renewable energy.

Development of Analytical Tools

Energy recovery systems can be complicated. Tools to facilitate analysis of the mass and energy balances, greenhouse gas emissions, and life-cycle environmental and economic impacts can help prove and quantify their economic and environmental value.

- Develop an **economic analysis tool** that uses other financial evaluation methods in addition to simple payback.
- Update the University of Alberta **Flare Emissions Calculator** to include nitrogen oxides and carbon monoxide to document the relative performance of biogas flares compared to CHP technologies.
- Develop a comprehensive **Life-Cycle Analysis** tool for biosolids treatment processes, including all biological and thermal energy recovery technologies.

Outreach and Communications

An educated population is invaluable for acceptance and support of new technologies. Education efforts should focus first on the key decision-makers: regulators and utility managers. Develop active communications between stakeholders – wastewater utilities, power companies, regulators, and the general public – to ensure that the best solutions for all stakeholders are achieved. Recommended activities in this category include:

- Develop a **training course** to assist in the understanding of the benefits of energy recovery from biosolids, including a course specifically for decision-makers.
- Expand outreach and **information exchange** between the wastewater industry and power companies and natural gas utilities.

Primary Research

Primary research at academic and other institutions includes bench-scale and pilot studies to further understand and develop innovative technologies – and potentially discover new ones. Recommended activities include:

- Continue to quantify and define the **energy generation potential** from anaerobic digestion and thermal processes throughout the U.S.
- Promote research to develop **more efficient mechanical dewatering** technologies, so that the energy losses associated with drying solids prior to or during thermal oxidation processes can be minimized.
- Promote research into technologies that **increase the ratio of primary to secondary solids** by either minimizing production of waste activated solids or improving primary clarification. Primary solids are more readily biodegradable in anaerobic digestion.
- Promote research to identify **less-costly methods to achieve anaerobic digestion** and biogas production, so it can become more widely applicable, particularly to small WRRFs.
- Promote research on **innovative gasification and pyrolysis technologies**. Transfer lessons learned from biomass full-scale installations into the biosolids industry.
- **Follow performance and O&M cost data** for demonstration and full-scale installations of innovative technologies: digester pretreatment installations, advanced digestion, gasification, and SCWO.

Development and Maintenance of Databases

In addition, secondary research is needed to gather information and consolidate it into publicly available databases. Once developed, the databases require continued maintenance efforts to keep them up to date. The following database is needed:

- **High-strength waste database**, such as that developed by U.S. EPA Region 9, listing potential sources of high-strength waste (FOG, food waste, etc.) that could be used to boost biogas production. Support the expansion of the Region 9 database to the rest of the country.

References

Arespachaga, N.; Balseiro, C.; Bouchy, L.; Peregrina, C. (2011) *State of the Science on Biogas: Treatment, Co-generation, and Utilization in High Temperature Fuel Cells and as a Vehicle Fuel*; Water Environment Research Foundation and R+i Alliance: Alexandria, Virginia.

Beecher, N.; Qi, Y. (2013) *Biogas Production and Use at Wastewater Treatment Plants in the United States;* Water Environment Federation: Alexandria, Virginia; January.

BioCNG (2012) Janesville, WI BioCNG Vehicle Fuel Project Fact Sheet. www.biocng.us/wp-content/uploads/2013/03/janesville-fact-sheet.pdf (accessed May 11, 2013).

Fillmore, L.; Shaw, A.; Stone, L.; Tarallo, S. (2011) Energy Management – Towards Energy Neutral Wastewater Treatment. *Proceedings of the 84th Annual Water Environment Federation Technical Exhibition and Conference* [CD-ROM]; Los Angeles, California, Oct 16–19; Water Environment Federation: Alexandria, Virginia.

Gary, D.; Morton, R.; Tang, C.-C.; Horvath, R. (2007) The Effect of the Microsludge™ Treatment Process on Anaerobic Digestion Performance. *Proceedings of the 80th Water Environment Federation Technical Exhibition and Conference* [CD-ROM]; San Diego, California, Oct 13–17; Water Environment Federation: Alexandria, Virginia.

Gidner, A.; Stenmark, L. (2001) *Super Critical Oxidation of Sewage Sludge – State of the Art.* http://www.sswm.info/sites/default/files/reference_attachments/GIDNER%20and%20STENMARK%20ny%20Supercritical%20Water%20Oxidation%20of%20Sewage%20Sludge%20State%20of%20the%20Art%20.pdf (accessed May 11, 2013).

Greenhouse Gas Technology Center (2012) *Technology Assessment Report – Aqueous Sludge Gasification Technologies;* Greenhouse Gas Technology Center, Southern Research Institute: Research Triangle Park, North Carolina; January.

Greer, D. (2011) Codigestion and Cogeneration in Des Moines. *BioCycle*, **52** (2), 38.

Maestri, T. (2009) *The Use of Biosolids as a Renewable Fuel;* Chesapeake Water Environment Association Conference, June; Chesapeake Water Environment Association: Hunt Valley, Maryland.

O'Regan, J. (2012) Business Manager. Personal communication. Bishopstown, Cork, Ireland; December.

O'Regan, J.; Preston, S.; Dunne, A. (2008) *Supercritical Water Oxidation of Sewage Sludge—An Update*. 13th European Biosolids & Organic Resources Conference & Workshop. http://scfi.eu/korean/downloads/SWCOSludgeTreatment.pdf (accessed May 11, 2013).

Oda, T. (2007) Making Fuel Charcoal from Sewage Sludge for Thermal Power Generation Plant – First in Japan. *Proceedings of the 80th Annual Water Environment Federation Technical Exhibition and Conference* [CD-ROM]; San Diego, California, Oct 13–17; Water Environment Federation: Alexandria, Virginia.

Qi, Y. (2011) *OpenCEL Performance Evaluation;* Black & Veatch: Overland Park, Kansas.

Stirling DK (2012) Selected Reference: Wastewater Treatment Plant in Niederfrohna. Stirling DK Web site. http://www.stirling.dk/page_content.php?menu_id=55&type=submenu (accessed Dec 2012).

Stone, L.; Kuchenrither, R.; Quintanilla, A.; Torres, E.; Groome, M.; Pfeifer, T.; Dominak, R.; Taylor, D. (2010) *Renewable Energy Resources: Banking on Biosolids*; National Association of Clean Water Agencies: Washington, D.C.

Tchobanoglous, G.; Leverenz, H. (2009). *Impacts of New Concepts and Technology on the Energy Sustainability of Wastewater Management*. Conference on Climate Change, Sustainable Development, and Renewable Resources in Greece, Oct 17. http://www.novawt.com/References/IMPACTS%20Paper%20with%20Cover%20Sheet-2-1.pdf (accessed May 11, 2013).

U.S. Environmental Protection Agency – Combined Heat and Power Partnership (CHPP) (2011) *Opportunities for Combined Heat and Power at Wastewater Treatment Facilities: Market Analysis and Lessons from the Field*; U.S. Environmental Protection Agency: Washington, D.C.; October.

Venderbosch, R. H.; Prins, W. (2010) Fast Pyrolysis Technology Development. Biofuels. *Bioprod. Biorefin.,* 178–208.

Water Environment Federation; National Biosolids Partnership (2011) *Charting the Future of Biosolids Management.* Water Environment Federation: Alexandria, Virginia. www.wef.org/cfbm_finalreport/ (accessed May 11, 2013).

Water Environment Research Foundation (2012) *Fact Sheet – Energy Production and Efficiency Research – The Roadmap to Net-Zero Energy;* Water Environment Research Foundation: Alexandria, Virginia.

Willis, J.; Stone, L.; Durden, K.; Hemenway, C.; Greenwood, R. (2012) *Barriers to Biogas Use for Renewable Energy*; Water Environment Research Foundation: Alexandria, Virginia; NYSERDA: Albany, New York.

Wiser, J. R.; Schettler, J. W.; Willis, J. L. (2012) *Evaluation of Combined Heat and Power Technologies for Wastewater Treatment Facilities*: Columbus Water Works and Brown and Caldwell: Columbus, Georgia.

Yurtsever, D.; Rowan, J.; Santha, H. (2009) *Comparison of Gasification, Pyrolysis and Incineration Technologies for Residual Management: Future of Advanced Biosolids Processes.* WEF Residuals and Biosolids Conference*;* Water Environment Federation: Alexandria, Virginia; 80–91.

Zhang, L.; Xu, C. (Charles); Champagne, C. (2010) Overview of Recent Advances in Thermo-Chemical Conversion of Biomass. *Energy Convers. Manage.,* **51,** 962–982.

Section 5

Changing Perspectives: From Nutrient Removal to Nutrient Recovery

> *"Recovery of nutrients from wastewater can play an important role in integrated nutrient management strategies that maximizes reuse"*

Nitrogen (N) and phosphorus (P) are life essential nutrients that are extensively used for agricultural purposes. At present, the synthetic N and P fertilizers that are used for food production are produced through energy intensive processes that use nonrenewable resources (e.g., natural gas and phosphate rock).

These nutrients once incorporated into crops are ingested by animals and humans who in turn excrete nutrients into wastestreams. It has been estimated that up to 8% of nitrogen and 14% of phosphorus used in agriculture enter municipal WRRFs (Penuelas et al., 2012). To avoid the accumulation of these nutrients in the environment, we typically employ technologies to remove these nutrients from the wastestreams entering the WRRF. In this combined scenario, we supply energy and other nonrenewable resources to constantly replenish nutrient supply for agricultural uses and then further supply energy and nonrenewable resources to remove these nutrients from wastewater before discharge to the environment. This approach to nutrient use is unsustainable and must change to reflect the nonrenewable nature of the resources used for fertilizer synthesis.

As the nutrients in these wastestreams represent a renewable resource, recovery of nutrients into a useable form from wastestreams has emerged as a key component of sustainable approaches to managing global and regional nutrient use. Indeed, research has indicated that recovery of resources (e.g., water, energy, nutrients) from wastewaters has the potential to reduce energy consumption and improve treatment efficiency for municipal WRRFs (Shu et al., 2006; Mulder, 2003).

This shift to embrace nutrient recovery embraces the "fit-for-purpose" concept (Novotny et al., 2010), whereby all resources in water are harvested to meet current and future demands of our growing urban society. It also fits within the larger concept of integrated nutrient management approaches that emphasize reuse and can allow utilities to truly become resource recovery plants.

Nutrients can be recovered in biosolids, liquid streams, or as chemical nutrient products. In this chapter, we focus on reviewing the state of science regarding nutrient recovery technologies that produce chemical nutrient products devoid of significant organic matter content. We have denoted this approach as extractive nutrient recovery, to differentiate from accumulative nutrient recovery in which biosolids are used as the primary vehicle for nutrient recovery and reuse.

Challenges in Implementing Extractive Nutrient Recovery

Nutrient removal from wastewater represents a major demand on resources and expenses for WRRFs. For instance, electricity costs for aeration can account for between 30 and 80% of total electricity expenditure at WRRFs performing biological nitrogen removal (Willis et al., 2012). These needs are expected to increase as more stringent effluent nutrient limits are promulgated in the future.

As a result, development of alternative nutrient treatment strategies that allow for effective nutrient removal in a cost-effective manner is needed. Extractive nutrient recovery could represent an alternative strategy for managing nutrients during wastewater treatment. In this option, energy and resources are used to accumulate and produce a nutrient product that has value in a secondary market. Resale of this product can also potentially help plants offset operating costs. It should be acknowledged that nutrient recovery and reuse is not a new concept. It has been applied in different forms in the past (e.g., land application of biosolids and reuse of secondary effluent for irrigation); however, extraction of a chemical nutrient product with low organic matter content has not been widely applied within the wastewater treatment industry. The key barriers against adoption of this type of extractive nutrient recovery are summarized in the following figure. Lack of knowledge regarding the options available for performing nutrient recovery as well as the cost of installation and operation can limit more widespread adoption of the extractive nutrient recovery approach. Consequently, there is a need to improve the transfer of knowledge to help utilities make rational and informed decisions about implementation of extractive nutrient recovery.

> *"The 'fit-for-purpose' concept recognizes that all water is good water and there is only one water cycle."*

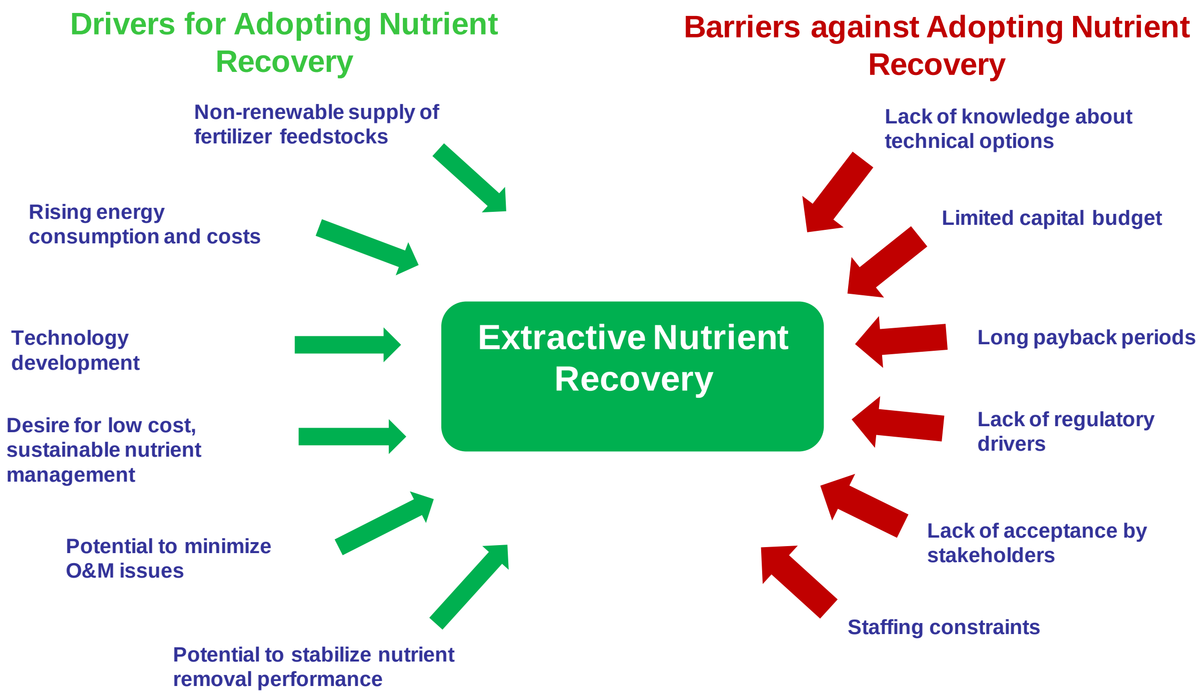


Figure 23: Drivers and barriers against adoption of extractive nutrient recovery at municipal WRRFs (from Latimer et al., 2012a)

Nutrients in Wastewater

The nutrient concentration in the influent to municipal WRRFs typically ranges from 10 to 50 mg N/L for N and from 1 to 10 mg P/L for P. As the nutrients progress through wastewater treatment, they can be removed in a gaseous form (N), accumulate in the solids (both N and P), or be discharged in the liquid effluent (both N and P). Since extractive nutrient recovery is most effective when nutrient concentrations are above 1000 mg N/L and 100 mg P/L, and when flows are relatively low, one primary opportunity to implement extractive nutrient recovery lies in the solids processing treatment train of a WRRF. This aligns with the existing strategy used to recycle nutrients through the production of biosolids. Indeed, extractive nutrient recovery can complement existing efforts in which biosolids are used as the primary means for nutrient recovery. However, in order to facilitate the adoption of extractive nutrient recovery as a separate process for managing nutrients in WRRFs, there is a need to develop multiple strategies that allow us to work with different concentrations and forms of nutrients at different points throughout the plant.

> *"There is no single technology that is perfectly suited for complete nutrient recovery from all scenarios."*

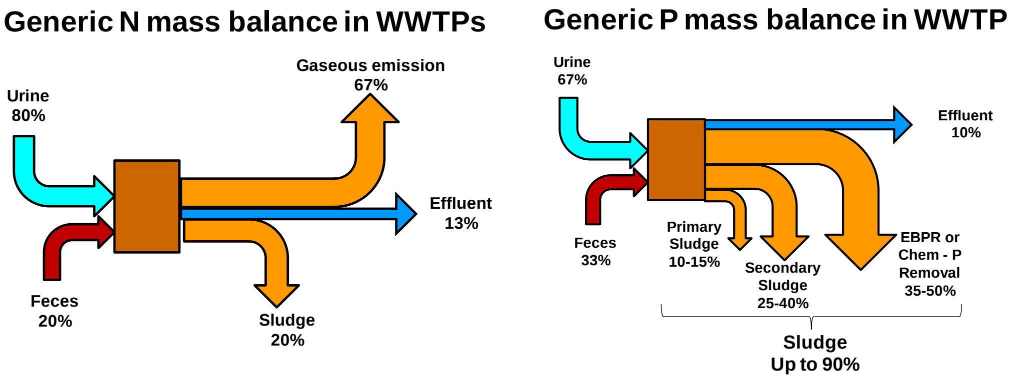
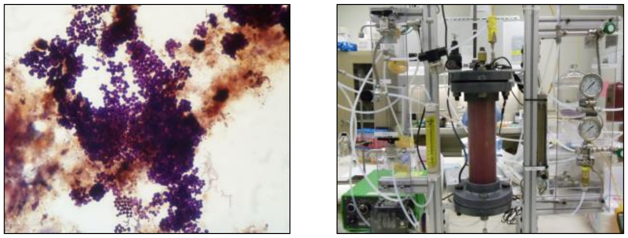


Figure 24: Nutrient balances in WRRFs (adapted from Cornel and Schaum, 2009; Jonsson et al., 2006; and Phillips et al., 2011)

Enabling Extractive Nutrient Recovery from Wastewater

The use of extractive nutrient recovery to help manage the nutrient content of domestic wastewater can be facilitates if it is performed within a three-step framework (**Error! Reference source not found.**; atimer, 2012):

1. Accumulation of nutrients to high concentrations,
2. Release of nutrients to a small liquid flow with low organic matter and solids content, and
3. Extraction and recovery of nutrients as a chemical nutrient product.


Phosphorus accumulating bacteria from full-scale WWTP

Lab-scale photobioreactor employing purple non-sulfur bacteria

Figure 25: Nutrient accumulating organisms (Battelle Memorial Institute, 2012; Latimer et al., 2012a,)

Figure 26: Integrated approach for implementing extractive nutrient recovery in WRRFs (Latimer et al., 2012a)

In this approach, biological, physical, thermal, and chemical methods can be used to manipulate the concentration and form of nutrients present in domestic wastewater into a chemical nutrient product that has a secondary market value. One of the advantages to using this approach is that multiple options for each stage of treatment can be developed and optimized separately, thereby allowing utilities to select the most appropriate solution for their needs. It is also possible that some utilities may not need capital investment for all three processes since existing infrastructure can be reused.

A thorough review of state-of-the-art options available for the accumulation, release, and extraction framework is provided as part of the WERF Nutrient Recovery Challenge (Latimer, 2012). In this work, we focus on providing a brief description of these options as well as the scale of applicability.

Nutrient Accumulation Options Suitable for Full-Scale Application

Nutrient accumulation technologies focus on concentrating the low nutrient content of municipal wastewater. This can be accomplished using biological (N and P), physical (N and P), and chemical (mainly P) techniques. Biological accumulation techniques center around microbial accumulation in which specially adapted microorganisms (e.g., microalgae, polyphosphate-accumulating bacteria (PAOs), purple non-sulfur bacteria, cyanobacteria) are able to uptake (N and P) and store nutrients (P). Plants such as duckweed can also be used as part of passive nutrient treatment/accumulation strategies.

Research has shown that biological systems can remove between 70 to 90% of N and P from wastestreams and are effective for treating a wide range of nutrient concentrations including the dilute content of nutrients typically associated with municipal WRRFs. Biological processes have already been extensively applied for wastewater treatment, with over 84% of WRRFs in the U.S. employing some form of biological process (CWNS, 2004). Since these processes are expected to be further employed as effluent nutrient regulations become more stringent, this represents a fortuitous opportunity for the extractive nutrient recovery field, as it becomes possible to stage implementation of the extractive nutrient recovery over multiple years, with the first step initially being use of biological nutrient accumulation processes. Key requirements for using biological accumulation processes are an effective solid-liquid separation process like clarification or membranes to allow recovery of the nutrient-rich biomass, as well as an appropriate release technology for subsequent processing.

Chemical accumulation using metal salt addition is another option that can be used to help accumulate nutrients (mostly P). In this process, the metal salt reacts with soluble P to form an insoluble phosphate complex, which is solid and can then be physically separated from the wastestream. Aluminum and iron solutions are often used for this purpose and can achieve greater than 85% P removal from the dilute stream, with the chemical solids being separated during clarification or filtration. One of the key challenges with using chemical accumulation techniques is that the chemically accumulated P is less useful because of the high metal salt content of the final product. This restricts its use in agricultural applications. Chemical accumulation is widely applied at domestic WRRFs. Therefore, it may be possible to accomplish extractive nutrient recovery at existing WRRFs by implementing suitable release and extraction processes to process the solids generated.

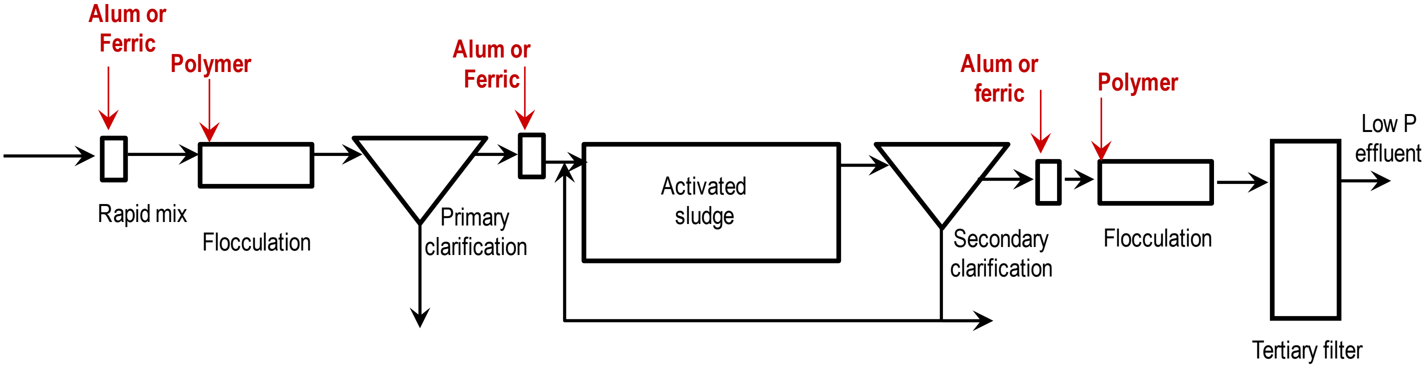


Figure 28: Multipoint injection approach for chemical accumulation/removal of phosphorus from wastewater (from Latimer et al., 2012a)

Another strategy that can be used to accumulate nutrients from the mainstream flow is adsorption and/or ion. These processes can be used to remove N and P from dilute wastestreams, with removal efficiencies ranging between 50 to 90% removal. In this approach, a sorbent or ion exchange material is packed into a column. As the wastewater flows through the column, N or P (depending on the material) is either sorbed or chemically attracted to specific sites on the material. This approach has been used at pilot and full-scale tertiary filtration applications to help remove phosphorus. One of the biggest challenges with using adsorption and/or ion exchange for nutrient accumulation is the regeneration step, which requires use of costly chemical brines and the need for replacement of spent adsorption media. Therefore, it may not currently be economically feasible to implement adsorption and/or ion exchange at larger plants.

Embryonic research at the lab-scale is investigating the use of bio-regeneration as a method to help reduce costs associated with regeneration and replacement of sorbent material. It is expected that these processes will continue to become more important as WRRFs are increasingly asked to achieve effluent total phosphorus limits below 0.1 mg/L. In this scenario, where adsorption and/or ion exchange are used in a tertiary filtration step, it may be possible to harvest the nutrient from this material for beneficial reuse.

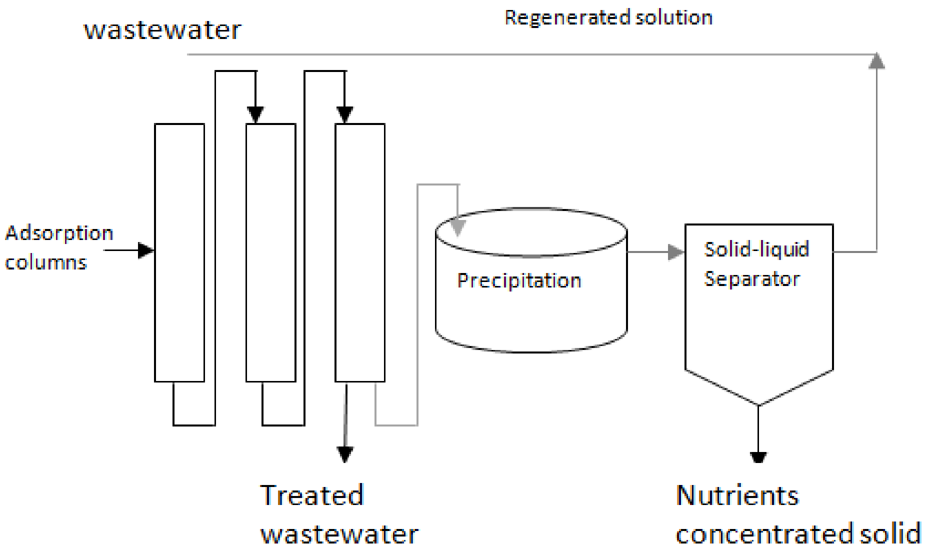


Figure 27: Conceptual process flow diagram for adsorption and/or ion-exchange for nutrient accumulation (from Latimer et al., 2012a)

Development Status		Operating conditions		Pretreatment required	Chemical input	Commercial process	Nutrient(s) accumulated
		Temp. (°C)	pH				
Embryonic	Microalgae	15–30	7.5–8.5	-		Lemna Technologies	N and P
	Cyanobacteria	5–40	6.5–8	-	Carbon source	-	N and P
Innovative	Adsorption/Ion exchange	NA	<8.0	Solid-liquid separation	Adsorbent, regeneration solution	P-ROC, RECYPHOS, PHOSIEDI, RIM NUT, BIOCON	N and P
Established	Enhanced biological phosphorus removal	5–40	6.5–8	-	Carbon	-	P only
	Chemical	25–40	6.5–10	-	Metal salts (Al or Fe)	-	P only

Table 14: Summary of technologies suitable for nutrient accumulation at full-scale WRRFs (from Latimer et al., 2012a)

embryonic – technologies that are in the developmental stage (bench/pilot scale)

innovative – developed technologies with limited full-scale application

established – commercially viable technologies with a proven history of success

Nutrient Release Options Suitable for Full-Scale Application

Once accumulated, the nutrients within the biomass or chemical sludge/slurry must be either released and then extracted to a chemical nutrient product or directly extracted to obtain a chemical nutrient product. Release technologies allow us to recover the nutrients into a low-flow high-nutrient content stream with minimal solids content, which can be used for extraction processes. Release technologies typically employ some combination of biological, thermal, chemical, or physical processes.

Biological release is the most commonly used process that has been implemented at WRRFs. In this process, the biomass is broken down and the organic carbon, nitrogen, and phosphorus are converted to carbon dioxide and methane, ammonia, and soluble phosphorus, respectively. Biological release can occur under anaerobic conditions (e.g., anaerobic digestion) or under aerobic conditions (e.g., aerobic digestion), and the extent of nutrient release is dependent on the conditions employed during digestion. After biological release, the effluent streams can contain greater than 100 mg P/L and 1000 mg N/L, as well as particulate matter that must be removed. One of the biggest advantages of using an anaerobic biological release process is the opportunity to not only recover nutrients, but also the biogas. Indeed, anaerobic digestion has been extensively applied as a cost-effective option for reducing the solids content of primary and waste activated sludges. Recent work performed as part of the WEF-funded national survey of anaerobic digestion and biogas use indicates that close to 25% of all WRRFs greater than 1 mgd currently employ anaerobic digestion (WEF Biogas Data Collection Project). Also, as the industry increasingly aims to achieve energy neutrality, it is expected that anaerobic digestion processes will be increasingly implemented. In a WRRF that already employs biological and/or chemical accumulation followed by biological release using anaerobic digestion, implementation of extractive nutrient recovery would simply require the installation of the extraction step. This latter upgrade has been done at several full-scale facilities in the U.S. and Europe.

Another option for biological release is enhanced P release processes. In this approach, phosphorus that has been biologically

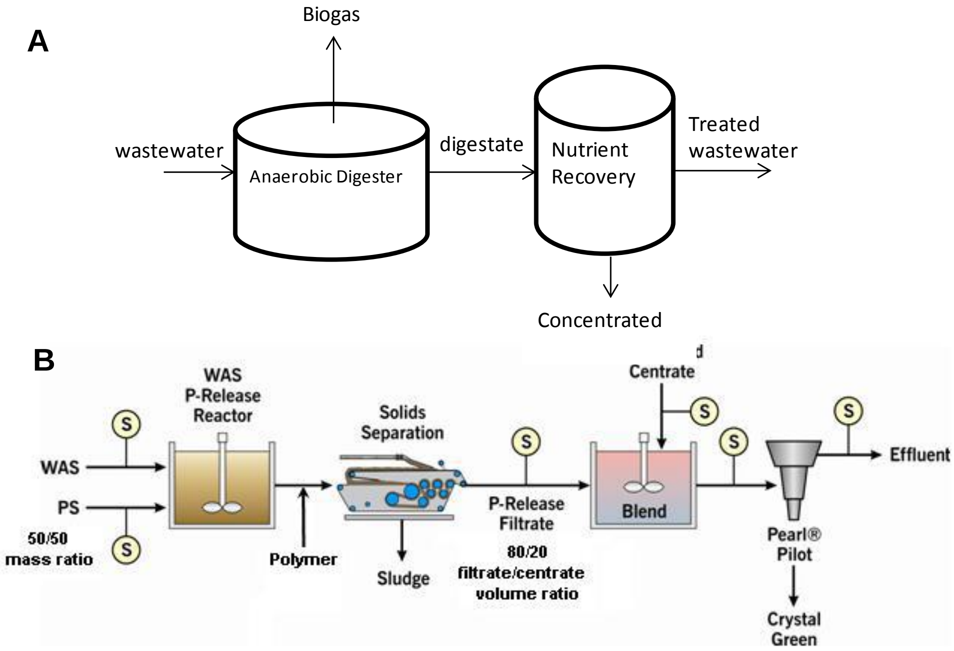


Figure 29: Conceptual process flow diagram for A) anaerobic digestion, B) enhanced waste activated sludge enhanced P release (from Latimer et al., 2012a; Latimer et al., 2012c)

accumulated by PAOs is selectively released from these microorganisms (in WAS). One variation of this process is called WASStrip™ and has been patented by Clean Water Services. Enhanced P release processes can be used in combination with anaerobic digestion to help minimize the O&M requirements associated with nuisance struvite/vivianite formation that is associated with the operation of biological accumulation processes.

Another commonly used practice for releasing nutrient bound in biomass and chemical sludge is thermochemical processes coupled with chemical release. Thermochemical options can include wet oxidation, incineration, gasification, or pyrolysis. In these processes, high temperature is used to destroy organic material and produce a solid product containing P, which can then be chemically released. It is important to note that N is typically lost through gaseous emissions during these processes. As a result, thermochemical processes are most suitable for extractive nutrient recovery of P. Great advances in thermochemical processes have been achieved over the past 5 to 10 years and they have emerged as innovative alternatives to using anaerobic digestion for managing solids at municipal WRRFs. Chemical release of nutrients from the char, ash, biosolids (digested, dewatered activated sludge), or undigested sludge can then be accomplished using concentrated acids or bases at temperatures between 100 to 200 °C. The liquid stream is then subjected to extraction technologies to recover the nutrients.

Coupling these processes to the extractive nutrient recovery framework could allow facilities who have limited expansion capacity or are limited in disposal options for biosolids to still become resource recovery treatment plants. One of the biggest challenges associated with this release option is presence of heavy metals in the liquid stream that is generated. Post-treatment will be required to limit the heavy metal content of the chemical product. This additional treatment step can make this option economically challenging to implement at the current market value of the chemical nutrient products that are typically recovered from these processes.

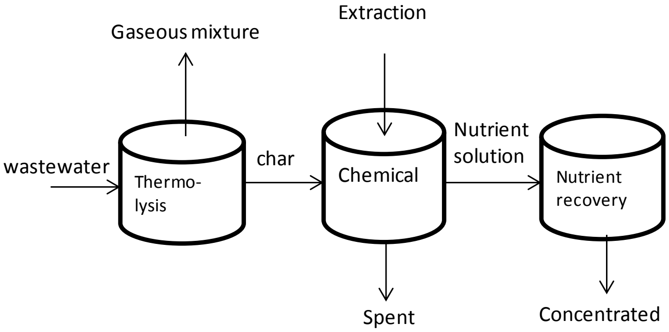


Figure 30: Conceptual Process Flow Diagram for Thermochemical and Chemical Release Processes(Latimer et al., 2012a, Latimer et al., 2012b)

Development Status		Operating conditions		Pretreatment required	Chemical input	Commercial process	Nutrient(s) released
		Temp. (°C)	pH				
Innovative	Chemical extraction	25–200	1–3	-	Leaching solution (sulfuric acid, hydrochloric acid, nitric acid, citric acid, oxalic acid, EDTA)	SEABORNE, STUTTGARTER VERFAHREN, LOPROX/PHOXAN, CAMBI, KREPCO, BIOCON, SEPHOS, AQUARECI, SESAL-PHOS, PASCH	N and P
	Thermochemical	150–1100	all	Temperature adjustment	-	MEPHREC, ASHDEC, THERMPHOS	P only
	Enhanced P release from WAS	5–40	6.5–8	-	Carbon (volatile fatty acids)	WASStrip, PRISA	P only
Established	Anaerobic digestion	35–60	6.5–7.5	-	-	-	N and P

embryonic – technologies that are in the developmental stage (bench/pilot scale)

innovative – developed technologies with limited full-scale application

established – commercially viable technologies with a proven history of success

Table 15: Summary of technologies suitable for nutrient release at full-scale WRRFs (from Latimer et al., 2012a)

Name of Technology	Pearl Nutrient Recovery Process	Multiform Harvest Struvite Technology	NuReSys	Phospaq	Crystalactor
Technology provider	Ostara	Multiform Harvest	NuReSys bvba	Paques	DHV (licensed by Procorp in North America)
Type of reactor	Upflow fluid bed	Upflow fluid bed	CSTR	CSTR with diffused air	Upflow fluid bed
Name of product recovered	Struvite (marketed as Crystal Green)	Struvite	Struvite (marketed as BioStru)	Struvite	Struvite, calcium-phosphate, magnesium-phosphate
% Efficiency of recovery/treatment (range)	80–90% P 10–50% N	80–90% P	45% P	80% P	85–95% P for struvite > 90% P for calcium phosphate
# of full-scale installations	8	2	7	2	30

Table 16: Description of commercial struvite crystallization processes (Latimer et al., 2012a)

Nutrient Extraction Options Suitable for Full-Scale Application

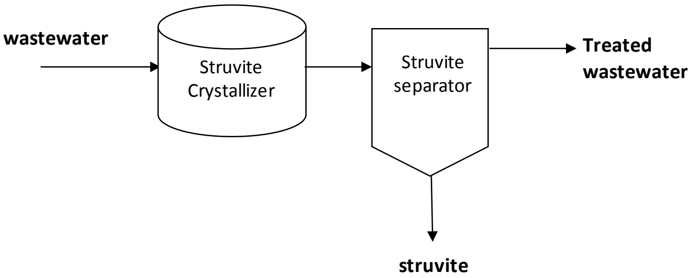


Figure 31: Conceptual process flow diagram for chemical crystallization (Latimer et al., 2012a; Latimer et al., 2012b)

The next step of the extractive nutrient recovery process is the extraction and recovery of chemical nutrient products from concentrated liquid streams. These extraction processes can be inserted downstream of accumulation or release technologies. At present, each extraction technology requires pretreatment to reduce the solids content and/or change the temperature or pH of the liquid stream to a suitable condition for the extraction technology. One example of a commonly applied extraction technology is chemical crystallization. In this process, the soluble nutrient is precipitated and recovered as crystalline products. Products that can be generated by this process include are struvite (magnesium ammonium phosphate) and calcium phosphate (hydroxyapetite, P only). In the case of struvite formation, the pH and concentration of magnesium, phosphate, and ammonium is controlled to allow the precipitation of the chemical nutrient product, which is then separated from the liquid stream via gravity or mechanical separation. Further drying and processing of the product is also commonly performed.

There are multiple variations of this chemical crystallization process that have been commercialized. In each of these systems, soluble P removal efficiencies up to 90% and ammonia removal efficiencies up to 30% can be expected if struvite is the product of choice. Addition of magnesium chloride or hydroxide as well as caustic (NaOH) is typically needed for the process to proceed. Precipitation of calcium phosphate is also possible with the addition of calcium instead of magnesium. There are over 49 full-scale installations of these processes throughout the world. For municipal WRRFs, these processes are commonly installed downstream of biological accumulation (e.g., EBPR) and biological release technologies (anaerobic digestion).

In order to recover N only products, liquid-gas stripping of ammonia can be used. In order to extract the ammonia from the nutrient-rich liquid stream, it is necessary to raise the pH above 9.3 and increase the temperature above 80 °C. Air can then be bubbled through the mixture. This forces the soluble N into the gas phase. This gas phase ammonia is then recovered by bubbling the nutrient-rich gas into sulfuric or nitric acid. This process produces ammonium sulfate or ammonium nitrate, respectively. In this process, ammonia removal efficiencies up to 98% are possible; however, the relatively high cost of this method makes this option challenging for implementation in wastestreams with N content less than 2000 mg/L. As thermal hydrolysis processes like CAMBI™ and Exelys are increasingly implemented at municipal WRRFs, liquid-gas extraction of ammonia will become more technically feasible; however, the ultimate implementation of this process will be dependent on the cost of the products that will be recovered. While this process is established in industrial applications, it has not been extensively applied for recovery of N from municipal WRRFs.

Electrodialysis represents an embryonic extraction technology that allows for the recovery of all ions from nutrient streams at nutrient concentrations below 2000 mg/L. It represents a highly promising technology to the extractive nutrient recovery field. In this process, an electrical current is used to separate anion and cations across an ion exchange membrane. At present, this technology has been implemented at the lab-scale; however, its suitability for implementation at low concentrations of nutrients matches well with the domestic WRRF industry needs. Ongoing research has shown that successful application of this technology in full-scale facilities may be hampered by the high energy consumption, chemicals required for the regeneration of the membranes, membrane fouling, and heavy metal contamination. Additional research into this technology is warranted.

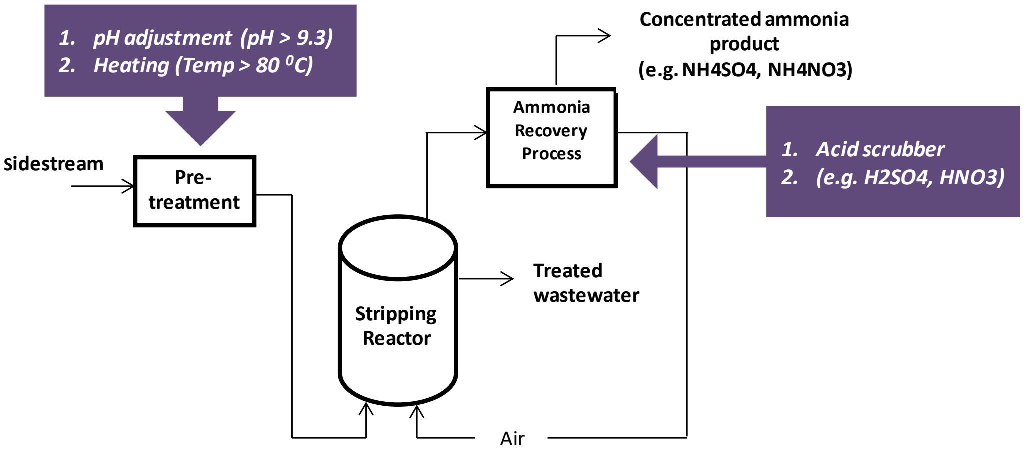


Figure 32: Conceptual process flow diagram for liquid-gas stripping (Latimer et al., 2012a)

Table 17: Summary of technologies suitable for nutrient extraction at full-scale WRRFs (from Latimer et al., 2012a)

		OPERATING CONDITIONS		PRE-TREATMENT REQUIRED	CHEMICAL INPUT	COMMERCIAL PROCESS	NUTRIENT(S) EXTRACTED
		Temp. (°C)	**pH**				
Embryonic	Electrodialysis	10–40	< 8.0	Solid-liquid separation	Electricity	GE Water	N and P
Innovative	Liquid-gas stripping	>80°C	> 9.5	pH and temperature adjustment	Caustic	ThermoEnergy Castion™	N only
Established	Struvite crystallization	25–40	8–9	Solid-liquid separation	Caustic, magnesium, or calcium	PHOSTRIP, PRISA, DHV CRYSTALACTOR, CSIR, KURITA, PHONIX, OSTARA, BERLINER VERFAHEN, FIX-PHOS	N and P

embryonic – technologies that are in the developmental stage (bench/pilot scale)

innovative – developed technologies with limited full-scale application

established – commercially viable technologies with a proven history of success

Considerations for Chemical Nutrient Products

At present, commercial technologies for extractive nutrient recovery primarily produce chemical nutrient products that are used in agricultural applications. This is because 85% of all nutrient products are associated with agronomy. Since food demand is expected to rise with an increasing global population, it is expected that demand for chemical nutrient products will also increase. This represents an opportunity for the wastewater treatment market to develop niche products that can be used in this field.

At present, biosolids are commonly the primary product used to recycle nutrients from wastewater. One of the biggest challenges with biosolids is the expense associated with transporting a product with a high moisture content (~80 to 90%). Since the current value of nutrients in biosolids (~$US8 per tonne) is a fraction of the transport costs ($US30 per tonne to transport 50 km in the U.S. or Australia with higher costs in Europe), nutrient recovery via biosolids can be an expensive undertaking. Even in scenarios where thermal processes are used to reduce the moisture content, the energy required (~800 kWh of energy (as gas) required to evaporate one tonne of water) is significant.

Consequently, recovery of nutrients into chemical nutrient products like struvite is the primary focus of several commercial extractive nutrient recovery technologies. In addition to struvite, other products like calcium phosphate, (hydroxyapetite), iron phosphate (vivianite), phosphoric acid, ammonium sulfate, and ammonium nitrate can also be recovered depending on the nature of the wastewater as well as the secondary market being targeted. An additional advantage of recovering chemical nutrient products is the fact that some of these products have use in alternative industries.

COMMON NAME	CHEMICAL NAME	PRODUCT FORM	USES
Struvite	Magnesium ammonium phosphate	Solid	Agricultural and ornamental crop fertilizer
Hydroxyapatite	Calcium phosphate	Solid	Agricultural and ornamental crop fertilizer Sorbent for heavy metal contained in flue gas
Vivianite	Iron phosphate	Solid	Ornamental crop fertilizer Inexpensive blue pigment for arts and crafts
Phosphoric acid	Phosphoric acid	Liquid	Agricultural and ornamental crop fertilizer Removal of rust, de-scaling of boilers, and heat exchange tubes
Ammonium nitrate	Ammonium nitrate	Liquid or solid	Agricultural and ornamental crop fertilizer Oxidizing agent in explosives
Ammonium sulfate	Ammonium sulfate	Liquid or solid	Agricultural and ornamental crop fertilizer Used in flame retardant materials

Table 18: Summary of chemical nutrient products resulting from extractive nutrient recovery processes (from Latimer et al., 2012a)

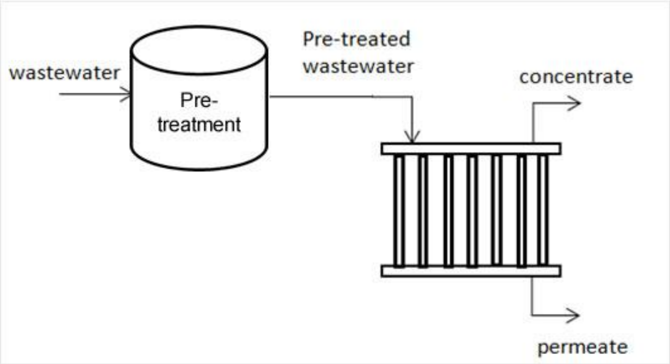


Figure 33: Conceptual process flow diagram for electrodialysis (Latimer et al., 2012a)

In order for chemical nutrient products to be used for agricultural purposes, they must meet some minimum requirements. For instance, all products must have consistent nutrient content and possess no/minimal odors. Solid products must have uniform size, comprise no less than 95% total solids, have less than 1% dust content and have a minimum bulk density of at least 45 pounds per cubic foot. Due to the limited mass production rate of the wastewater treatment sector, it will be challenging to compete with existing supply chains. Instead, recovered products from WRRFs should be marketed within niche markets to maximize resale. An example of this is the case of the Ostara CrystalGreen product, which is used as a soil amendment product.

Figure 34: Example of struvite product (from Latimer et al., 2012a)

In addition to having specific physical characteristics, chemical nutrient products must also have minimal pathogen content and low concentrations of trace organic contaminants (TOrC). To date, research has shown that chemical nutrient products resulting from extractive nutrient recovery processes have negligible pathogen or TOrC content. This is an additional benefit that these products have over biosolids.

“Perhaps the most critical aspect of extractive nutrient recovery processes is the resale price of the chemical nutrient product.”

Perhaps the most critical aspect of extractive nutrient recovery processes is the resale price of the chemical nutrient product. Work performed as part of the WERF Nutrient Recovery Challenge (Latimer et al., 2012c) shows that products comprising P only or N and P tend to have a higher resale value than products comprising N only. This may be directly related to the high demand for easily minable phosphate rock, which can drive up the cost of P fertilizers. As natural prices vary due to its adoption as a mainstream transportation fuel, it is expected that N product resale values will also increase. If the price of N products increases, this can make extractive nutrient recovery of N products more economically feasible. At present though, current market prices favor recovery of chemical P products. While technologies like struvite crystallization in which both N and P are recovered provide the added treatment benefit of removing N from the wastewater, the primary value of the product will continue to lie in the P content.

	AMMONIUM SULFATE SOLUTION	AMMONIUM NITRATE SOLID	AMMONIUM SULFATE SOLID	TRIPLE SUPER-PHOSPHATE	DI-AMMONIUM PHOSPHATE
Recovered product analogue from WRRFs	Ammonium sulfate solution	Ammonium nitrate solid	Ammonium sulfate solid	Hydroxyapetite	none
%TP-%TN-%K-%S-%Ca content	0-30/34-0-0-0	0-34-0-0-0	0-21-0-24-0	46/46-0-0-0-15	46-18-0-0-0
Chemical formula	-	NH_4NO_3	$(NH_4)_2SO_4$	$Ca_3(PO_4)_2$	$(NH_4)_2HPO_4$
Price / lb. of nutrient product in 2011	58.5¢	71.5¢	$1.00	70¢	76¢

Table 19: Average price for recovered product analogues (from Latimer et al., 2012a)

Challenges and Solutions for Implementing N and P Recovery at WRRFs

Although there appears to be a general consensus that nutrient recovery can benefit the industry, there remain technical, social, and economic challenges towards an industry-wide adoption of this approach (Guest et al., 2009). Many of these barriers largely revolve around a lack of technical and economic knowledge. For instance, although there are multiple options that can be considered for recovery, a systematic evaluation of treatment efficiencies, costs, energy balances, and recovered product yields is currently absent. Thus, when faced with the option of recovering resources, utilities must generate these data from scratch. To address this need, WERF is funding active research that will provide peer reviewed resources (reports/databases/tools) that can aid the technical selection process. This database, including references to technology providers and existing sites of nutrient recovery facilities, was published in December 2012 (Latimer et al., 2012b). WERF subscribers will have unlimited access to this tool. This product, together with regional workshops and seminars will be used to increase the extent of knowledge that is transferred to utilities who may be considering extractive nutrient recovery.

In addition to this tool, the WERF Nutrient Recovery Challenge project will further characterize the barriers preventing adoption of extractive nutrient recovery by collecting data from 20 facilities that are considering, implementing, or operating extractive nutrient recovery processes. These data will be used to identify scenarios that allow for more widespread adoption of extractive nutrient recovery. Efforts will be made to parallel the progress made as per the WERF Energy Challenge in the development of case studies for all participating utilities.

To date, collective experience has shown that successful implementation of extractive nutrient recovery systems is highly dependent on the amount of nutrient that must be removed or recovered and that payback periods are shorter for more concentrated wastestreams. Accordingly, direct extraction of nutrients from mainstream flows is not technically or economically feasible. Instead, it will be more appropriate to use the three-step framework whereby nutrients are first accumulated, released, and then extracted. It is important to note that not all WRRFs will require all three components. Indeed, the existing data from WRRFs that have successfully implemented extractive nutrient recovery show that there are three scenarios where adopting extractive nutrient recovery at WRRFs can be economically and technically viable solutions. In the first scenario, energy and chemical costs savings resulting from sidestream extractive nutrient recovery versus conventional mainstream nutrient removal treatment can allow the plant to implement extractive nutrient recovery. In the second scenario, extractive nutrient recovery can be used to help minimize nuisance struvite/vivianite formation. This can reduce operational and maintenance costs at WRRFs, making nutrient recovery an asset to plant operation. The third scenario is one in which extractive nutrient recovery processes are used to manage the nutrient content of the biosolids production process. By changing the nutrient content of the biosolids, WRRFs can add flexibility to their existing nutrient recovery efforts and allow them to maximize the use of acreage used for land application.

Each of these scenarios is based on providing utilities with a cost-effective solution for managing or removing nutrients from liquid or solids streams. As a result, it should be no surprise that the adoption of nutrient recovery is closely hinged to the economic viability of extraction options. As the economics of extractive nutrient recovery is plant- and region-specific based on markets for recovered products, detailed evaluations that encompass TBL assessments of nutrient recovery options are needed. These assessments must consider the social, technical, and economic aspects of nutrient recovery as part of an integrated nutrient management plan for utilities. This will continue to be challenging in the foreseeable future since extensive data on nutrient recovery is only available for a few commercial processes (e.g., struvite crystallization). Extreme care should be taken as we attempt to extrapolate results from established systems to innovative and embryonic technologies.

Research Needs for N and P Recovery Technologies

It should be acknowledged that there is no single technology that is perfectly suited for complete nutrient recovery from all scenarios. Therefore, it is critical that we develop robust data to define the optimum operation space for each option. At present, the dearth of information regarding nutrient accumulation, release, and extraction precludes detailed comparisons to conventional options for removing nutrients from wastewater. If we were to implement nutrient recovery as part of an integrated nutrient management plan for WRRFs, development of the performance benchmarks and cost data are necessary.

There is a need to facilitate further research into technologies defined as embryonic (technologies that are in the developmental stage with bench/pilot-scale data) and innovative (technologies with limited full-scale application). Future research should focus on compiling full-scale data for innovative technologies (e.g., adsorption/ion exchange accumulation and chemical release technologies), with a special emphasis of deriving costs associated with treatment of N and P. Efforts should also be made to pilot test embryonic options (e.g., electrodialysis) with a view to determining the operating space that may be appropriate for implementing these technologies. Once this is identified, full-scale data collection should aim to derive costs associated with recovery of N and P.

References

Cornel P.; Schaum, C. (2009) Phosphorus Recovery from Wastewater: Needs, Technologies and Costs. *Water Sci. Technol*., **59,** 1069–1076.

Guest, J. S.; Skerlos, S. J.; Barnard, J. L.; Beck, M. B.; Daigger, G. T.; Hilger, H.; Jackson, S. J.; Karvazy, K.; Kelly, L.; Macpherson, L.; Mihelcic, J. R.; Pramanik, A.; Raskin, L.; Van Loosdrecht, M. C.; Yeh, D.; Love, N. G. (2009) A New Planning and Design Paradigm to Achieve Sustainable Resource Recovery from Wastewater. *Environ. Sci. Technol*., **43** (16), 6126–6130.

Jonsson H.; Sonesson, U.; Vinneras, B.; Dalemo, M.; Hoglund, C.; Stenstrom, T.A. (2006) Source Separation of Human Urine – Nitrogen and Phosphorus Emissions. www.ramiran.net/doc98/FIN-POST/VINERAS.pdf (accessed May 10, 2013).

Latimer, R.; Khunjar, W.O.; Jeyanayagam, S.; Mehta, C.; Batstone, D.; Alexander, R. (2012a) *Towards a Renewable Future: Assessing Resource Recovery as a Viable Treatment Alternative*; Water Environment Research Foundation: Alexandria, Virginia.

Latimer, R.; Nguyen, V.; Rohrbacher, J.; Khunjar, W. O.; Jeyanayagam, S.; Mehta, C.; Batstone, D.; Alexander, R. (2012b) *Towards a Renewable Future: Assessing Resource Recovery as a Viable Treatment Alternative—Technology Matrix*; Water Environment Research Foundation: Alexandria, Virginia.

Latimer R.; Nguyen V.; Smeby K.; Vadiveloo E.; Pitt P.; Harris, P.; Porter, R.; Elmendorf, H.; Richards, T. (2012c) *Pilot Testing Nutrient Recovery from WAS Streams for Struvite Control and Recycle Load Reduction.* WEF Residuals and Biosolids Conference; Raleigh, North Carolina*;* Water Environment Federation: Alexandria, Virginia.

Mulder, A. (2003) The Quest for Sustainable Nitrogen Removal Technologies. *Water Sci. Technol.,* **48** (1), 67–75.

Novotny, V.; Ahern, J.; Brown, P. (2010) *Water Centric Sustanable Communities*; Wiley & Sons: Hoboken, New Jersey.

Penuelas J.; Sardans, J.; Rivas-Ubach, A.; Janssens, I. A. (2012) The Human-induced Imbalance between C, N and P in Earth's Life System. *Global Change Biol*., **18,** 3–6.

Phillips, H.; deBarbadillo, C.; Wimmer, B.; Barnard, J.; Steichen, M. (2011) *Perspectives on Nitrogen and Phosphorus Recovery from Wastewater: The State of the Industry*. WEF/IWA Nutrient Recovery and Management Conference; Water Environment Federation: Alexandria, Virginia.

Shu, L.; Schneider, P.; Jegatheesan, V.; Johnson, J. (2006) An Economic Evaluation of Phosphorus Recovery as Struvite from Digester Supernatant. *Bioresour. Technol*., **97** (17), 2211–2216.

Willis, J.; Stone, L.; Durden, K.; Hemenway, C.; Greenwood, R. (2012) *Barriers to Biogas Use for Renewable Energy;* Water Environment Research Foundation: Alexandria, Virginia; NYSERDA: Albany, New York.

Section 6

Other Resource Recovery Opportunities: Expanding Horizons

The biosolids industry is not alone in some of the challenges it faces – industries across a wide spectrum are grappling with economic constraints and the need for sustainable solutions. This need, coupled with technology transfers into the wastewater solids arena from other areas has spurred the emergence of new approaches that use biosolids as a feedstock to create a variety of nontraditional products, such as biodegradable plastics, fertilizers, and alternative fuels. This section features examples of emerging technologies that may offer the potential for future large scale applications.

In exploring these technologies, it is important to note that the evolutionary path for emerging technologies is not an easy one: new technologies must overcome tremendous obstacles to travel from “emerging” to “established” status. As shown in the figure below, technologies can be challenged at all stages of development, facing technical performance issues throughout their development and economic viability challenges as they move toward full-scale operation.

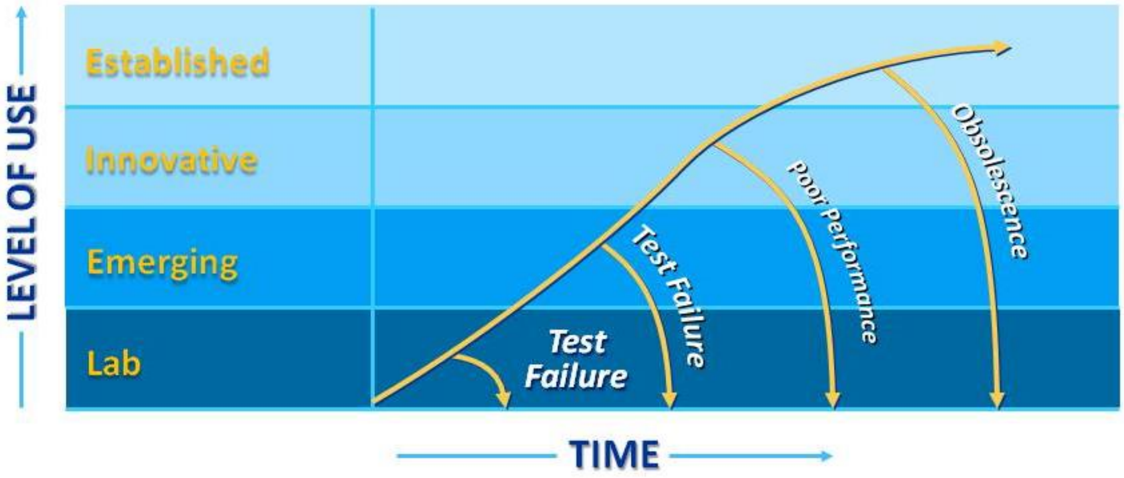


Figure 35: Technology evolution

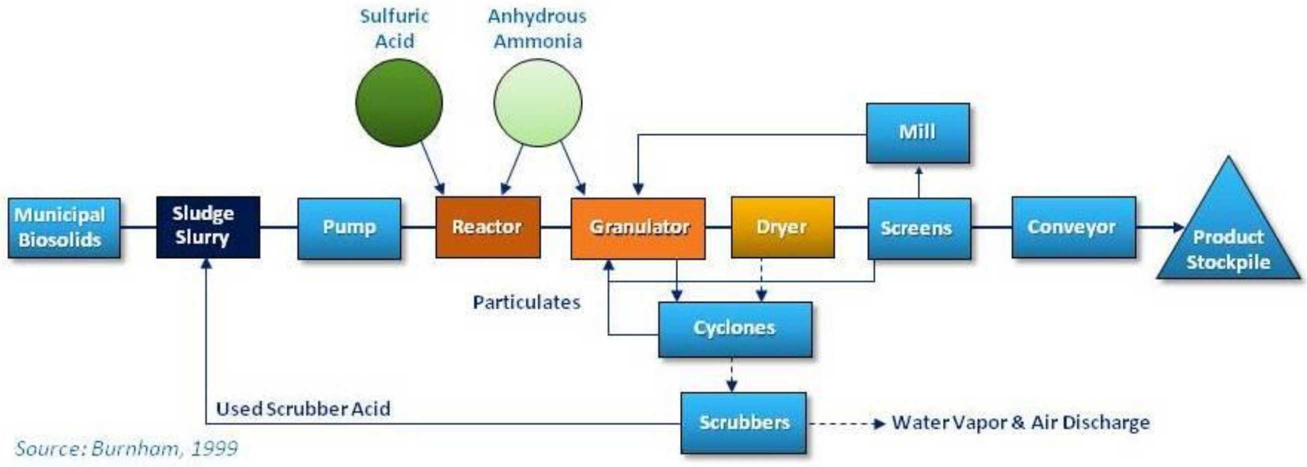
The nature of wastewater solids appears to be a specific challenge for processes operating at high pressures and or temperatures. Several promising technologies have been proven to work with homogenous materials as the raw feedstock, but have not been able to overcome the problems associated with the variable characteristics of biosolids. For example, the recent closure of the thermal conditioning plant operated by EnerTech Environmental, Inc., in Rialto, CA, culminates years of research and development in the formation of a biofuel from biosolids. The complexity of the process and other factors, including sidestream treatment and cost ultimately resulted in EnerTech being forced to cease operations. Minergy's Glass Pack technology is another example of a technology that tested out with promising results, working well with pulp wood processing wastes, but full-scale implementation with biosolids at Waukegan, IL, has encountered too many obstacles for it to be considered successful. That being said, the drive for new and synergistic technologies appears to remain strong, with new processes (including those featured below) working their way through the evolutionary process.

Overview of Technologies

Enhanced Fertilizer Production

Probably one of the most proven "nontraditional" technologies emerging in the marketplace is the manufacture of a chemical fertilizer with biosolids as a component. Two fertilizer manufacturing companies have built upon the Unity Process used by Cypress Chemical in the late 1990s to early 2000s period. Cypress Chemical developed a process for manufacturing ammonium sulfate fertilizer using biosolids as a component as illustrated in the figure below.

Over 100,000 tons of biosolids from New York City wastewater plants were processed at a rehabilitated fertilizer plant in Helena, AR, during this period. The economics of transporting the biosolids such long distances lead to the closure of the plant and the breakup of Cypress Chemical, but two new companies with enhancements to the process are now developing new facilities. Unity Environmental and VitAG LLC both have new facilities under development in the U.S. The resulting product will be a high-grade commercial fertilizer that will be marketed through fertilizer distributors and brokers. Both companies have adapted traditional chemical fertilizer technologies to use biosolids and introduce an organic fraction to the fertilizers. The facilities will vary in capacity but will typically have capacities exceeding 100 wet tons per day of dewatered biosolids.



Source: Burnham, 1999

Figure 36: Cypress chemical process for manufacturing ammonium sulfate fertilizer using biosolids as a component

Biodegradable Plastics

One of the most nontraditional technologies under development is the production of a biodegradable plastic using biosolids. Micromidas LLC is developing a biological process that will use the carbon and other nutrients in biosolids to generate small particles of biodegradable plastic, similar to the process that uses glucose or fructose to make biodegradable plastics. The resulting plastic will have a lifespan of months, instead of the centuries needed now to breakdown petroleum-based plastics.

Micromidas was founded in 2008 and has been focused on identifying the proper bacteria and environment for their growth. They are in the process of developing a trailer-mounted pilot unit that can be taken to WRRFs to be tested on a larger scale.

The figure below illustrates the Micromidas concept.

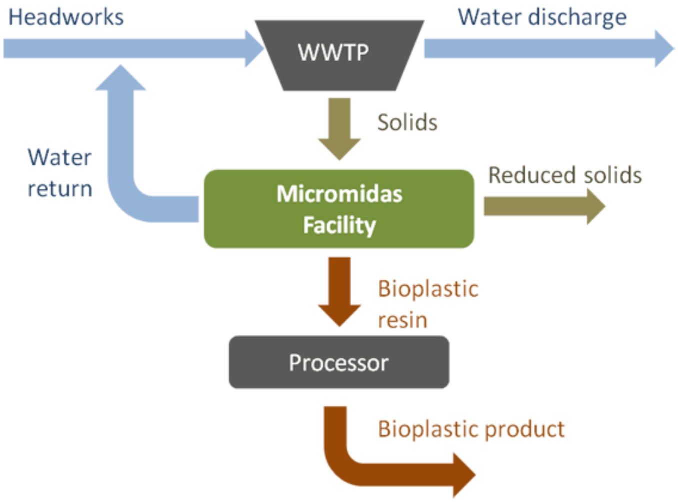


Figure 37: Micromidas concept for manufacturing bioplastic using biosolids. (Meyers, 2011)

Methanol Replacement

In contrast to the previous technologies that use biosolids to make alternative products, OpenCEL is developing an alternative use to their sludge conditioning process that will allow WRRF operators to replace a purchased chemical and reduce operational costs. OpenCEL uses focused pulse technology to lyse waste activated sludge and make it more amenable to biological degradation. In recent studies, OpenCEL determined that the conditioned sludge can enhance the denitrification aspect of biological nutrient removal process. The primary benefit of adding focused pulse treated sludge will be at plants that need to add methanol or another source of carbon to sustain the biological nutrient removal (BNR) process. The treated sludge can replace a portion of the outside carbon source. During full-scale testing at the Mesa Northwest Water Reclamation Plant, OpenCEL was able to demonstrate a 40% reduction in the methanol needed to support BNR. The figure below illustrates the major components required for an OpenCEL system.

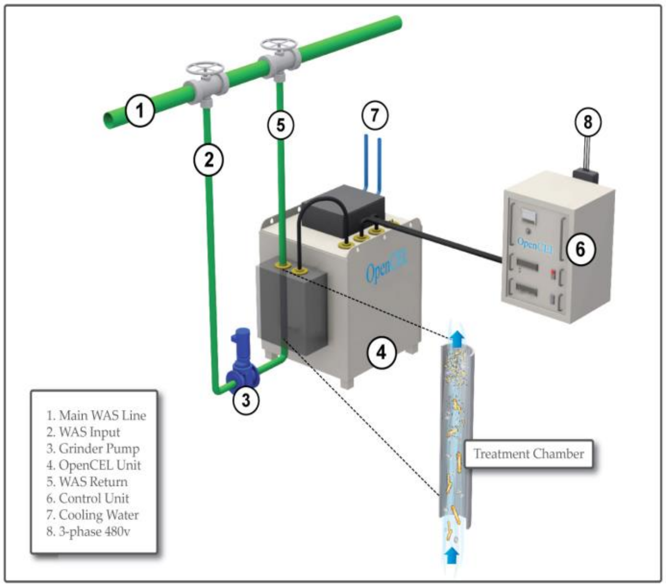


Figure 38: Simple equipment layout diagram provided by OpenCEL

Enabling Further Development

As previously noted, these technologies have many obstacles to overcome before they will be considered mainstream technologies. The overarching obstacle is proving the technology will work consistently on a large scale. To reach that point, developers typically invest in years of bench and pilot-scale studies to identify the proper materials and processing methodologies. They then usually have to find a utility willing to allow them to test on a full-scale basis at no cost to the utility. All this requires significant financial resources, time, and patience on the part of the developer. Owners and their engineers are often resistant to experimenting with new technologies because of the involvement of public funds and the risk associated with the unproven technology.

Even after being proven on a full-scale basis, some technologies will be best suited as niche technologies serving a select few WRRFs. One of the best examples of this is the use of biosolids in the manufacture of bricks. During the late 1980s and early 1990s, several brick manufacturers used biosolids in the manufacture of brick. Small quantities of biosolids would be added to the clay prior to firing to add organic matter that would combust during the firing process, producing the desired brick density. In other applications, ash from incineration of sludges was used in the brick manufacturing process to add color from the minerals in the ash. Despite the proven success of the process, it did not take off on a large scale because of the limited number of brick manufacturers and the difficulty the manufacturers experienced in dealing with the solids. The batch process for making bricks and small percentage of solids used in each base created logistics problems, and in some states special permits were required for firing alternative wastes. Worker perceptions of biosolids also proved to be an issue for some manufacturers. Therefore, even if a technology is technically and economically feasible, other factors could prevent it from becoming an established technology or practice.

Once a technology has made it out of the lab to emerging status, utilities and engineers can help enable further development of the technology by looking for opportunities to team with the developer for full-scale tests. The developer should be willing to shoulder the burden of development, however, and should be conscious of minimizing the impacts on the existing operations.

Incentives to utilities by state and federal programs to test and implement innovative technologies would facilitate the development and application of these technologies by reducing the economic risk. For example, the Innovative and Alternative Technologies for Wastewater Treatment program operated by the U.S. EPA in the 1970s and 1980s helped advance numerous technologies (such as composting) from emerging to established status. This program involved cost sharing with a utility willing to implement a new wastewater or sludge treatment process that demonstrated promising benefits for reducing costs or enhancing environmental benefits.

Reference

Meyers, G. (2011) Micromidas Makes Biodegradable Plastic, Sans Petroleum. *Green Building Elements,* Jan 20. http://greenbuildingelements.com/2011/01/20/micromidas-makes-biodegradable-plastic-sans-petroleum/ (accessed May 11, 2013).

Section 7

Enabling the Future: Investing in People, Quality, and Communications

The WEF and NBP effort in “Charting the Future of Biosolids Management” (2011) and this report have defined and documented important millennial turning points in biosolids management in North America.

Over the past several years, there has been a paradigm shift in how wastewater solids are perceived within the wastewater and biosolids management profession. This perception is driven by forces internal and external to the field, including widespread interest in sustainability, energy, climate change, resource depletion, materials cycling, and zero-waste goals. WEF and other professional organizations have recognized the new paradigm in position statements (WEF, 2011).

As biosolids management professionals look to the future, what will be needed to make the new paradigm, the vision, a reality? In 2013, the U.S. EPA Part 503 biosolids rule is 20 years old. Risk management, regulation, and best management practices have advanced. Biosolids are products widely bought and sold in the marketplace. There are still skeptics, and biosolids recycling continues to need defending. But now we are looking ahead more, seeing the potential of maximizing resource recovery. What will it take to get there?

This chapter identifies five steps to be taken toward maximum resource recovery.

Five Steps Toward Maximum Resource Recovery

If enabling the future of biosolids management means maximizing the use of this resource, then reaching that goal will require continuous, consistent efforts toward the five specific initiatives shown below. Each of these necessary steps is further explored in this section.

1. Increase the capacity and skills of the biosolids profession by providing more biosolids management information, training, and other support.
2. Advance policies, legislation, and regulations that allow for – and create incentives for – resource recovery.
3. Continue to improve the quality of biosolids and biosolids management programs of all sizes and in all regions.
4. Increase communications and outreach with environmental and agricultural groups and the general public about the beneficial uses of biosolids and the importance of maximizing resource recovery from these materials.
5. Advocate for increased funding for these initiatives, as well as for infrastructure needed to maximize resource recovery.

Increase Professional Capacity and Skills

Over the next decade, the wastewater and biosolids management profession will continue to lose the largest cohort of retiring engineers and operators in U.S. history. This is the wave of professionals who came to work during the 1980s, the period of large federal construction grants. They designed, managed, and operated thousands of new or upgraded secondary treatment systems and figured out how best to manage the solids. As retirements occur, experience and knowledge will be lost in record numbers. As WEF and other organizations have recognized, this loss can only be mitigated by increased recruitment and training and increased support for young professionals.

But the need for education and training is even greater than merely replacing what is quickly being lost. The field also needs even greater expertise, especially in areas not traditionally associated with wastewater treatment, such as computer technologies (SCADA and other systems), energy management, new technologies (e.g., for combined heat and power), agronomy, climate change mitigation and adaptation, financial management, and public outreach and communications. Providing training costs money.

In addition, the expectations for increased professionalism and higher skill levels in the field means that the staff to run WRRFs costs more than in the past. Crawford (WERF, 2010) reported this fact in reviewing the success of the approximately 10-mgd Strass, Austria, WRRF in producing more energy than it consumes.

….as the focus on resource recovery intensifies, the importance of the distributed support network for biosolids professionals will increase correspondingly.

The key factors he noted were:

- A "highly educated, well-paid workforce",
- A "high level of automation",
- A "use of advanced process analysis tools", and
- A "tolerance of process risk" and "quantifying gains".

There is no way to maximize resource recovery without more investment in people to match the increased investment in advanced infrastructure. Some of the investment will be paid back through energy savings and improved efficiencies in cycling of resources – but even calculating those returns on investments becomes ever more complicated, requiring even more educated people.

Training in university engineering departments will continue to need to diversify, providing budding professionals with courses beyond engineering, such as communications and sustainability. WEF and its member associations (MAs), regional biosolids groups, and state operator associations that offer training will need to keep pace with the demands of the profession too. Currently, the Mid-Atlantic Biosolids Association is working with WEF to develop a biosolids land applier training program that will prepare professionals for new exams developed by the Association of Boards of Certification (ABC) from 2008 to 2010. Getting this program off the ground has been a challenge due to limited resources, and it is only one aspect of biosolids management for which the future will require higher levels of training and skills.

Finally, information, training, and day-to-day support for biosolids management professionals and their programs are currently provided by a variety of organizations and agencies around the continent. For example:

- *National wastewater organizations* – WEF, NACWA, and the Canadian Water & Wastewater Association provide information and support biosolids programs. WEF and NACWA have staff dedicated to supporting biosolids management.
- *Regional biosolids associations* – Located in California, the Northwest, the Northeast, the Mid-Atlantic states, and Virginia, these associations are designed and operated to provide support specifically to biosolids management programs and professionals, through paid staff.
- *Regulatory guidance programs* – Some state and provincial regulatory programs provide considerable assistance to biosolids managers through regular training programs, operator certifications, newsletters, and informal consultations. However, many state programs may be susceptible to budget cuts that could reduce or eliminate assistance.
- *Biosolids Committees of WEF MAs* – These committees are driven by volunteers, and, therefore, provide varying and limited levels of support to biosolids professionals.

These organizations form a distributed support network for biosolids professionals that has considerable strength and resiliency, which supports and facilitates the exchange of accurate information. Today, as the focus on resource recovery from biosolids intensifies, the importance of the distributed network of support for biosolids professionals becomes even greater. The increased complexity of biosolids management and the need for increased communications with more diverse audiences requires that these support mechanisms continue to grow and evolve to meet future needs.

Enabling the future will require enhancing the capacity, skills, and knowledge in the public utility and private sectors involved in biosolids management.

Advance Policies and Rules Supporting Resource Recovery

Current laws and regulations related to biosolids management were developed within the paradigm of waste management, and while this approach is important, adjustments are necessary to move forward with maximal resource recovery from these materials. For example, some wastewater agencies are running into obstacles with state policies that preclude co-digestion of biosolids with other organics or with energy utilities that are unable or unwilling to accept treated biogas (biomethane) or biosolids-generated electricity (Willis et al., 2012). In addition, energy derived from biosolids and other organic residuals is not recognized in some states' REC programs or other incentive programs. Legislation or regulatory changes are needed to correct these policies.

The paradigm shift from wastewater plants to WRRFs must be integrated into policy, legislation, regulations, and politics, if maximum use of this resource is to be achieved. This will require expanded outreach to organizations outside of the biosolids profession. Biosolids interests should – and can – join coalitions focused on renewable energy, nutrient management, and green infrastructure; however, it will take concerted effort to explain to some of these organizations and people, who are focused on other issues, how biosolids can be a part of what they work on and offer solutions:

Continuing to demonstrably minimize risk… and advance best practices builds public confidence and will increase opportunities for resource recovery.

- Water resource recovery facilities can provide communities with integrated management of challenging low-solids organic "wastes" from diverse sources, wastes that can be significant sources of pollution if not managed properly.

Maximizing resource recovery will require more outreach to organizations outside of the biosolids profession. Biosolids interests should – and can – join coalitions focused on renewable energy, nutrient management, and green infrastructure.

- Biogas generated from these facilities is a reliable, 24-hour renewable energy source.
- Nutrients in biosolids can reduce reliance on fertilizers mined and transported from a distance.
- Biosolids products are suited for building soils for improved stormwater retention and treatment.
- Maximizing use of the resources in biosolids reduces greenhouse gas emissions in several ways, including reduced use of fossil fuels and sequestration of carbon (C) in soils.

These are messages that should resonate with other environmental professionals and advocacy groups.

Maximizing and demonstrating quality is a prerequisite for successful resource recovery…

Continue to Improve Biosolids Quality and Programs

Maximizing resource recovery from biosolids cannot be achieved if specific issues of public concern are not adequately addressed.

For land-applied biosolids, the following concerns should continue to be addressed, as needed, through research, regulations, and best management practices:

- Trace elements (e.g., heavy metals),
- Chemicals (including emerging contaminants, pharmaceuticals and PPCPs, flame retardants, perfluorinated compounds [PFCs], etc.),
- Pathogens (including "emerging pathogens" such as norovirus),
- Nutrients (e.g., N and P), and
- Odors and other nuisances.

The most significant concerns related to these topics (in terms of risk to public health and the environment) have been addressed, but refinements are needed as science develops further understanding. Biosolids land appliers need to continue to update their knowledge and practices to keep up with the science and public expectations for quality. For example, the current isolated situation of relatively high soil levels of PFCs associated with biosolids application in Decatur, Alabama, is a situation to learn from (Lindstrom et al., 2011). Precautionary actions to avoid similar issues in the future have been taken (phasing out of some PFCs) and should continue to be taken (e.g., stricter pretreatment and monitoring at facilities that potentially receive wastestreams from industries manufacturing or using such chemicals).

With regards to thermal processing, biosolids managers must pay attention to such public concerns as:

- Air emissions (e.g., heavy metals, NOx, nitrous oxide [N_20], dioxins/furans, CO, HCl, SO_2, particulate matter),
- Net energy consumption, and
- Odors and other nuisances.

In the coming years, best management practices for incineration will require greater net energy efficiency through increased combustion efficiencies, heat recovery and utilization, and ash utilization.

The public – and regulators – demand quality and expect continual improvement. The biosolids management profession must continue to meet these expectations.

Since the late 1990s, there has been a formal program that advances best management practices: the National Biosolids Partnership Environmental Management System (EMS, also known as the "Biosolids Management Program" or BMP). More than 30 wastewater treatment utilities and private biosolids management companies have been certified through an independent audit process that recognizes the extensive quality practices and continual improvement demanded of the program.

Other programs encouraging best management practices are referenced in state regulations (e.g., New Hampshire biosolids regulations require adherence to university cooperative extension BMPs) or have been developed by biosolids organizations; for example, the Northwest Biosolids Management Association has been amassing "continual improvement tips" and is planning to publish them in a compendium.

And, of course, there is ever-improving guidance on current best practices in documents such as the U.S. EPA *Guide to Field Storage of Biosolids and Other Organic By-Products Use in Agriculture and for Soil Resource Management* (U.S. EPA, 2000), the NBP *National Manual of Good Practice for Biosolids* (NBP, 2003), and *Solids Process Design and Management* (WEF, 2012). BMPs ensure:

- Biosolids products of appropriate quality for the intended use,
- Managed to standards beyond those required by minimum regulations,
- Avoiding creation of nuisances, and
- With attention to building trust and relationships with neighbors, other stakeholders, and the general public.

Continuing to demonstrably minimize risk as much as is reasonably possible and advance best practices that build public confidence will increase opportunities for resource recovery. Thus, maximizing and demonstrating quality is a prerequisite for successful resource recovery and the communications and outreach that accompany it.

Expand Dialogue Outside of the Biosolids Profession

To fully leverage resource recovery potential, the biosolids profession must improve communications and outreach with environmental groups, agricultural groups, and the general public about the beneficial uses of biosolids and the importance of maximizing resource recovery from these materials.

In the past decade, biosolids professionals have been encouraged to increase public involvement, communications, and outreach to interested parties, addressing topics such as the risks and benefits of biosolids use on soils and the acceptability of solids combustion facilities in neighborhoods. Understanding and use of risk communications has increased, and there are several resources

Resources for Biosolids-Specific Outreach & Public Involvement

Beecher, N.; Connell, B.; Epstein, E.; Filtz, J.; Goldstein, N.; Lono, M. (2004) *Public Perception of Biosolids Recycling: Developing Public Participation and Earning Trust;* Water Environment Research Foundation: Alexandria, Virginia.

Decision Partners (2011) *Conducting Effective Outreach and Dialogue on Biosolids Land Application;* Water Environment Research Foundation: Alexandria, Virginia.

Eggers, S.; Thorne, S.; Butte, G.; Sousa, K. (2011) *A Strategic Risk Communications Process for Outreach and Dialogue on Biosolids Land Application*; Water Environment Research Foundation: Alexandria, Virginia.

Federation of Canadian Municipalities and National Research Council (2005) *Communication and Public Consultation for Biosolids Management*. http://fcm.ca/Documents/reports/Infraguide/Communication_and_Public_Consultation_for_Biosolids_Management_EN.pdf (accessed Jan 9, 2013).

Water Environment Federation; Water Environment Research Foundation; U.S. Environmental Protection Agency (2012). *Solids Process Design and Management* (see Chapter 3: Public Outreach and Involvement)*;* Water Environment Federation: Alexandria, Virginia.

Other Outreach and Public Involvement Resources

Deeb, R.; Means, E. (2009) *Communication Principles and Practices, Public Perception and Message Effectiveness*; Water Environment Research Foundation: Alexandria, Virginia.

Hartley, T. W. (2001) *Public Perception & Participation in Water Reuse*. Water Environment Research Foundation; National Water Research Institute (NWRI); American Water Works Association Research Foundation (AWWARF); WateReuse Foundation: Alexandria, Virginia.

International Association for Public Participation (2000) IAP2 Public Participation Toolbox. http://www.iap2.org (accessed Jan 9, 2013).

Water Environment Federation (2002) *Survival Guide: Public Communications for Water Professionals;* Wantland, S., Ed.; Water Environment Federation: Alexandria, Virginia.

specific to biosolids management now available (see resources listed below). These efforts are important and must continue.

Going forward, new outreach and education efforts should also focus on biosolids for renewable energy, recycling of nutrients, land and ecosystem restoration, and solutions to management of trace pollutants.

An essential part of the understanding about progressive biosolids management programs of today and of the future is that *biosolids products are tools valued in the marketplace.*

Accordingly, biosolids managers are increasingly focused on creating products of real value – with low contaminant levels. The ongoing regulatory structure and the focus on product quality are driving scrutiny of what's in biosolids, what's in wastewater, and ultimately, what's in use in society. As more biosolids are recycled and put to use, there is more emphasis on cleaning up the "waste" stream, to make it truly a "resource" stream.

By moving in this direction of quality, solids management is aligned with progressive environmental efforts. Biosolids recycling becomes something that community, agricultural, conservation, and environmental groups embrace. Biosolids managers communicate with such groups, share visions and goals, and work together. There are some examples of this cooperation (shown below) dating back 15 years and more and there will be more into the future.

As the quality of biosolids products and programs continues to improve, and their value in environmental projects and for environmental good is further demonstrated, biosolids managers will need to go beyond risk communications and step up communications with environmentalists and the public to develop the appreciation of what is a story of sustainability – the recycling of the "waste" about which most humans would prefer to forget.

The **King County , Washington,** biosolids program has been an instrumental part of the visionary "Mountains-to-Sound Greenway" along Interstate 90 from Seattle to Snoqualmie Pass. The program is a cooperative venture of numerous organizations, including environmental groups like the Sierra Club. Biosolids have been a valued tool for re-vegetating logging roads and improving timber stands. Today, King County continues to advance sustainability by, for example, using biosolids to grow oil seed crops for biodiesel production and using the biodiesel in its trucks that haul biosolids.

For decades, the **Philadelphia Water Department** used biosolids for restoration of coal mine lands. "The bituminous coal mining area of northcentral Pennsylvania is a strong hunting region. The establishment of permanently improved wildlife habitat has helped develop public support for the program…. Wildlife has responded enormously to the vegetative cover at the biosolids sites. A Pennsylvania District Forester was excited by the hold over of hawks at the edge of one reclamation site. The hawks are drawn to the mice and voles residing in the dense matting. A bald eagle was seen at one site and has been nesting for several years. Turkey flocks have grown large,…doves have flocked to these sites,…and… deer frequent biosolids-amended reclamation sites…. An elk herd is being relocated to some large field reclaimed with biosolids and planted to warm weather grasses…." (Toffey et al., 2000)

Since 2002, biosolids from nearby water resource recovery facilities have been used to support hybrid poplars growing on reclaimed areas of the Sechelt mine in British Columbia. After 20 years of growth enhanced by the biosolids, the poplars will be harvested, pulped, and made into new paper – likely toilet paper. Mike Latimer, mine manager, was quoted as saying "We talk about having a poplar plantation that will be turned into toilet paper someday, and it becomes the ultimate recycling program." In 2010, the reclamation project was recognized with an annual provincial award, in large part because of its excellent outreach efforts: "open houses at the mine, school tours, contributions to projects like the Dolphin Street supportive housing project, as well as for its working relationship with the Sechelt Indian Band whereby the company employs and trains Band members and hires Band member-owned companies for work on the site" (Richter, 2010).

Secure Funding for Resource Recovery Initiatives and Infrastructure

The recommendations above reflect a dramatic need for increased funding for resource recovery from wastewater and solids. Improved technical efficiencies and resource recovery (e.g., electricity production) will provide some payback, but not enough to fund the needed work on policies, laws, and regulations, as well as the higher costs for more educated and professional staff, plus the added costs of improved programs and more infrastructure and better outreach.

As WEF, its MAs, and related organizations working on water-related topics recognize, there needs to be renewed public focus on this field. Wastewater and solids management are some of the most basic functions in which a society must focus. Biosolids professionals are increasing efforts to bring attention to our work. Society needs to come to see how cost-efficiently these wastes/resources are being managed, given the stakes in terms of public health and the environment.

The challenge for the biosolids management profession (and the wastewater field in general) is to convince decision-makers and the public of the need to increase funding dramatically. And this must be done soon, because of aging infrastructure. And it has to happen in this time when the U.S. is struggling economically and all levels of government are being forced to cut budgets.

At the same time, because necessity drives invention, biosolids professionals are figuring out innovative ways to do more with fewer public dollars – and they will have to continue to do so in the foreseeable future. For example, there is considerable discussion and increased use of:

- Public-private partnerships;
- Outsourcing and privatizing;
- Design-build-operate and other even more complex configurations of projects;
- More complex financing arrangements, such as having the capital costs of energy projects being borne through operational budgets; and
- Use of more accurate and helpful financial analysis and decision-making tools, such as those discussed in the follow-up to WERF's project Barriers to Biogas Use for Renewable Energy (WERF, 2012).

Of course, different approaches add complexity and require even more skills and education – requiring additional investment.

Funding is critical to perform the integrated activities needed to support biosolids resource recovery

Critical Success Factors

To manifest the developing paradigm of maximizing biosolids resource recovery, biosolids management professionals will need to pay attention to the following critical success factors:

- The skills and knowledge of biosolids management professionals;
- The age distribution of biosolids management professionals;
- The strength and capacity of biosolids-focused organizations;
- The status (number, tone, and complexity) of federal and state policies, laws, and regulations pertaining to biosolids;
- The quality of biosolids products (trace elements, trace chemicals, pathogens, nutrient balance, odors);
- The quality of biosolids management, including the constant of continual improvement;
- The level of federal and state policy support for biosolids resource recovery;
- The level of agricultural, conservation, and environmental group support;
- The level of public support (trust);
- The levels of public and private funding for biosolids management infrastructure, training, and operations; and
- The trend in biosolids resource recovery and the rate of biosolids recycling.

References

Lindstrom, A.B.; Strynar, Mark J.; Delinsky, A.D.; Nakayama, S.F.; McMillan, L.; Libelo, E.L.; Neill, M.; Thomas, L. (2011) Application of WWTP Biosolids and Resulting Perfluorinated Compound Contamination of Surface and Well Water in Decatur, Alabama, USA. *Env. Sci. Tech.*, **45** (19), 8015–8021.

National Biosolids Partnership (2003) *National Manual of Good Practice for Biosolids*; National Biosolids Partnership: Alexandria, Virginia.

Richter, B. (2010) Lehigh's Sechelt Mine Wins Provincial Recognition. *Coast Reporter,* Oct. 8. http://www.coastreporter.net/article/20101008/SECHELT0101/310089980/-1/sechelt/lehigh-146-s-sechelt-146-mine-wins-provincial-recognition (accessed May 11, 2013).

Toffey, W.; Miller, C. R.; Saylor, L. D. (2000) Two Decades of Mine Reclamation: Lessons Learned from One of the Nation's Largest Biosolids Beneficial Use Programs. http://www.dep.state.pa.us/dep/subject/advcoun/minrec/Reclamtn.pdf (accessed May 11, 2013).

U.S. Environmental Protection Agency (2000) *Guide to Field Storage of Biosolids*; EPA-832/B-00-007; Office of Water, Office of Wastewater Management; Environmental Protection Agency: Washington, D.C.

Water Environment Federation (2011) Position Statement, Biosolids, Adopted by the Board of Directors Dec 2, 2011; Water Environment Federation: Alexandria, Virginia.

Water Environment Federation; National Biosolids Partnership (2011) *Charting the Future of Biosolids Management.* Water Environment Federation: Alexandria, Virginia. www.wef.org/cfbm_finalreport/ (accessed May 11, 2013).

Water Environment Research Foundation (2010) *Best Practices for Sustainable Wastewater Treatment: Initial Case Study Incorporating European Experience and Evaluation Tool Concept*; Water Environment Research Foundation: Alexandria, Virginia; International Water Association: London.

Water Environment Research Foundation (2012) *Reframing the Economics of Combined Heat and Power Projects: Creating a Better Business Case Through Holistic Benefit and Cost Analysis* (a publication building on Willis et al., 2012); Water Environment Research Foundation: Alexandria, Virginia.

Willis, J.; Stone, L.; Durden, K.; Beecher, N.; Hemenway, C.; Greenwood, R. (2012) *Barriers to Biogas Use for Renewable Energy;* Water Environment Research Foundation: Alexandria, Virginia; NYSERDA: Albany, New York.

Section 8

The Pulse of the Industry: Biosolids and Related Data

This report focuses on the new paradigm of resource recovery from biosolids (and, by inference, other residuals). In order to understand the full potential for resource recovery, data are needed. To date, the biosolids profession has had minimal data available. For example, even basic data on the generation of wastewater solids in the U.S. is inadequate for helping biosolids managers and policy-makers understand the potential amounts and qualities of energy and nutrient resources.

Some data surveys have been performed and are highlighted below, but as made clear in the text, updates are required.

Biosolids Generation, Use, and Disposal in the United States

In the late 1990s, U.S. EPA and WEF developed estimates of wastewater solids generated nationwide based on data on flows treated at WRRFs and standard per-person sludge generation estimates. The data were presented in the report *Biosolids Generation, Use and Disposal in the United States* (U.S. EPA, 1999).

At the time, some states were keeping more accurate data based on actual reports of solids generated and managed at each WRRF, and U.S. EPA was receiving paper copies of required annual reports from facilities generating biosolids. But this information was not easily accessible. Therefore, U.S. EPA's Office of Solid Waste (1999) used flow data to generate the most comprehensive estimates of that time: 6.9 million tons of biosolids generated, of which 60% were beneficially used (land application, composting, and landfill cover). The report estimated that, by 2010, 70% of wastewater solids would be recycled to land. This prediction was not borne out; the likely percentage was probably closer to 55% (authors' estimate based on NEBRA 2007 data and industry trends).

A National Biosolids Regulation, Quality, End Use, and Disposal Survey

In the mid-2000s, the U.S. EPA Office of Water funded *A National Biosolids Regulation, Quality, End Use & Disposal Survey* (NEBRA, 2007), which used 2004 data from the Clean Watersheds Need Survey and from state regulatory agencies to improve estimates of the mass of wastewater solids generated and managed in each state and for the country as a whole. The data for many states were based on annual reports to state agencies of actual solids production. But, for some states, no such tracking existed, and solids production continued to have to be estimated. In total, approximately 7,180,000 dry U.S. tons of wastewater solids were used or disposed in the U.S. in 2004.

More than 5 years later, the 2007 report is becoming outdated, although the overall picture it paints is not dramatically different from what we estimate is happening today. A compilation of current (2011) biosolids generation and management in the New England states shows significant, but mostly not dramatic, changes in the rates of biosolids beneficial use in five of the six states. The one exception is Vermont, where biosolids beneficial use dropped from 70% in 2004 to 29% in 2011, with landfill disposal increasing to 69%. (However, because Vermont is a small state, this dramatic change has negligible impact on national data.)

Other North American Biosolids Practice Surveys

Data for Canada are just as limited. A report from 2000 was quoted as estimating "approximately 388,700 dry [metric] tonnes of biosolids are produced every year. About 43% of these biosolids are applied to land, 47% are incinerated and 4% are sent to landfill, with the remainder used in land reclamation and other uses" (Apedaile, 2001).

Additional descriptions of biosolids management in North America and around the world are reported in the second "Global Atlas", produced in 2008 (Leblanc et al. [Eds.], 2008).

If resource recovery from biosolids is to advance, basic data are imperative. In addition, goals should be encouraged at the national level and in every state, similar to municipal solid waste (MSW) recycling goals, and tracking of progress toward these goals will be needed. This requires an ongoing requirement for current data. At the minimum, biosolids generation, use, and disposal data should be updated every few years.

Routine Wastewater and Solids Surveys

U.S. EPA conducts the CWNS every 4 years; the most recent report to Congress was in 2011 for data collected in 2008. Wastewater treatment facilities are generally required to report data for this survey, but not all do, and some of the data is out-of-date. In addition, the CWNS is focused on identifying the funding needs for wastewater infrastructure. It contains scant data on solids treatment, use, and disposal.

In the meantime, annual wastewater sludge/biosolids reports required under Part 503 are in paper form, and few states convert the data into useable electronic format. The annual Discharge Monitoring Reports (DMRs) required by the NPDES program have very little data pertaining to solids management (e.g., solids stabilization code).

Current Online U.S. EPA Water, Wastewater, and Biosolids Data for the U.S.

- Facility Registry System (FRS): http://www.epa.gov/enviro/html/fii/
- U.S. EPA Clean Watershed Needs Survey: http://water.epa.gov/scitech/datait/databases/cwns/index.cfm
- Enforcement & Compliance History (ECHO): http://www.epa-echo.gov/echo/
- Discharge Monitoring Report (DMR): http://cfpub.epa.gov/dmr/index.cfm

Barriers to Biogas Survey

As noted in Section 4, this 2012 survey of over 200 wastewater treatment utilities, conducted in 2011 by WERF and NYSERDA, focused on the barriers to biogas use (Willis et al., 2012). While biogas was the singular focus, most of these barriers are common to those faced by other energy recovery technologies. The survey found that the most important barrier to biogas use was economic, related to higher priority demands on limited capital resources or to perceptions that the economics do not justify the investment. A key component of the survey was the identification of strategies, developed during focus group meetings, to overcome identified barriers.

Biogas Use Survey

Through WEF and NBP seed funding, as well as substantial team contributions and volunteer efforts, NEBRA, Black & Veatch, American Biogas Council, BioCycle, CAMBI, CASA, Hazen and Sawyer, HDR Inc., InSinkErator, MABA, Material Matters, NBMA, NYSERDA, and WEA TX began the march toward a collection of reliable biogas data. The most recent biogas survey results were released in October 2012 and are available at www.biogasdata.org. The site provides updated data on anaerobic digestion and biogas production at WRRFs across the U.S. Data collected through the survey, which build on U.S. EPA data, show that wastewater solids from more than 1200 U.S. WRRFs undergo anaerobic digestion and produce biogas. Almost all of this wastewater biogas production occurs at facilities that treat from 1 to hundreds of millions of gallons per day of wastewater. However, two-thirds of these 3300 major facilities do not send solids to anaerobic digestion and produce biogas. In addition, there are more than 13,000 minor facilities (less than 1 mgd in size); a small number of these operate anaerobic digesters. There is clearly potential for considerably more biogas production from wastewater. The use of biogas at wastewater facilities is also underdeveloped: the data show that one-third of the treatment facilities that produce biogas do not put it to use for energy, and only about 300 use it to generate electricity. The new biogas survey supersedes recent surveys performed by U.S. EPA's CHPP in 2007 and 2011.

Enabling Resource Recovery: Data Support Needed

The recent biogas-focused surveys will be invaluable tools to support resource recovery in biosolids, but more is needed, and the wastewater and biosolids management professions should consider taking steps to ensure that we have the data we need. Specific needs identified are described below.

Strategies to Overcome Barriers to Energy Recovery (adapted from Willis et al., 2012)

Barrier	Solutions
Inadequate Payback/Economics and/or Lack of Available Capital	■ Use better financial comparison metrics, such as net present value and operational savings, instead of relying solely on payback period. ■ Increase biogas production by co-digestion, improved anaerobic digestion operations, and digestion pretreatment processes. ■ Negotiate better contracts with power utilities and natural gas companies. ■ Use triple-bottom-line evaluations that consider the value of environmental and social benefits in addition to economic factors. Consider benefits of renewable energy production and greenhouse gas emission reductions. ■ Consider RECs in financial analysis. ■ Consider partnering with third-party that can fund the initial capital and ongoing O&M costs in a build-own-operate or similar model. ■ Investigate alternative sources of funding, such as grants, low-interest loans, and state-supported financing. ■ Track energy use and benchmark energy use against other WRRFs. Use energy as a performance metric ad incentive for renewable energy development.
Complications with Outside Agents	■ Leverage existing relationships with regulators, power companies, and natural gas utilities to discuss energy recovery projects. ■ Educate regulators and the public on the benefits of energy recovery from biosolids. ■ Promote and encourage the classification of biogas and biosolids as a renewable energy resource.
Plant Too Small	■ Increase biogas production by co-digestion or WAS pretreatment. ■ Consolidate solids handling at a larger centralized facility.
O&M Complications and Concerns/Technical Merits	■ Provide better training for operators on energy recovery technologies. ■ Consider third-party maintenance service contracts. ■ Visit successful sites to improve familiarity/acceptance.
Difficulties with Air Regulations or Obtaining Air Permit	■ Educate air permitting authorities on the benefits of CHP. ■ Select technologies with low emissions.
Maintain Status Quo and Lack of Community/Utility Leadership Interest in Green Power	■ Involve potential blockers and engage internal stakeholders in the decision-making process. ■ Involve a strong supporter or advocate (a champion) for energy recovery. ■ Highlight risk of status quo to decision-makers. ■ Provide holistic education on energy recovery technologies.

Maintaining and Expanding Current Databases

Continuing the data collection process that provides accurate data will help reduce the uncertainties that vendors, project developers, and policy-setters face due to the unknowns associated with current and potential for biogas utilization in the U. S. The processes for data collection and reporting that were developed and followed in the biogas data project can be built upon to enhance efficient duplication of future data collection efforts.

As the paradigm of resource recovery from biosolids takes hold, there will be additional metrics for which data will be needed on a regular basis, in order to keep the profession focused on resource recovery and to track its progress.

Define Sustainability Metrics

Finally, it is important for the profession to consider how biosolids management can be an indicator of the level of sustainability of a particular community, state, region, or nation. Biosolids quality and how they are managed tells a lot about the impacts civilization is having on the environment.

Potential candidates for metrics that could be used as indicators for the sustainability of biosolids management could include the following (most of the following to be expressed as a ratio in relation to the total dry solids managed per year):

- The national biosolids recycling rate (calculated in the same ways as MSW recycling rates);
- The amount of energy generated (thermal, electrical, and kinetic combined into a common unit);
- The number of paying jobs and/or the average salary (as a measure of professionalism);
- The number of certified land appliers (or other measures of biosolids-specific training);
- The number of recognized quality management programs for biosolids (NBP EMS/BMP certifications, ISO 14001 certifications, etc.);
- The age distribution of skilled biosolids management professionals;
- The net income or expense of solids management (biosolids, biogas, electricity, and heat product revenues *minus* treatment and management costs); and
- The concentrations of sentinel, representative trace contaminants of concern (e.g., Hg, Pb, dioxins, PCBs, estrogen, PBDEs, PFCs, in representative biosolids), which represent the level of use and circulation of these contaminants in society and the environment.

References

Apedaile, E. (2001) A Perspective on Biosolids Management. *Can. J. Infect. Dis.,* **12** (4), 202–204. http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2094821/ (accessed May 11, 2013).

Leblanc, R. J.; Matthews P.; Richard, R. P.; Eds. (2008) Global Atlas of Excreta, Wastewater Sludge, and Biosolids Management: Moving Forward the Sustainable and Welcome Uses of a Global Resource. United Nations HABITAT. http://www.unhabitat.org/pmss/listItemDetails.aspx?publicationID=2551 (accessed May 11, 2013).

North East Biosolids and Residuals Association (2007) A National Biosolids Regulation, Quality, End Use & Disposal Survey. http://www.nebiosolids.org/uploads/pdf/NtlBiosolidsReport-20July07.pdf (accessed May 11, 2013).

U.S. Environmental Protection Agency (1999) *Biosolids Generation, Use, and Disposal in the United States*; EPA-530/R-99-009; Office of Solid Waste & Emergency Response; Environmental Protection Agency: Washington, D.C.

Willis, J.; Stone, L.; Durden, K.; Beecher, N.; Hemenway, C.; Greenwood, R. (2012) *Barriers to Biogas Use for Renewable Energy;* Water Environment Research Foundation: Alexandria, Virginia; NYSERDA: Albany, New York.

Conclusion

The water sector as whole continues to work in collaboration with federal, state, and local public and private organizations to provide the necessary information to ensure that infrastructure investments and resource recovery efforts continue to reinforce the move toward sustainable communities. Economic challenges can drive innovation. Promoting innovative biosolids solutions that are enriched by the growing knowledge provided through societal, environmental, and economic collaboration is imperative to creating a focus on more holistic approaches to resource recovery focused on sustainability. With a continued focus on best practices, quality, and management, coupled with communication, collaboration and innovation, biosolids as a valuable resource is being realized.

Resource recovery facilities that produce clean water, recover nutrients, and have the potential to reduce the nation's dependence upon fossil fuel through the production and use of renewable energy play an integral role in addressing and enabling the priorities of sustainable and resilient communities. Biosolids are a renewable resource too valuable to waste. This perception is driven by forces internal and external to the field, and includes widespread interest in sustainability, energy, climate change, resource depletion, materials cycling, and zero-waste goals.

Efforts in informing decisions regarding resource recovery must include the use of data to establish goals and outcomes in budget decisions, set performance targets, communicate, collaborate, and learn from other organizations and stakeholders in order to provide and shape improvements in the industry. Resource recovery and innovative technologies in biosolids continues to evolve. The added harsh economic climate lends itself to an increased need for sustainable development. As the focus on resource recovery from biosolids intensifies, the importance of the distributed network of support for biosolids professionals becomes even greater. Communication of research findings – both historic and new – is a specific pressing need, as it appears that existing research has been underutilized as a tool to communicate the safety of biosolids to the public. The increased complexity of biosolids management and the need for increased communications with more diverse audiences requires that these support mechanisms continue to grow and evolve to meet future needs. Engaging in effective communication continues to be a key tenet to successfully developing systematic, proactive response and education strategies in which public outreach ensures appropriate developmental materials and biosolids curriculums are in place, as well as ensuring that working relationships with key environmental and public health organizations are cultivated.

Biosolids can play a critical role with respect to climate change and its impacts on soil by providing the SOC and organic matter to build soils. Protocols to estimate GHG emissions from biosolids processes are still evolving, but the development of the BEAM provides a strong foundation for such assessments. Biosolids can reduce agricultural carbon footprints through both fertilizer production offsets and biosolids use to meet plant nutrient requirements. Recognizing the role that biosolids can play in sequestering carbon and continued research on this topic will continue to serve as a catalyst for value recognition of this valued resource.

Solids treatment provides the greatest potential for energy recovery and production, with the chemical energy embedded in biosolids greater than the energy needed for treatment. Recovering that energy is an opportunity for wastewater utilities to reduce costs and increase sustainability. Energy neutrality is an attainable goal when wastewater facilities are designed and operated for this objective through a combination of energy efficiency best practices and energy production technologies.

There is a clear need for the development of cost-effective alternative nutrient removal strategies. Extractive nutrient recovery could meet this need, as it provides a mechanism to both effectively remove nutrients and create a marketable product. At present, commercial technologies for extractive nutrient recovery primarily produce chemical nutrient products that are used in agricultural applications. This is because 85% of all nutrient products are associated with agronomy. Since food demand is expected to rise with an increasing global population, it is expected that demand for chemical nutrient products will also increase. This represents an opportunity for the wastewater treatment market to develop niche products that can be used in this field.

The water sector continues to enable a future where advancing resource recovery from biosolids is realized through transformed understandings of innovation, development, and implementation of technologies that focus on sustainability for the long term. Biosolids as a resource is a building block for environmentally friendly effective and efficient utility management. Effecting change requires critically analyzing and clearly articulating the necessary changes and path to sustainability that can yield highly innovative solutions; therefore enabling a future where biosolids are a valued resource.

Appendix A - WERF Biosolids Research 2002 to Present

Publication Year	Project Number	Project Title	Principal Investigator(s) and Contracting Organization(s)		Research Objectives
2012	SRSK3R08	Site Specific Risk Assessment Tools for Land Applied Biosolids	Patrick Gurian, Ph.D.	Drexel University	Provide wastewater utilities, land appliers, regulatory agencies and public administrators' state-of-the-science, practical, locally applicable pathogen risk assessment and communication approaches, with methodologies tailored to a variety of conditions. Appropriate risk assessment methodologies will accommodate varying levels of expertise and resources. Knowledge from the overall research project was incorporated into an environmental dispersion, exposure, and risk model, known as the Spreadsheet Microbial Assessment of Risk: Tool for Biosolids ("SMART Biosolids").
2012	SRSK3R08a	Calibrating the SMART Biosolids Model and Applying It to Fault Scenarios	Mira Olson, Ph.D. and Patrick L. Gurian, Ph.D., Drexel University	Irene Xagoraraki, Ph.D., Michigan State University	Calibrates groundwater transport pathway of the SMART biosolids model (see above) to data obtained from field monitoring of wet weather events. The calibrated model is then applied to a wide variety of fault scenarios developed from an expert elicitation exercise. Estimated risks associated with scenarios are compared with estimated frequencies of occurrence found by a survey of biosolids land application practitioners to identify scenarios of greatest concern.
2012	08-HHE-5PP	Pilot Testing: Surveillance and Investigation of the Illness Reported by Neighbors of Biosolids Land Application and Other Soil Amendments	Paul Rosile, M.P.H.	Franklin County Department of Health	This project (Phase II) field-tested and refined the Phase I draft protocol (06-HHE-5PP) which was the highest ranked priority at the 2003 Biosolids Research Summit. Future stakeholders should benefit from this project's helping to lay the groundwork and framework for a surveillance and rapid response investigation system starting on a local level using a standardized investigation protocol.
2012	TOBI1T11	Gathering Unpublished Data for Compounds Detected in Biosolids	Andrew Maier	Toxicology Excellence for Risk Assessment (TERA)	Building on WERF's 2010 report, State-of-the-Science Review of Occurrence and Physical, Chemical, and Biological Processes Affecting Biosolids-borne Trace Organic Chemicals in Soils (SRSK5T09), this research assembled high-quality, unpublished data on specific trace organic compounds detected in biosolids. Study compiled data on physical-chemical, environmental fate, ecotoxicology, and mammalian toxicology endpoints. Findings can support risk evaluations, narrow the list of compounds and data gaps for subsequent research.
2012	OWSO4R07T and H	Life Cycle Assessment Manager for Energy Recovery (LCAMER) version 2.0	George V. Crawford, P. Eng., CH2M-Hill	Hugh Monteith, P. Eng., Hydromantis	The original LCAMER tool has been updated to be more user friendly, include updated costs for fuel cells and Stirling engines, and be compatible with newer versions of Excel. Includes a new version of the User Manual.

Publication Year	Project Number	Project Title	Principal Investigator(s) and Contracting Organization(s)		Research Objectives
2012	OWSO4R07I	LCAMER: An Assessment Tool for Managing Cost-Effective Energy Recovery from Anaerobically-Digested Wastewater Solids	George V. Crawford, P. Eng., CH2M-Hill	Hugh Monteith, P. Eng., Hydromantis	A report documenting the upgrades incorporated into the new version of the LCAMER tool.
2012	OWSO11C10	Barriers to Biogas Utilization for Energy Recovery	John Willis, P.E., Brown and Caldwell	Lori Stone, P.E., Black & Veatch	Not all wastewater treatment plants with anaerobic digestion beneficially use their biogas beyond process heating. Knowing this, there must be actual or perceived barriers to broader use of biogas to produce combined heat and power (CHP). This study documented these barriers so that actions can be taken to reduce or remove the barriers that promote energy recovery using proven technology – anaerobic digestion with combined heat and power generation. Includes case studies and biogas factsheet.
2012	WERF2C10	Characterization of Volatile Organic Compounds (VOCs) Emitted from Biosolids Composting	Greg Kester	California Association of Sanitation Agencies (CASA)	Characterize VOCs emitted from biosolids composting to determine to what degree these VOCs are reactive and thus could contribute to ground level ozone. It is known that not all VOCs are reactive, but biosolids have not been studied. There are proposed rules in California on this subject and it is expected that other parts of the country will face similar rules. The two test sites are in California, but the intent is that the findings would be applicable to other parts of the country. A wind tunnel will be used collect gas emission samples from the test compost piles.
2012	WERF6C11	Omni-Processor Landscaping Project	Richard Kuchenrither, Ph.D., PE, BCEE	University of Colorado-Boulder	Review current technologies / processes to see if they can meet the vision of an Omni-Processor that can convert excreta (latrine waste) into beneficial products such as energy and soil nutrients with the potential to develop local business and revenue. The Omni-Processor should produce a safe product that has value, support a sustainable business model, be adaptable to changing conditions, be community based, and use local skills and materials. Project was funded by the Bill and Melinda Gates Foundation.
2012	WERF2T12	Geological Map and Permitting Roadmap for Biosolids and Brine Injection Project	Mike Bruno, Ph.D.	GeoEnvironment Technologies	This project resulted in the creation of a user-friendly map (using Google Earth) of the U.S. and southern Canada that indicates areas with geologic strata appropriate for large-scale biosolids and brine injection, a guidance document summarizing state-by-state regulatory requirements for permitting of brine and biosolids injection, and a case study of the City of Los Angeles TIRE (Terminal Island Renewable Energy) facility's pathway to gain public support and approval of their project. The TIRE project was the first in the nation to successfully demonstrate and monitor this innovative technology.
2011	OWSO12PR11	Peer review support for Bay Area Biosolids to Energy Coalition	Caroline Quinn, P.E.	Delta Diablo Sanitary District	The technology demonstration under evaluation uses steam / CO2 reforming to convert biosolids to hydrogen, a renewable fuel. This project is on hold pending further financing of the demonstration facility.

Publication Year	Project Number	Project Title	Principal Investigator(s) and Contracting Organization(s)		Research Objectives
2011	SRSK2R08	A Strategic Risk Communications Process for Outreach and Dialogue on Biosolids Land Application	Sara Eggers, PhD.	Decision Partners	Provide wastewater utilities, land appliers, regulatory agencies and public administrators' state-of-the-science, practical, locally applicable pathogen risk assessment and communication approaches, with methodologies tailored to a variety of conditions. Appropriate risk assessment methodologies will accommodate varying levels of expertise and resources.
2011	U1R08	Developing Better Indicators for Pathogen Presence in Sewage Sludges	Suresh D. Pillai, Ph.D.	Texas A&M University	Provides information about the concentrations of an extensive selection of raw sewage-associated organisms across warm and cool seasons and from locations across the United States. Identifies sewage-related indicator organisms suitable for wastewater screening. Identifies indicator organisms suitable for screening temperature-based wastewater treatment processes. Developed information on the time-temperature relationships of indicator organisms and microbial pathogens. Information can be used to assess pathogen kill predictions for temperature-based treatment technologies.
2011	U3R08	Use of Nanoparticles for Reduction of Odorant Production and Improvements in Dewaterability of Biosolids	Matthew J. Higgins, Ph.D.	Bucknell University	Demonstrate that nanoscale particles can improve polymer-aided dewatering and reduce odor production from biosolids. Characterize performance of a number of different nanoadditives with varying size, charges, chemistry, and structure. Characterize performance of nano-additives during dewatering with polymers of different charge densities, molecular weight and configuration. Illustrate performance of nano-additives during dewatering under various shear conditions. Provide preliminary concepts on role of nano-scale additives for dewatering and odor control.
2011	U2R08b	Combined Heat and Power System Evaluation Tool	John Willis, P.E.	Brown and Caldwell	The CHP-SET is a spreadsheet-based calculator designed for evaluating CHP system performance and is intended for use by utilities already operating CHP systems. The CHP-SET calculates total system efficiencies (inclusive of appurtenant equipment electrical demands) for the production of electricity and collection of heat. The tool also provides a conversion of exhaust emissions (NOx, CH4, CO2, CO, and N2O) into units of mass per unit of net energy output.
2011	OWSO4R07f	Site Demonstration of the Life Cycle Assessment Manager for Energy Recovery (LCAMER) Tool	George V. Crawford, P. Eng.	CH2M-Hill	WERF developed the Life Cycle Assessment Manager for Energy Recovery (LCAMER) spreadsheet-based tool in 2006 to help utilities compare costs for energy recovery systems using anaerobic digestion. This project demonstrated the applicability of LCAMER to provide planning-level cost comparisons and showed the effectiveness of LCAMER tool by evaluating proposed anaerobic digestion and biogas-to-energy improvements for two wastewater utilities.

Publication Year	Project Number	Project Title	Principal Investigator(s) and Contracting Organization(s)		Research Objectives
2011	OWSO10C10a	State of the Science on Biogas: Treatment, Co-Generation and Utilization in High Temperature Fuel cells and as a Vehicle Fuel	Collaboration with Suez		A series of reports prepared by Suez Environnement researchers on biogas, including a literature review of the state of the science on the treatment of biogas for further use, a review of co-generation technologies focusing on the use of high temperature fuels cells and for use as a vehicle fuel.
2010	02-CTS-8-P	Advanced Biosolids Flow-Through Thermophilic Treatment (BFT3) Demonstration Project	Billy Turner and Cliff Arnett, Columbus Water Works, GA, John Willis, Brown & Caldwell, and Mike Aitken & Mark Sobsey, University of North Carolina – Chapel Hill		Evaluated the BFT3 process for retrofitting existing digestion systems to upgrade them from Class B to Class A. WERF provided peer review of the protocols definition, experimental testing for health risk assessment of microbial contaminants, and full-scale start-up.
2010	03CTS9a	Evaluation of Aluminum and Iron Addition During Conditioning and Dewatering for Odor Control	Matthew J. Higgins, PhD, P.E.	Bucknell University	Investigate factors impacting the effectiveness of metal salts in reducing the production of volatile organic sulfur compounds in biosolids, and develop recommendations for applying metal salt addition for odor reduction.
2010	03CTS9b	Effect of Aluminum and Iron on Odors, Digestion Efficiency and Dewatering Properties	John T. Novak, PhD, P.E.	Virginia Tech University	Investigate the impact of iron and aluminum addition in determining odor generation from dewatered sludge cakes. Iron and aluminum addition to activated sludge for phosphorus removal and directly to anaerobic digestion were studied. Data on sludge dewatering properties also was collected.
2010	03CTS9c	Biosolids Odor Reduction - Development of Web-Based Decision Tool	Zeynep Erdal, P.E. and Robert Forbes, P.E.	Ch2M-Hill	Web-based roadmap to integrate the findings of all four phases of the biosolids-odor-reduction research and encompass real solutions to enhancing biosolids odor quality, beyond the use of odor-scrubbing or masking agents. Incorporates a cradle-to-grave approach from early treatment processes to the biosolids end use or disposal point.
2010	04-HHE-6	Fate of Estrogenic Compounds During Municipal Sludge Stabilization and Dewatering	Kathleen Esposito, P.E. & Beverly Stinson, Ph.D., P.E., AECOM, Inc., Ed Furlong, Ph.D., U.S. Geological Survey, David Quanrud, University of Arizona		Investigated the fate of known estrogenic compounds and total estrogenic activity in solids derived from wastewater treatment, in processes commonly used to stabilize, disinfect and dewater municipal wastewater treatment sludges.
2010	05-CTS-3	Evaluation of Processes to Reduce Activated Sludge Solids Generation and Disposal	Julian Sandino	CH2M-Hill	Developed and demonstrated an evaluation methodology that will be used to independently assess the effectiveness of at least one selected commercially available process. This tool can be used by industrial and municipal wastewater treatment facility owners and operators to technically and economically evaluate processes that can reduce waste activated sludge quantities

Publication Year	Project Number	Project Title	Principal Investigator(s) and Contracting Organization(s)		Research Objectives
2010	05-CTS-2T	Evaluation of BMPs for Sustainable Groundwater Protection at Biosolids land application Sites	Mike McFarland, Ph.D.	Utah State University	Developed a protocol to evaluate the effectiveness of best management practices to mitigate the potential risk of groundwater contamination at biosolids land application sites. Describe the range of groundwater protection BMPs currently in practice at land application sites.
2010	U4R06	Disinfecting and Stabilizing Biosolids Using E-Beam and Chemical Oxidants	Suresh D. Pillai, Ph.D.	Texas A&M University	Demonstrated that 10 MeV E-beam is capable of cost effectively inactivating bacterial and viral pathogens in aerobically and anaerobically digested biosolids. This suggests that when E-beam is combined with ferrate, significant reductions of microbial pathogens, estrogenic compounds and biosolid stabilization can be achieved. In the future, wastewater treatment plants can be high-value resource recovery operations, not just sites for treatment and disposal of municipal wastes.
2010	SRSK5T09	State-of-the-Science Review of Occurrence and Physical, Chemical and Biological processes Affecting Biosolids-borne Trace Organic Chemicals in Soils	Christopher Higgins, PhD	Colorado School of Mines	Identifies TOrCs of potential greatest concern for the land application of biosolids and prioritized them based on occurrence data and readily available data on bioaccumulation and toxicity. Provides a detailed overview of what is currently known about the physical, chemical, and biological processes affecting TOrC fate, transport, bioavailability, and toxicity in biosolids-amended soils for the targeted TOrCs.
2009	01-CTS-18-UR, (Use updated version of LCAMER 2012)	An Assessment Tool for Managing Cost-effective Energy Recovery from Anaerobically Digested Wastewater Solids	Hugh Monteith, Ph.D.	Hydromantis, Inc.	Identified cost-effective alternatives for energy recovery from solids treatment (anaerobic) based on key factors such as energy costs, regulatory conditions, plant capacity, social values, and more. Provided information to develop the LCAMER model.
2009	03-HHE-2	Pathogen Risk Indicators for Wastewater and Biosolids	Judy Blackbeard	CRC Water Quality and Treatment, Australia	Compared the accuracy, advantages, and disadvantages of existing indicator organisms with proposed indicators in wastewater and biosolids. If successful, alternative organisms can provide better indicators of public health impacts, more accurate tools for setting appropriate standards, and more effective monitoring of water and biosolids, leading to increased confidence in the quality of effluent and residuals.
2009	04-CTS-7T	Minimizing Mercury Emissions from Biosolids Incinerators	Carl E. Hensman, Ph.D.	Frontier Geosciences, Inc.	Quantified mercury emissions from representative biosolids incinerators located in the United States. Established test protocols that POTWs that practice incineration can use to accurately determine the fate of the mercury that enters their plants. Identified practices and control technologies to cost-effectively reduce mercury emissions from biosolids incinerators.
2009	04-HHE-7	An Investigation into Biosolids Sampling and Handling Methods for USEPA-Approved Microbial Detection Techniques	Sharon C. Long, Ph.D.	University of Massachusetts – Amherst (now with University of Wisconsin- Madison	Developed scientifically defensible methods for collecting and handling representative samples for microbial analysis from biosolids matrices with the greatest potential impact to public health (liquid, cake, compost).

Publication Year	Project Number	Project Title	Principal Investigator(s) and Contracting Organization(s)		Research Objectives
2008	01-CTS-19-UR	Effects of Biosolids Properties on Membrane Bioreactors (MBRs) and Solids Processing	Slav Hermanowicz, Ph.D., P.E.	University of California, Berkeley, CA	Investigated the effects of biosolids characteristics on membrane performance and solids processing. Helped define the operating limits of MBRs in municipal wastewater treatment and improve understanding of the behavior of solids to be processed.
2008	03-CTS-9	Biosolids Processing Modifications for Cake Odor Reduction	Gregory M. Adams, P.E., Los Angeles County Sanitation District	Jay Witherspoon, Ph.D., P.E., CH2M-Hill	Built upon an enhanced an existing process, anaerobic biosolids digestion, to produce lower-odor biosolids. Equipment / process vendors invited to demonstrate their processes full-scale at one or two plants, with researchers collecting and analyzing data and comparing results. Builds upon work conducted in Identifying and Controlling Municipal Wastewater Odors (00-HHE-5T).
2008	04-CTS-3T	Fecal and Pathogen Regrowth/ Reactivation From Centrifugation of Anaerobically Digested Sludges	Matthew J. Higgins, PhD, P.E., Bucknell University	Sudhir Murthy, Ph.D., P.E., DC Water & Sewer Authority	Determined the extent that reactivation / regrowth of microbes in digested and dewatered biosolids, which has been the focus of 03CTS13T, is occurring for both indicator organisms and pathogens. Special attention was given to the effect that variability of microbe measurements may be having on observed results, and the best analytical methods to use to assess this observed phenomenon.
2008	OWSO3R07	State of the Science Report Energy and Resource Recovery from Sludge	Hugh Monteith, P. Eng	Hydromantis, Inc.	A Global Water Research Coalition report on the state of the science for recovering energy and resources, such as nutrients, from wastewater sludge. A triple bottom line approach was applied to identify suitable options.
2007	01-HHE-3	Assessing the Fate of Emerging Pathogens in Biosolids	Scott Yates, Ph.D.	University of California-Riverside	Helped detect and follow the fate of emerging pathogens in biosolids from the treatment process through land application until they are undetectable. Research helped address public health concerns regarding land application of biosolids.
2007	02-CTS-3	Innovative Technologies to Reduce Water Content of Dewatered Sludges	Sarah Miller	CSIRO Manufacturing & Infrastructure Technology	Evaluated methods to improve water removal from dewatered cakes, including innovative equipment, new additives, additive or conditioning agent combinations, physical modifications, or a combination of these or other approaches.
2007	02-HHE-2	Biosolids Sample Processing for Analyses of Pathogens	Morteza Abbaszadegan, PhD	Arizona State University	Addressed concerns raised by NRC's recent report on biosolids. Helped develop sample preparation methods for use with molecular detection techniques such as microarray analysis, quantitative PCR, fiber-optic biosensors, and other new technologies. This helped address public concern over land-applied biosolids by measuring the presence and fate of pathogens.
2007	02-PUM-1	Quantification of Airborne Biological Contaminants Associated with Land Applied Biosolids	Jordan Peccia, PhD	Arizona State University	Addressed concerns raised by NRC's recent report on biosolids. Provided fundamental data to assess the potential release and exposure to airborne biological contaminants from land application of Class B biosolids by analyzing current health-impact literature. Data produced helped provide basis for a comprehensive, full-scale analytical investigation.

Publication Year	Project Number	Project Title	Principal Investigator(s) and Contracting Organization(s)		Research Objectives
2007	04-CTS-2	An Economic Framework for Evaluating the Benefits and Costs of Biosolids Management Options	Robert S. Raucher, Ph.D.	Stratus Consulting, Inc.	Developed a method for evaluating the costs and benefits of various sludge/biosolids disposal and beneficial use options that provides utility and industry managers with the information necessary to make a decision on which option to use. This information can be shared with the general public to help explain the disposal or beneficial use options made by the utilities.
2007	06-HHE-5PP	Epidemiologic Surveillance and Investigation of Illness Reported by Neighbors of Biosolids Land Application Sites – Phase I	Steve Wing, Ph.D.	University of North Carolina	This project was the highest ranked priority at the 2003 Biosolids Research Summit. The first phase of the project developed a protocol to be used in conjunction with established public health investigation procedures and implemented through the existing network of public health organizations.
2006	98-REM1a	Application of a Dynamic Model to Assess Microbial Health Risks Associated with Beneficial Uses of Biosolids and Research Digest	Joseph Eisenberg, Ph.D.	University of Michigan	The second phase applied the framework developed in Phase I to characterize risk associated with real-world biosolid application scenarios. Risk assessment framework provides a mechanism to discuss biosolids management microbial risk using a common metric for comparison of treatment methods, management alternatives, and to set risk-based standards for microbial contaminants in biosolids.
2006	98REM1b	Research Digest	Joseph Eisenberg, Ph.D.	University of Michigan	Research Digest aimed at a more general audience to emphasize the practical aspects of the findings.
2006	99-HHE-3	Control of Human Parasites in Municipal Biosolids	Christine L. Bean	University of New Hampshire, Durham, NH	Screened, identified, and selected an appropriate surrogate human parasite(s), in lieu of helminth ova, and develops protocols to recover, detect, and measure surrogate organism(s) for municipal wastewater biosolids.
2006	99-PUM-2T (Phase II)	Characterizing the Forms, Solubilities, Bioavailabilities and Mineralization Rates of Phosphorus in Biosolids, Commercial Fertilizers and Animal Manures	George O'Connor, Ph.D.	University of Florida, Gainesville, FL	Phase II research confirm and expanded Phase I findings on the fate of phosphorus added to soil from biosolids and manures and improved our ability to use these amendments for environmentally sound crop production.
2006	00-PUM-6	Development of a Metals Toxicity Protocol for Biosolids	Katherine M. Banks, Ph.D.	Purdue University	Developed a series of toxicity bioassay tests that provide practitioners with a way to address citizen concerns regarding the human health and environmental impacts of biosolids reuse.
2006	01-CTS-1	Understanding Factors Affecting Polymer Demand for Conditioning and Dewatering	Matthew J. Higgins, Ph.D.	Bucknell University	Improved understanding of the nature of flocs and the specific chemical interactions that alter floc properties. Results could lead to better selection of conditioning chemicals, help to reduce chemical costs and/or lead to improved dewatering techniques.
2006	03-CTS-13T	Examination of Reactivation of Fecal Coliforms in Anaerobically Digested Biosolids	Matthew J. Higgins, PhD, P.E., Bucknell University	Sudhir Murthy, Ph.D., P.E., DC Water & Sewer Authority	Studied the phenomenon of reactivation of pathogens through the digestion process. Demonstrates that pathogens exist in a viable-but-non-culturable state through the digestion process but are induced to become culturable due to the presence of a substrate in the dewatering process, which allows for rapid growth in the final cake material.

Publication Year	Project Number	Project Title	Principal Investigator(s) and Contracting Organization(s)		Research Objectives
2005	99-PUM-5T	Manual of Good Practice for Biosolids (Product available from the NBP website: http://biosolids.policy.net/emsguide/manual/goodpractmanual.vtml))	Mark Lang, P.E.	Sear Brown Group, Rochester, NY	A targeted collaborative project that developed an online resource document on the issues to be considered when designing and implementing a biosolids management program. [Managed by WERF for the National Biosolids Partnership.]
2004	95-REM-2	Producing Class A Biosolids with Low Cost, Low Technology Treatment Processes	Perry Schafer, P.E.	Brown & Caldwell	Described low tech treatment processes for producing Class A Biosolids. Class A biosolids have been and are now being produced by low-cost, low-technology biosolids treatment processes including lagoon storage, air drying, and cake storage. Reviewed the available literature and municipal agency data about these processes.
2004	97-REM-2	Pathogen Destruction Efficiency in High Temperature Digestion	Donald Gabb, Ph.D., P.E.	East Bay Municipal Utility District, Oakland, CA	Compiled information available worldwide on high temperature digestion studies. Develop practical and economical high temperature (mesophilic / thermophilic) digestion protocols to yield Class A biosolids products and augment existing processes to further reduce pathogens. Resulted in WERF's first patent.
2004	00-CTS-10T	Minimizing Biomass Production from Biological Treatment	David H. Stensel, Ph.D., P.E.	University of Washington, Seattle, WA	Identified and evaluated methods to reduce biological solids in aerated biological reactors. Determined whether cost savings can practically be realized by reducing the ultimate amount of waste requiring treatment and disposal.
2004	00-HHE-5C (Phase I)	Identifying and Controlling Municipal Wastewater Odor Environment – Literature Review	Gregory M. Adams, P.E., Los Angeles County Sanitation District	Jay Witherspoon, Ph.D., P.E., CH2M-Hill	The primary objective was to evaluate the state of knowledge and science about odors and odor control for all stages of treatment and disposal of wastewater and residuals. It provided a basis from which to begin a multi-phase process to develop efficient, effective odor control technologies at all stages of wastewater treatment and disposal. Phase 1 involved critical reviews and syntheses of published information (includes conventional and grey literature), findings from recent and upcoming odors-related workshops, as well as electronic databases.
2004	00-HHE-5T (Phase II)	Identifying and Controlling Odor in the Municipal Wastewater Environment Phase II: Impacts of In-Plant Parameters on Biosolids Odor Quality	Gregory M. Adams, P.E., Los Angeles County Sanitation District	Jay Witherspoon, Ph.D., P.E., CH2M-Hill	Phase 2 collected objective data to demonstrate the influence of anaerobic digestion system design and operating parameters on the odor quality of the final product. Biosolids odor emissions measured before and after anaerobic digestion and operations and treatment parameters measured to determine the influence of these parameters on biosolids odor quality. A total of 10 POTWS were involved in the Phase 2 research effort.
2004	00-HHE-5T (HEA)	Identifying and Controlling Municipal Wastewater Odor Environment – Health Effects Addendum	William Cain, Ph.D. and Gregory M. Adams, P.E	Los Angeles County Sanitation District, and Jay Witherspoon, Ph.D., P.E., CH2M-Hill	The overall objective was to identify the research gaps and needs through a review of appropriate literature and to prioritize the future direction of research on health effects associated with POTW biosolids odors.
2004	00-PUM-5	Biosolids: Understanding Public Perception and Participation	Ned Beecher	New England Biosolids & Residuals Association, NH	Lessons learned from successful and unsuccessful biosolids recycling programs were synthesized and shared to provide guidance in incorporating stakeholder priorities.

Publication Year	Project Number	Project Title	Principal Investigator(s) and Contracting Organization(s)		Research Objectives
2004	01-CTS-32-ET	A New Tool for Measuring Biosolids Floc Strength	Mohammad Abu-Orf, Ph.D.	US Filter NATC / Vivendi Water	Established a standard method and set of procedures for measuring floc strength. Aided in understanding fundamentals of conditioning and enhance full scale dewatering
2004	02-HHE-1-CO	Analytical Method for Endocrine Disruptors in Sewage Sludge	Cooperative Project with UKWIR	Contractor: WRc	Helped solidify methods for extracting steroidal hormones from biosolids.
2004	03-HHE-1	WERF/EPA Biosolids Research Summit	WERF and Consensus Building Institute		Multi-stakeholder workshop that developed a research agenda to address scientific issues related to the land application of biosolids.
2003	97-REM-5	Assessing Bioavailability of Metals in Biosolid-Amended Soils: Root Exudates and their Effects on Solubility of Metals	Andrew Chang, Ph.D., P.E.	University of California, Riverside, CA	Explored phenomena that control the fate of metals in biosolids and soil mixtures, and impacts on ecological and human health. Helped improve technical basis of 503 Rule, thereby enhancing its acceptability within the scientific community and improving public confidence.
2003	98-REM-1 (Phase 1)	A Dynamic Model to Assess Microbial Health Risks Associated with Beneficial Uses of Biosolids	Jack Colford, M.D., Ph.D.	University of California, Berkeley, CA	The first phase developed an assessment framework for microbial exposures associated with beneficial biosolids reuse, and a streamlined protocol to assess risks from various exposure pathways.
2003	00-CTS-8	Membrane Technology: Feasibility of Solid/Liquid Separation in Wastewater Treatment (Subscriber Tool)	Glen Daigger, Ph.D., P.E., George Crawford, P.E.	CH2M-Hill	Provided a comprehensive assessment of membrane applications and identifies a method to evaluate the use of membrane technologies for specific treatment applications. Results from this research allowed for a direct comparison of membrane technologies with more conventional methods of solid/liquid separation.
2003	00-PUM-7	Development of a Cost Determination Protocol for Use in Benchmarking Biosolids Management Programs	Eliot Epstein, Ph.D.	E&A Environmental Consultants, Inc.	Developed a protocol to identify and quantify direct and indirect costs associated with management of biosolids for all reuse and disposal options. The protocol was tested and refined at several sites that represent wide range of biosolids management options in diverse geographic areas. Helped utility managers evaluate the cost of biosolids management programs on a consistent basis with other agencies.
2002	98-REM-3	Thickening and Dewatering Processes: How to Evaluate and Implement an Automation Package (Product No. D13006)	Robert Gillette, P.E., DEE	Carollo Engineers	Evaluated state of current practices, screens and field tests selected automation processes. Provided information to improve dewatering operations to cut the cost of dewatering biosolids in POTWs and in downstream operations.
2002	99-PUM-1	Evaluating Risks and Benefits of Soil Amendments Used in Agriculture 99PUM1RD research digest also available	Lynne H. Moss, P.E.	Camp, Dresser, & McKee, Austin, TX	Determined the risks and benefits, advantages and potential disadvantages associated with the use of a variety of soil amendments in comparison to chemical fertilizers. Provided information to determine which soil amendment can be used in or for a specific soil, crop, or climatic condition.

Publication Year	Project Number	Project Title	Principal Investigator(s) and Contracting Organization(s)		Research Objectives
2002	99-PUM-2T	Characterizing the Forms, Solubilities, Bioavailabilities and Mineralization Rates of Phosphorus in Biosolids, Commercial Fertilizers and Animal Manures (Phase 1)	George O'Connor, Ph.D.	University of Florida, Gainesville, FL	Phase I characterized the forms and solubilities of phosphorus in a variety of biosolids products and in biosolids-soils matrices. Phase II further defined this work.
2002	99-PUM-3	Developing Protocols for Measuring Biosolids Stability	Michael S. Switzenbaum, Ph.D.	Univ. of Massachusetts, Amherst, MA	Developed standard, detailed protocols for conducting tests that are commonly used to assess stability in the associated biosolids/products.
Ongoing	OWSO5R07	Assessment of Operational and Performance Parameters for Co-Digestion	David Parry, Ph.D. P.E.	CDM	A practical procedure developed to assess the potential impacts of a particular organic waste as a co-digestion feedstock in anaerobic digestion. The project provides access to empirical data necessary to support digester design and operational stability parameters. Will result in an economic model to assess the viability of co-digestion.
Ongoing	SRSK4T08	Wastewater Treatment Plant Design Operation and Modification to Improve Management of Biosolids Odors and Sudden Increases in Indicator Organisms	Matthew J. Higgins, PhD, P.E., Bucknell University	Sudhir Murthy, Ph.D., P.E., DC Water & Sewer Authority	Provide wastewater treatment personnel and their consultants with practical design and operational procedures that holistically address biosolids odors and sudden increases in indicator organisms.
Ongoing	OWSO10C10	Evaluation of Biogas Treatment for the Removal of Siloxanes	Nicolas de Arespacochaga	Suez Environnement	Researchers will assess commonly employed sampling and analytical methods for determining siloxane content in biogas, identify the impact of the analytical method on measured siloxane content and evaluate method sensitivity for measurement of low concentrations. They will develop practical guidelines for sampling and analysis of siloxanes in biogas and validate a protocol for sampling and analysis of siloxanes in biogas.
Ongoing	INFR1SG10	Wastewater Treatment Anaerobic Digester Foaming Prevention and Control Methods	Krishna Pagilla, Ph.D.	Illinois Institute of Technology	Investigate causes and identify effective prevention and / or control measures for anaerobic digester foaming. Implementation of longer SRT processes such as biological nutrient removal (BNR) and MBR (membrane bioreactor) processes may have increased the incidence of digester foaming. Digester foaming has caused significant reduction in performance, capacity, and/or operational difficulties in the liquid and solids processing trains. Anaerobic digestion is also the primary energy production method from organic matter in wastewater, and it is the key to the overall energy sustainability of WWTPs.
Ongoing	U1R10	Fate of Engineered Nanomaterials in Wastewater Biosolids, Land Application and Incineration	Paul Westerhoff, Ph.D.	Arizona State University	Develop tools to quantify and understand how engineered nanomaterials accumulate in biosolids, undergo biosolids treatment, and are disposed of and potentially accumulate in the environment. Include both model ENMs and ENMs in consumer products to improve our knowledge into their material life cycles, final disposition in the environment, and exposures to ENM by biota in rivers and soils.

Publication Year	Project Number	Project Title	Principal Investigator(s) and Contracting Organization(s)		Research Objectives
Ongoing	INFR6R11	Full-Plant Deammonification for Energy-Positive Nitrogen Removal	Maureen O'Shaughnessy	O'Shaughnessy Water Consulting, LLC	The successful application of full-plant deammonification could save wastewater utilities hundreds of millions of dollars in aeration and external carbon costs in the life cycle. For municipalities, wastewater treatment plants (WWTP) are frequently the largest point requirement of energy with significant energy used to provide aeration to oxidize organic carbon and ammonia. This research will demonstrate energy-neutral or even energy-positive wastewater treatment and reduction of external carbon for denitrification by applying a more efficient alternative biological pathway.
ongoing	ENER1C12	Energy Balance and Reduction Opportunities, Case Studies of Energy-Neutral Wastewater Facilities and Triple Bottom Line (TBL) Research Planning Support	Lori Stone, P.E., Paul Kohl, P.E.	Black & Veatch, Philadelphia Water Department	Part of a project to evaluate the energy balance and identify the opportunities for wastewater facilities over 5 mgd to become net-energy neutral. Task 3 of this project is a Triple Bottom Line (TBL) Evaluation of Biosolids Management Alternatives with a focus on the potential for energy (and heat) recovery.